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Introducing Co-composting to Fecal Sludge Treatment Plants in Benin and Burkina Faso: A Logistical and Financial Assessment

Josiane Nikiema, Rebecca Tanoh-Nguessan, Francine Abiola and Olufunke O. Cofie

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The authors

Dr. Josiane Nikiema is Research Group Leader - Circular Economy and Water Pollution at the International Water Management Institute (IWMI), Accra, Ghana. She has a PhD in chemical engineering from the Université de Sherbrooke, Canada. Her fields of expertise include domestic wastewater treatment and reuse, recovery of nutrients and organic matter from fecal sludge and organic solid waste, and testing business models for safe resource recovery and reuse (j.nikiema@cgiar.org).

Mrs. Rebecca Tanoh-Nguessan holds Master's degrees in water and sanitation, and environmental studies. Her fields of expertise include sanitation, environmental and meteorological research (rebeccatanohbanga@gmail.com).

Dr. Francine Abiola is a lecturer at the Interfaculty Center for Training and Research in Environment for Sustainable Development at the University of Abomey-Calavi, Benin. She holds a PhD in environmental sciences and has been working on issues related to fecal sludge management for over 10 years (francine.abiola@gmail.com).

Dr. Olufunke O. Cofie is Country Representative for IWMI in Accra, Ghana. She is a principal researcher with a background in soil science, and has worked on the interface of sanitation and agriculture over the past 15 years (o.cofie@cgiar.org).

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ACRONYMS AND ABBREVIATIONS

AMA	Accra Metropolitan Assembly
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
EUR	Euro
FC	Fecal Coliforms
FS	Fecal Sludge
FSM	Fecal Sludge Management
FSTP	Fecal Sludge Treatment Plant
HH	Households
LANE	Laboratory of Analysis of Quality and the Environment
LEDES	Laboratory of Water, Decontamination, Ecosystem and Health
LSD	Least Significant Difference
LSTE	Laboratory of Sciences and Water Technologies
M&E	Monitoring and Evaluation
MT	Metric Ton
NH_3-N	Ammonia Nitrogen
NO_3-N	Nitrate Nitrogen
NPV	Net Present Value
O&M	Operation and Maintenance
OC	Organic Carbon
OM	Organic Matter
OSS	On-site Sanitation System
PPP	Public-Private Partnership
PT	Public Toilet
RRR	Resource Recovery and Reuse
RVO	Netherlands Enterprise Agency
SD	Standard Deviation
SSA	Sub-Saharan Africa
ST	Septic Tank
TK	Total Potassium
TMA	Tema Metropolitan Assembly
TN	Total Nitrogen
TP	Total Phosphorus
TS	Total Solids
TSS	Total Suspended Solids
UASB	Up-flow Anaerobic Sludge Blanket
WW	Wastewater
WWTP	Wastewater Treatment Plant

SUMMARY

In West Africa, sewer systems are mostly found in larger (originally well-planned) urban areas, but with limited extent and household (HH) coverage. Efforts undertaken in recent years to increase decentralized wastewater treatment remain challenging. Compared to sewers, a much higher HH coverage is achieved through on-site sanitation systems (OSS), which allow for intermediate storage and (pre-) treatment of human excreta within the plot occupied by a dwelling or its immediate surroundings. After collection through vacuum trucks, the fecal sludge (FS) remains a challenge even if it is not indiscriminately dumped. The reasons are that designated treatment plants are often missing, or not within an economically acceptable distance, or their treatment performance is unsatisfactory, usually through overloading.

Based on primary data from fecal sludge treatment plants (FSTPs) in three West African urban regions (Ouagadougou in Burkina Faso, Greater Accra in Ghana, Grand Nokoué in Benin), we assessed FS collection and treatment patterns to analyze possible scenarios for resource recovery (RR) through FS co-composting based on our experience in Ghana. To understand the capacities needed, FS collection was analyzed for up to 7 years, in part per day, month and season, as well as FS characteristics to understand peak flows, FS qualities and related variations to plan for appropriate RR technology and capacities.

Overall, the collected FS volumes by vacuum trucks were not significantly affected by the calendar days, months or seasons over our period of observation. Nevertheless, we noted a 14 to 26% increase in FS collection during rainy months in Ouagadougou, Burkina Faso, although the same observation could not be established for the other two urban regions in Benin and Ghana. Between 2014 and 2016, the maximum annual FS collection capita^{-1} and disposal at designated sites was in the range of 0.06 to 0.10 cubic meters (m^3) capita^{-1}, assuming the administrative boundaries for each region were aligned with the operational boundaries of the FSTPs. In addition, FS composition appeared highly variable with pronounced difference in total solids between FS collected from HH versus institutional sources, likely indicating that institutions are served more frequently. Also, the FS collected in Ouagadougou appeared to have higher biodegradability than the FS collected in Accra, indicating similar differences in storage time versus collection.

Waste stabilization ponds are the dominant treatment process for FS in the West African region and managed either by public or private entities or through public-private partnerships (PPPs). Despite some differences due to site location and access, most treatment plants appear to be exploited beyond their capacity and need increased capacities or sister plants to meet the growing FS treatment needs. To cater to additional space requirements, it is recommended that FSTPs consider resource recovery and reuse (RRR) from the onset of operation. RRR can turn sludge disposal from a cost into a revenue with co-benefits for farmers and the environment.

With RRR, cost recovery will increase and benefit from compost sales, reducing the pressure on tipping fees. Total compost volumes between approximately 750 and 4,500 metric tons (MT) year^{-1} could be possible in the studied FSTPs in Burkina Faso and Benin. The probability of the added co-compost production being financially viable on its own was 73, 45 and 48% in Kossodo, Zagtouli and Ekpè, respectively, with an earliest breakeven point after 5 to 8 years. However, partial cost recovery might already be possible given the economic benefits of RRR.

1. INTRODUCTION

In Africa, many countries are still exploring sustainable ways to address the severe challenges of solid and liquid waste management, starting with appropriate HH services. For human waste management in particular, the focus in the past was to pursue efforts to increase HH access to sewer systems. However, with a growing understanding of the related costs and water demands for flushing, many countries are rediscovering the benefits of on-site sanitation systems (OSS) that are reputed to be more affordable for HH and the public sector and less water-intensive. This is also the trend in West Africa (ONEA 2017; Roche et al. 2017).

One key objective of this report is to close data gaps in the commonly grey area of fecal sludge (FS) management in West Africa, focusing on the examples of Ouagadougou, Greater Accra and the Grand Nokoué area (with its main cities being Cotonou, Abomey-Calavi, Porto-Novo and Sèmè-Podji). The selected three urban agglomerates include the capital cities of Burkina Faso, Ghana and Benin. The study involved analysis of FS volumes and quality as well as FS collection patterns, which influence the technical and logistical designs of fecal sludge treatment plants (FSTPs). We also analyzed the resource recovery potential of selected FSTPs, especially the potential benefits and the profitability of FS co-composting, as it has been tested in Greater Accra. Based on the findings from this work, recommendations are provided for improved FS management (FSM) within and beyond the selected city areas.

The findings of this report are divided into the following sections:

- Section 2 reviews the status of sanitation in West Africa regarding sewered wastewater and FS generation and management. We discuss the current challenges that liquid waste management faces and we present the avenues that are being considered for these issues to be addressed.
- Section 3 focuses on the three target countries and regions to present in detail what is being done locally to manage FS.
- Section 4 presents the results of our analytical study. We discuss the FS volumes collected according to days, months or seasons and we analyze the FS quality in the three target regions. We derive the key trends in FS quality and management practices.
- Section 5 analyzes the potential of integrating co-composting at FS treatment plants in Ouagadougou, Burkina Faso and Grand Nokoué, Benin, following the model that has been implemented and is being tested further in Greater Accra, Ghana.

2. REVIEW OF THE STATUS OF SANITATION IN WEST AFRICA

In Sub-Saharan Africa (SSA), 28% of the population has access to at least basic sanitation, 18% relies on shared toilet facilities, 31% uses unimproved toilet facilities and 23% practices open defecation (WHO 2017). Beyond toilet access, there is also a need to manage the generated toilet waste safely. There are two main processes for the management of excrement. These involve either the use of a sewer or, more often, OSS. The two systems and their prevalence in the study region are discussed in the following sections.

2.1 Sewer Systems

In West Africa, where 46% of the population lives in urban areas, 12% of the total urban population (or 15% of those with access to improved sanitation) is connected to sewers (JMP 2018). Larger centralized sewers are mostly found in selected urban areas. The extent of the network varies widely across the region (Table 1) and available data are scarce. For instance, Abidjan and Dakar, the most populated cities of Côte d'Ivoire and Senegal, respectively, have the highest sewer coverage (about 30-45%) while in Bamako (Mali), sewers are almost inexistent. In between these extremes, many cities in the subregion have small sewer (decentralized) systems but are unable to cover a meaningful proportion of citizens. In some areas (for example in Togo), informal and nonstandard sewer systems have been put in place by local residents but barely function because they have not been designed properly (e.g. the topography prevents proper drainage) (Ahatefou et al. 2013).

As sewer coverage is limited, and often poorly maintained, most greywater is channeled into storm water drains, streets, other land or open canals (Soro et al. 2010; Bakenou 2011; Ahatefou et al. 2013; Bah 2013), while black water from toilets is captured on site (see below).

Across West Africa, many of the sewer systems were constructed in the 1950s and 1960s or even earlier and require at least renovation or complete rehabilitation to support current population needs. The same applies to the treatment plants (Murray and Drechsel 2011). The extent of these urban sewers has long been outpaced by population growth, not to mention missing connections to peri-urban areas. In recent years, some attempts to increase (decentralized) sewer coverage for institutions, housing schemes and so forth have been undertaken (for example in Ghana, Burkina Faso and Togo), resulting in a slight increase of served HH.

TABLE 1. STATUS OF SEWER USAGE IN SELECTED CITIES OF WEST AFRICA.

City, country	Population increase[a] (%) (2000-2018)	Population coverage	Length of sewer network	Amount of wastewater (WW) collected or treated (m^3 day^{-1})	Treatment process	References
Abidjan, Côte d'Ivoire	2.7	30%[b]	810 kilometers (km)[c]	77,274 (2002, collected and treated)	Stabilization ponds	Hounkpe et al. 2014; Soro et al. 2010; IMF 2009; pS-Eau 2004
Accra, Ghana	2.1	4-6%	63 km (20 km under construction)	• 16,000-18,000 m^3 day^{-1} (Mudor plant)[d] • Up to 6,424 m^3 day^{-1} (Legon plant)[d] • For other plants see[e]	Up-flow Anaerobic Sludge Blanket (UASB), stabilization ponds[d]	SSGL 2019; Adank et al. 2011; AfDB 2005
Bamako, Mali	4.2	< 2%	Only minisewers, 1-8 km long, each with 65 km of greywater drainage canals	32,000 (2007, generated), with 10% from domestic sources	Stabilization ponds (capacity of 5,000 m^3 day^{-1}) for industrial WW. Another plant (with capacity of 600 m^3 day^{-1}) is under construction for domestic WW	AfDB 2017; Konate 2012; DNACPN 2007; Collignon et al. 1998
Conakry, Guinea	2.4	> 200,000 people	70 km	• 19,850 (generated), including 10% from agro-industrial sources • > 7,000 (collected and treated)	Stabilization ponds	Wenchuan et al. 2015; Bah 2013
Cotonou, Benin	5.4	2.2%[f]	13 km	477 (collected)	Stabilization ponds	Hounkpe et al. 2014; Seureca 2014; MEA 2007
Dakar, Senegal	2.6	30%-40%	1,028 km	• 29,059 (collected) • 19,200 (treated)	Activated sludge	ONAS 2014; Norman et al. 2011
Lagos, Nigeria	3.4	2%	5,250 km (planned in 2011)	1.5 million (produced)	5,250 km (planned in 2011)	NLÉ 2012; Adesogan 2013; Adegboye 2011
Lomé, Togo	3.0	< 1%	32 km (246 HH connected in 2006) (8 km under construction)	800 (2006, collected)	None Under Construction: 20,000 m^3 day^{-1} to be treated	Panapress 2015; Lene 2006
Ouagadougou, Burkina Faso	5.6	< 2%	About 45 km	4,500 (collected and treated)	Stabilization ponds	ONEA 2015

[a] UNDESA (2019).

[b] Reported to be 30% (Hounkpe et al. 2014), 40% (IMF 2009) and 45% (pS-Eau 2004).

[c] This number corresponds to the length of the WW sewer network. An additional 1,200 km of sewers exist and are used for draining rainwater.

[d] The Legon WWTP was rehabilitated in 2015. For both the Legon and Modor plants, the exact volumes collected or treated are unknown as houses shy away from the connection.

[e] A few more treatment plants, mostly small, serve individual hotels or institutions (schools, communities, etc.) and therefore are managed privately.

[f] In 2002, MEA (2007) reported coverage data of 0.4% for sewers plus 1.6% released into gutters (0.9% and 0.7% for closed and open gutters, respectively). More recently, Hounkpe et al. (2014) reported coverage of 2.2%.

However, even with more opportunities to connect, HH often decide against a link because of high connection fees, usually mandatory up-front payments, lack of incentives for HH to connect and other limiting factors.

The wastewater collected through the sewer network generally includes domestic wastewater (mostly from kitchens, bathrooms and toilets) to provide sufficient flushing power. On average, wastewater generation for West African cities is between 20-150 liters (l) capita^{-1} day^{-1} (Lene 2006; Mohammed 2013). This wide variability reflects different wealth classes as well as access to tap water. Also, wastewater from institutional (e.g. restaurants, hotels, airports) and small industrial sources is collected using the same sewer systems.

The presence of a sewer in a city does not necessarily mean the existence of a functional wastewater treatment plant (WWTP) for the collected wastewater (Murray and Drechsel 2011). In many cases, treatment plants, including decentralized institutional plants, are dysfunctional and raw or slightly treated sewage is discharged into the sea or rivers. Also, most (small) industries in the subregion discharge their wastewater effluent without proper treatment, directly into the environment. This has negative impacts on human health and endangers ecosystems. In Bamako for example, it was estimated that 5,000 m^3 of industrial wastewater have been discharged daily into the Niger River without treatment until recently (Keita 2008). There are a few exceptions, especially in Ghana, where industrial wastewater is being treated by the industry itself, such as by breweries (Waterbiotech 2012).

In some cases, a WWTP was not part of the initial planning of the sewers (for example in Lomé, which is now building a treatment plant for collected domestic/institutional wastewater). In other cases, the implemented WWTP did not survive over time. In Accra for instance, a modern Up-flow Anaerobic Sludge Blanket (UASB) WWTP was built in 2000 but remained out of service for many years because of broken pumps and poor management. This plant was rehabilitated in 2016 (SSGL 2019). Challenges that public authorities face while attempting to operate and maintain WWTPs include lack of adequate finances, incentive systems or in-house capacity (Murray and Drechsel 2011). Moreover, to facilitate HH participation, there is resistance to the implementation/acceptance of fees and where they are being paid, they may hardly cover treatment costs. Complaints regarding high operation costs (for example the electricity cost required for the treatment process to operate) or vandalism (blocked sewers) have also been recorded as challenges (Nikiema et al. 2013; Weissenbacher et al. 2013). Given this predicament, many West African countries promote low-cost technologies for wastewater treatment, i.e. those requiring low energy and maintenance, such as waste stabilization ponds. Another option would be the use of renewable energy (including biogas) to reduce in-house energy demand and allow for a less-expensive treatment process to be implemented (Waterbiotech 2012). In Senegal, at the Camberene WWTP, biogas harvesting and reuse generated a reduction in operational cost of up to 20% (Mbéguéré et al. 2011).

Even under optimistic investment scenarios, it appears difficult for sewer systems to keep pace with urban growth and OSS will remain the norm for most African cities (Hawkins and Muxímpua 2015).

2.2 On-site Sanitation Systems

An OSS allows for storage and (pre-) treatment of human excreta within the plot occupied by a dwelling or its immediate surroundings. For some systems (e.g. double-pit or vault latrines) used in rural areas, excreta treatment is achieved on site through extended in-pit consolidation and storage. With other systems in urban areas (such as septic tank or single-pit systems), the stored waste has to be collected from time to time and treated off site (WHO 2006).

FS is a partially digested slurry or semisolid that is extracted from the OSS (Nikiema et al. 2014). It is a mixture of excreta, water and toilet paper and may also contain various other forms of waste, depending on the location. FS is rich in nutrients but also in pathogens. The high density of latrines in West African cities and their poor design contribute to the pollution of ground and surface water (Koné and Strauss 2004).

Table 2 shows the 2017 status of OSS usage in West Africa. Overall, OSS cover 69% of the urban population. This means that about 85% of the population with access to basic or improved sanitation services relies on OSS for excreta management, of which 42% is septic tanks, while 58% depends on pit latrines or other improved OSS options (JMP 2018). There are disparities between cities and while septic tanks dominate in large cities like Greater Accra, Abidjan, Dakar or Lagos, in most cities, pit latrines generally prevail (JMP 2018; Abiola 2015; Mangoua-Allali et al. 2015; Waterbiotech 2012; Ezekwe et al. 2011; GSS 2012; Nigeria Census 2010; INSG 2008; Collignon et al. 1998). However, in recent years, the share of septic tanks compared to other OSS in cities has increased (for example it was 38% in 2015), at the expense of pit latrines; this is probably linked to changes in lifestyle.

TABLE 2. STATUS OF SANITATION AND OSS USAGE IN SELECTED URBAN AREAS OF WEST AFRICA.

Country	Urban sanitation services (% of total urban population)				Urban sanitation type (% of urban population with improved, including shared, facilities)		
	Improved (at least basic) services	Shared facilities	Open defecation	Unimproved	Improved latrines and other types	Septic tanks	Sewers
Benin	27	32	29	12	81	14	5
Burkina Faso	39	49	7	4	91	6	3
Cabo Verde	80	8	12	<1	0	59	41
Côte d'Ivoire	46	30	8	16	49	35	15
Gambia	45	35	1	20	60	35	5
Ghana	24	60	7	8	59	34	7
Guinea	34	52	1	13	63	31	6
Guinea-Bissau	37	30	2	32	45	46	9
Liberia	28	36	19	17	35	65	<1
Mali	53	29	1	16	85	11	4
Mauritania	75	9	8	8	65	29	6
Niger	44	33	11	12	79	17	4
Nigeria	48	32	9	11	40	40	20
Senegal	65	26	2	7	30	52	19
Sierra Leone	26	49	6	20	84	15	1
Togo	29	82	13	7	48	52	<1

Source: JMP 2018.

2.2.1 Emptying and Transport of FS

Removal of sludge from OSS and transport of FS to the treatment or disposal site are the first two steps in FSM (Strande 2014). FS can be removed from OSS using manual or mechanized techniques. The specific method utilized will be based on the type of on-site system, accessibility of the site, consistency of the sludge, type of equipment owned by the service provider and the level of expertise. Emptying fees are usually borne by the HH and are USD 60 on average in Africa, ranging from about USD 40 in Burkina Faso and Senegal to up to USD 100 in Nigeria (Chowdhry and Koné 2012).

Due to the lack of any larger sewer system in Ouagadougou, OSS are used by 9 out of 10 HH with access to sanitation. A recent study established that 50% of Ouagadougou's OSS has been emptied since they were built, 75% by vacuum truck and the other 25% manually (DGAEUE 2011). Often, use of vacuum trucks is restricted to middle- and high-income HH that have modern OSS facilities (such as septic tanks) with easy access from the street (Zoungrana et al. 2011). Manual emptying is done by low-income HH, particularly those relying on traditional latrine facilities, or in high-density housing areas. It is also practiced for pits with content that cannot be emptied mechanically because it is too compact (dry).

In Greater Accra, there is negligible manual emptying (although it occurs to a larger extent in smaller cities in Ghana). Pan/bucket latrines, emptied at central collection points by individuals, have been banned in Ghana but are still in use, for example in slum areas.

Similar to Burkina Faso, the collection of FS in Benin is done via mechanical and manual means. In 2015, a study of 480 HH in Cotonou and 289 HH in Sèmè-Podji showed that mechanical emptying is the most common practice (Cotonou: 65%, Sèmè-Podji: 33%). Few people relied on manual emptying (Cotonou: 2%, Sèmè-Podji: 4%). However, 33% of the respondents in Cotonou and 63% in Sèmè-Podji were not able to give information about the modes employed for emptying their septic tanks or pits. The reasons may be that they never emptied their sanitation units during their tenure or that the information they had was incomplete (Abiola 2015). The FS received at the designated/approved sites is conveyed by FS vacuum trucks only.

Findings in these three West African countries compare well with other African and Asian locations (Chowdhry and Koné 2012) and reveal significant gaps in the regulatory frameworks around FS emptying and collection. As a result, most people involved in manual emptying do not use the required protective equipment, such as hand gloves or body suits, to reduce contact with faeces. In general, tools used for manual emptying are simple and limited to buckets, shovels, ropes, bare hands and so forth. Therefore, capital costs involved are quite low (USD 20-100 per kit). Workers in this sector earn USD 20-400 month^{-1} depending on the number of calls. But they are exposed to several sanitation-related diseases, such as skin rashes and infections (Rao et al. 2016). Otherwise, mechanical emptying relies on the use of vacuum trucks, pumping systems or mechanical augers. This service is provided, for the most part, by small private operators in the informal sector in cities rather than by water and sanitation utilities (Chowdhry and Koné 2012). In this case, there are also issues with monitoring of these entities' practices.

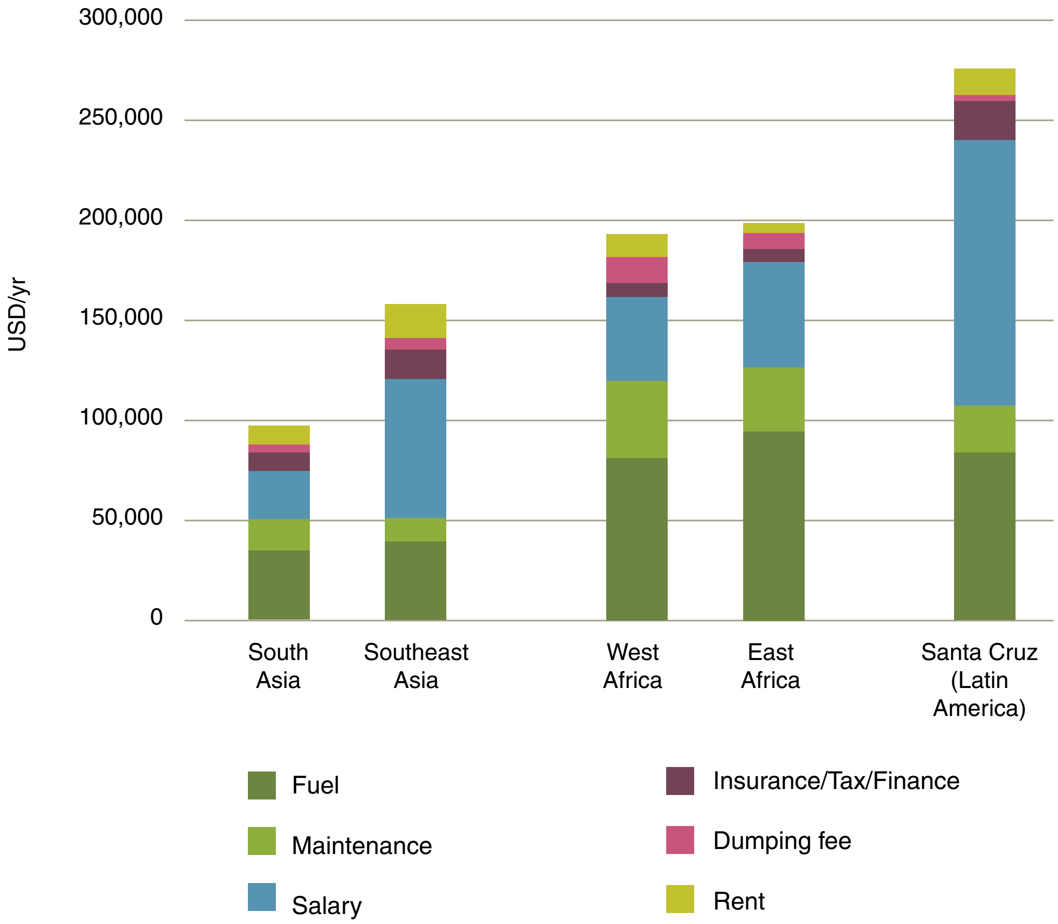
One key challenge in the mechanical emptying sector in West Africa relates to the high capital cost involved in acquisition of the truck itself (USD 25,000-45,000), usually via second-hand import from Europe (Mbéguéré et al. 2010; Zoungrana et al. 2011). The operational costs of such business include labor (two to three staff truck^{-1}), fuel, and periodic repair and maintenance of the truck, which are substantial for old fleets typically found in the region (Figure 1). Trucks are at least 15 years old when purchased (Zoungrana et al. 2011). Minor costs include telephone expenses and advertising costs (printing leaflets, signboards and visiting cards). There are other more affordable mechanical systems for OSS emptying in other parts of the world such as gulper pumps (USD 40-1,400 unit^{-1}), screw augers (USD 700 unit^{-1}) and diaphragm pumps (USD 300-850 unit^{-1}) (Strande 2014; Rao et al. 2016).

2.2.2 Treatment and Disposal of FS

FS that is emptied manually is usually disposed of inappropriately. It is either buried in nearby land or dumped in fields or open drains. According to Hounkpe et al. (2014) about 35% of houses in Benin was using manual emptying and dumped their sludge directly into the public drain or onto the street. Similarly, Koanda (2006) reported that 45.3% of sludge removed manually in Ouagadougou was dumped onto the street. However, FS collected through mechanical means (like vacuum trucks) is sent to designated FSTPs when they exist, or to informal dumping sites, which include farmland.

There are several possible technological options for FS treatment. Standalone FSTPs exist in many countries (Figure 2). Although the capital costs of FSTPs are considerably higher than the emptying and transport businesses, operation and maintenance (O&M) costs are relatively lower due to lower maintenance cost, especially of pond-based systems with almost no expenses on fuel/energy for pumping (Rao et al. 2016). But co-treatment with sewerage is also being practiced successfully. Nevertheless, many cities lack treatment facilities that can process FS before it is dumped in the environment. Even when they exist, their operation may not always be optimal.

FIGURE 1. ANNUAL O&M COSTS FOR FS EMPTYING BUSINESSES IN DIFFERENT REGIONS FOR A POPULATION OF 100,000 PEOPLE.[1]



Source: Rao et al. 2016.

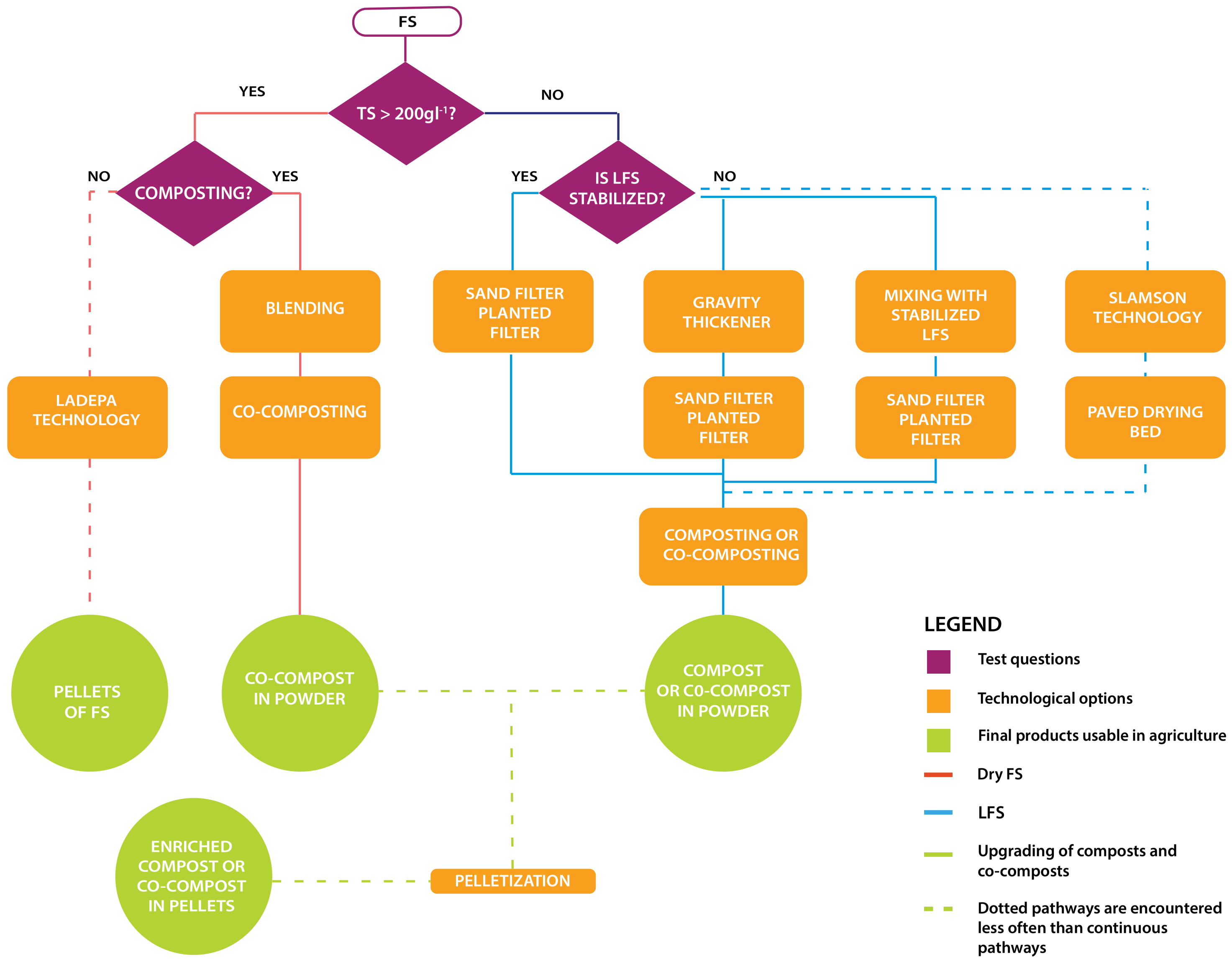
Note: [1] As a rule of thumb, one truck might serve 10,000 people or an area of 2,000-2,500 HH.

2.2.3 Resource Recovery from FS

Resource recovery from FS can deliver several products through different processes. Composting is often considered to be a low-cost and easy-to-operate technical option for FS sanitization in low- and middle-income countries, compared to other recycling options. Composting involves microbial degradation of organic solid waste. It can be achieved under aerobic (i.e. with oxygen) or anaerobic (i.e. without oxygen) conditions and even alternate between the two modes. Open/aerobic systems such as windrows and static piles have been used for dewatered FS composting (Nikiema et al. 2014; Cofie et al. 2009, 2016) and are often preferred to other methods because they allow temperatures to rise during composting and material to be sanitized more quickly. Heating remains the most reliable sanitization method and composting processes which do not result in sufficient temperature increase (e.g. vermicomposting) should be avoided as much as possible because they require longer periods for FS composts to be sanitized, hence increasing storage time and the footprint of the process. To accelerate the process, other more expensive composting variants may be used, which are described in detail by Cofie et al. (2016).

Beyond the agricultural options shown in Figure 2, biogas generation from co-digestion of FS is seen as a promising technology, given its potential to produce electricity and feed the national grid in countries where electricity charges or demand remain high. In Burkina Faso, the first FS-based biogas plant, which has capacity of 400 m^3 day^{-1}, was commissioned end 2016. It is expected to produce up to 2,160 MWh $year^{-1}$ of electricity (ONEA 2017). Another similar plant has been in operation in Ghana since 2016. On the other hand, dewatered FS may be used as solid fuel for selected industries, such as for curing of clay bricks or to regenerate waste oil, as tested in Senegal (Gold et al. 2017). It may also undergo carbonization through pyrolysis, i.e. thermal decomposition under a limited supply of oxygen (Table 3). This produces FS biochar, which is considered a simple way to sequestrate carbon, if the end use is in agriculture. Biochar has a longer lifecycle in soils than ordinary biomass and can bind organic contaminants and heavy metals for example. The carbonized FS may also be briquetted and used instead of wood-based charcoal, as tested in many places, including Ghana (Tandukar and Heijndermans 2014).

FIGURE 2. CONVENTIONAL PROCESSES IMPLEMENTED FOR TREATMENT AND RECYCLING OF FS IN AGRICULTURE.



Source: Nikiema et al. 2014.

TABLE 3. DESCRIPTION OF CARBONIZATION.

Description	Advantages	Limitations
• Converts organic waste into biochar; • Operating conditions: ✓ High temperature (350-500 °C) ✓ Limited oxygen ✓ Residence time: 30-90 minutes after the drying phase; and • Yield: 65-80%* weight loss.	• Biochar may serve as fuel or as an adsorbent for air/wastewater treatment; • Provides an option for carbon sequestration; and • Allows 100% removal of pathogens in the final product.	• The process may require an external energy source; • The process leads to loss of volatile elements, including nutrients in dewatered FS; and • Predrying may be required, depending on the process selected.

* Yacob et al. 2018 (weight loss of 65% following excreta pyrolysis); Tandukar and Heijndermans 2014 (weight loss of 80% following FS pyrolysis yield was 20%).

Another recycling option is the use of excreta or FS mixed with organic wastes as feedstock for the rearing of insect larvae (such as black soldier fly larvae). Once harvested, the insects constitute a protein source to feed fish and other animals to support an RRR business at scale (Joly and Nikiema 2019).

3. DESCRIPTION OF THE FSTPs IN TARGET COUNTRIES

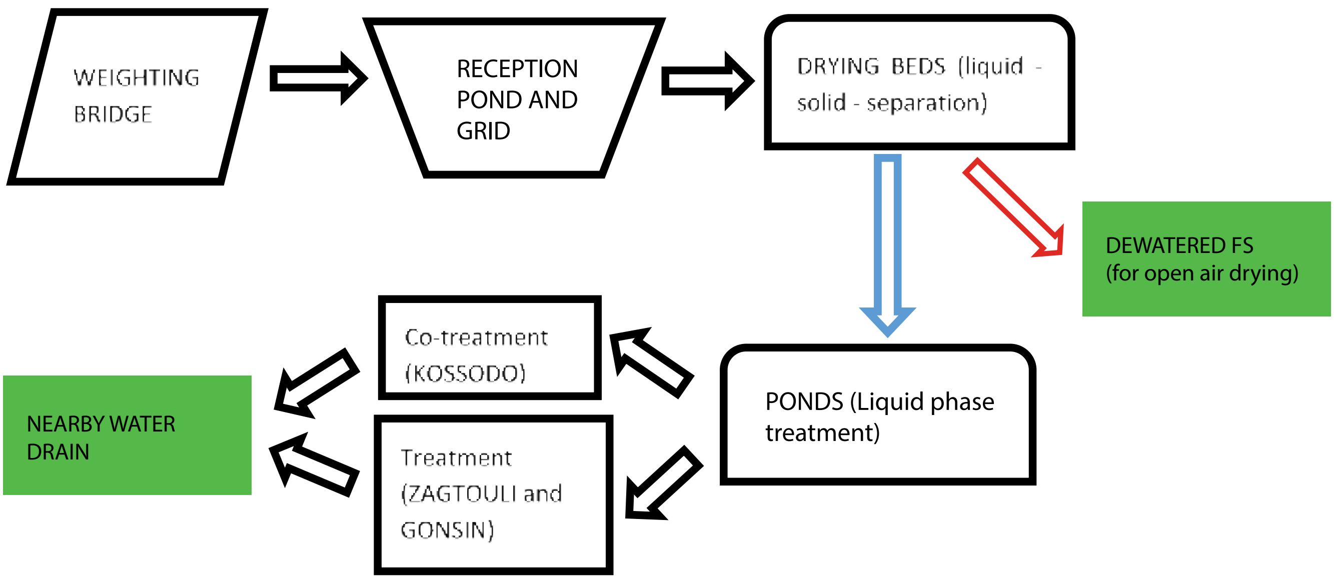
3.1 Ouagadougou, Burkina Faso

Ouagadougou, the capital of Burkina Faso, had an estimated 2018 population of 2,531,000,[1] representing about 13% of the nation's population. The city's population is growing currently at a rate of about 4.8% year^{-1}. About 29% of the country's population resides in urban areas (UNDESA 2019). The city lies in the Sudano-Sahelian climate zone that has two distinct seasons: the dry season from October to May and the rainy season from June to September.

Ouagadougou has three FSTPs in operation. All FSTPs have similar designs and started operating in September 2014 (Kossodo), October 2014 (Zagtouli) and November 2016 (Gonsin). The main difference between the three FSTPs is the treatment of leachates as described subsequently. There is a high probability of informal dumping sites used by some truck operators, implying that more FS is collected than reported here. Figure 3 shows the FS treatment process in the FSTPs.

On arrival, and when they leave the plant, the FS trucks are weighted using a weighting bridge. This helps to obtain an accurate idea of the weight of FS being received. At the FS

FIGURE 3. THE TREATMENT PROCESS FOR THE FSTPs IN OUAGADOUGOU.



[1] https://www.macrotrends.net/cities/23192/ouagadougou/population

discharge point, the FS is emptied into a chamber feeding alternatively up to two unplanted drying beds. A movable grid is placed at the entrance of each drying bed to hold back coarse elements. The drying beds are sand filtration systems that enable solid-liquid separation to occur. They serve as drying devices, filters and bioreactors.

The dewatered FS, obtained after scrapping the drying bed, is stored in the open air near the FSTP. This by-product is not always recycled and its management may constitute a challenge. The filtrates from the drying beds are sent to waste stabilization ponds. At Kossodo, the drying bed leachate is pumped into the nearby municipal WWTP where it undergoes co-treatment with a mixture of industrial and domestic wastewater. However, at Zagtouli and Gonsin, the leachate is treated separately.

3.2 Greater Accra, Ghana

Accra, the capital of Ghana, had an estimated 2018 population of 2,439,000. The Greater Accra region, which includes among others, the Tema metropolitan district, had an estimated 2018 population of approximately 4.83 million, representing approximately 16% of the nation's demographic (UNDESA 2019; The Atlas 2018). The coastal savannah climate of Accra has a major rainy season from April to July and a minor rainy season from September to October.

For decades, a location called 'Lavender Hill' has been the main FS dumping site of Accra, where depending on the status of other FSTPs, between 30 and 90% of the city's FS was directly released onto the beach (and into the ocean) from septic trucks.

In October 2016, the Accra Sewerage Treatment Plant (or the 'Mudor plant') was recommissioned after rehabilitation and subsequently able to treat up to 18,000 m^3 day^{-1} of sewered wastewater. At the same time, a new FSTP named 'Lavender Hill Faecal Sludge Treatment Plant' or 'Mudor Faecal Sludge Treatment Plant' was built nearby to treat 2,000 m^3 day^{-1} of FS, i.e. most of the generated FS formerly dumped into the sea at Lavender Hill. The FS treatment process design involves screening and mechanical dewatering of the FS followed by anaerobic treatment of leachate using the UASB reactor system to eventually generate electricity from the biogas (for internal use). The private company in charge of the facility (Sewerage System Ghana Limited) explored sustainable management options for the dewatered sludge, but they were not integrated into the existing plant design. Another FSTP located north of Adjen Kotoku at the Accra Compost and Recycling Plant is currently being managed by the same entity. It can treat 600-1,000 m^3 day^{-1} of FS (SSGL 2019). It was commissioned towards the end of 2016.

In 2004, a smaller FSTP started operations at Nungua Farms between Accra and Tema. The FSTP consists of eight stabilization ponds (four anaerobic, one facultative and three for maturation) and four sand drying beds (240 m^2 each) on a 10-acre plot of land. The FSTP underwent partial rehabilitation during 2011 and 2012. Figure 4 shows the treatment process.

Since 2017, a new FS processing unit has enabled dewatered FS to be co-composted with municipal organic solid waste near Nungua Farms through the process described in Figure 5 (also see Nikiema et al. 2020). In Greater Accra, there is also comment about other (informal) dumping sites used by some truck operators; however, no data are available about the capacity of these locations and frequency of use.[2] This implies that the recorded FS volumes are likely to be conservative and do not represent the total amount collected. New FSTPs supported by the World Bank are also in the pipeline.

3.3 Grand Nokoué, Benin

The urban agglomeration of Grand Nokoué comprises four districts: Cotonou (the capital city, with about 679,012 inhabitants in 2013), Abomey-Calavi (656,358 inhabitants), Sèmè-Podji (224,207 inhabitants) and Porto-Novo (264,320 inhabitants) (INSAE 2015; Abiola 2015). The urban agglomeration had about 1.8 million inhabitants in 2013, which has recently been estimated at 2.3 million inhabitants,[3] representing about 20% of the population of Benin (INSAE 2019).

To date, there is only one FSTP in Benin, which is based on a 100-year land lease agreement between the Government of Benin and the private company SIBEAU, which owns the treatment plant. The plant is located in the Grand Nokoué area in Ekpè near Sèmè-Podji. This FSTP is the officially designated site for receiving all the FS collected in the Grand Nokoué area. It was built by SIBEAU between 1991 and 1994 to treat 180-200 m^3 of FS daily, but shortly after it was asked to also accept trucks belonging to other parties (Abiola 2015).

Figure 6 shows the treatment process for FS. A concrete structure with three receptacles enables three trucks to simultaneously discharge their loads. This reduces the overall emptying time for each truck. At each receptacle, there is a movable horizontal metallic grid that is used to filter the raw FS discharged and remove coarse elements.

The grit chamber is a concrete structure (16.8 x 5.6 m) with a depth of nearly 2 m. It allows for the removal of sand from the FS. From there, the liquid flows into the treatment system organized as two parallel units, each composed of one

[2] https://www.slideshare.net/AndreHead/gtg-webinar-june; slide 41
[3] https://www.lespharaons.com/benin-gestion-des-dechets-dans-le-grand-nokoue-23-millions-dhabitants-impactes/

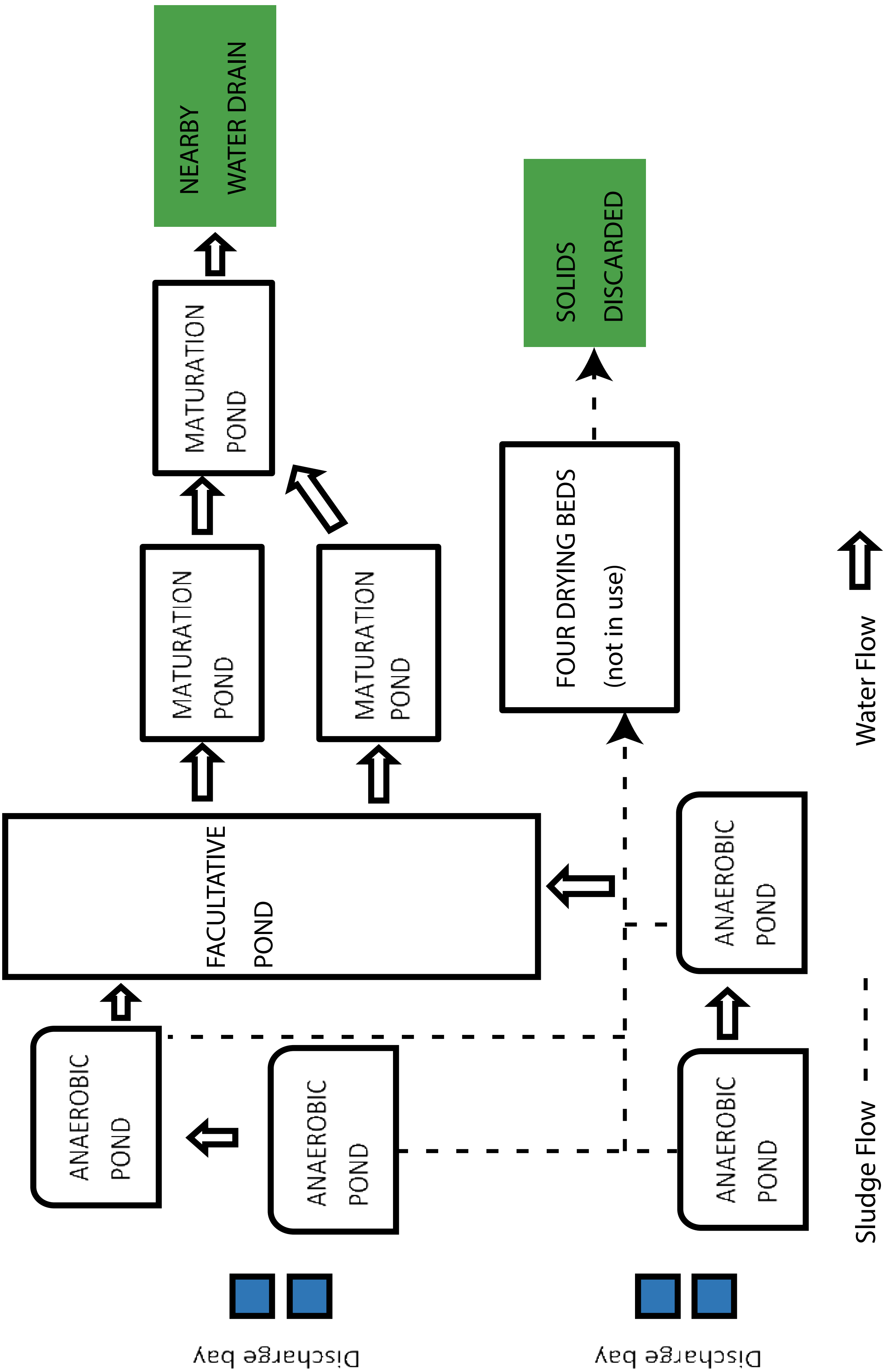
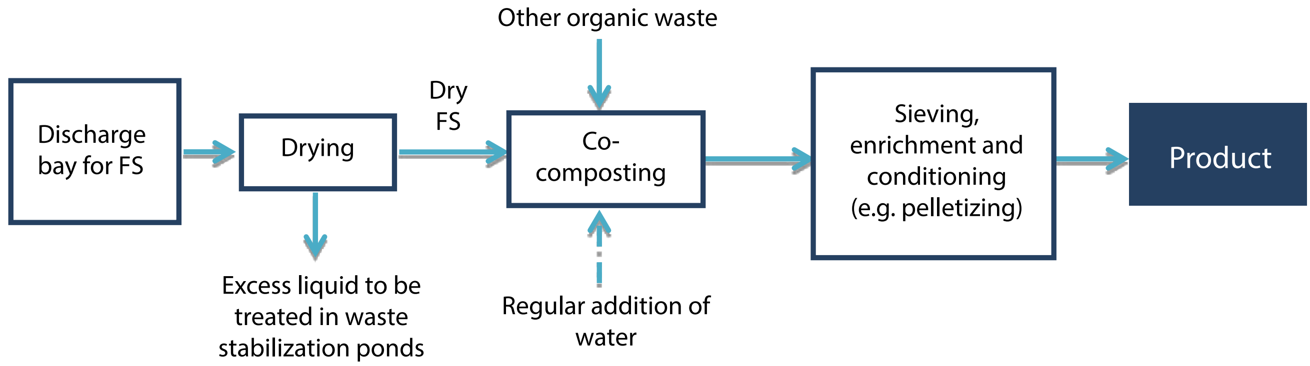


FIGURE 4. THE TREATMENT PROCESS AT NUNGUA FARMS FSTP IN ACCRA.

FIGURE 5. THE CO-COMPOSTING PROCESS USED FOR RESOURCE RECOVERY FROM FS, NEAR NUNGUA FARMS, ACCRA.



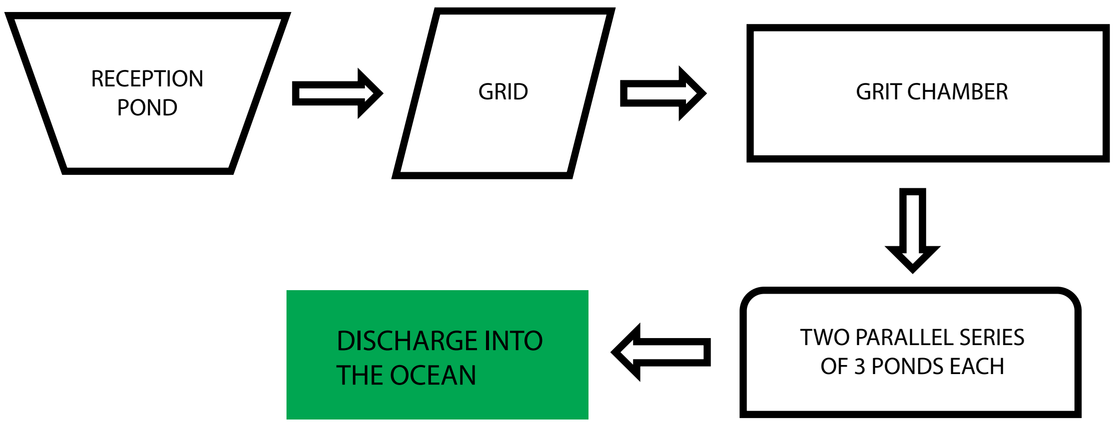
anaerobic pond, one facultative pond and one maturation pond (i.e. six ponds in total). At the outlet of the maturation pond, the water is discharged into the sea through a pipe. Due to overloading, sometimes only one series of ponds receives new sludge, resulting in ponds filling up with sludge, thus reducing the retention time of the wastewater down to less than 1 hour, which has a serious effect on the effluent quality (Hounkpe et al. 2014). According to the World Bank (2016), the plant needs substantial repair and it is being increasingly affected by coastal erosion.[4]

4. VOLUMES AND CHARACTERISTICS OF FS COLLECTED AND TREATED

FSTPs and compost stations are normally dimensioned to absorb actual and forthcoming FS volumes. Previous studies have demonstrated that FS generation and characteristics can be highly variable. For instance, while in Dakar, Senegal, the generation of FS capita^{-1} was 0.99 m^3 year^{-1}, in Accra, Ghana it was estimated to be 0.36 m^3 year^{-1}. Variations can be due to different prevalence of flush toilets, differences in social practices, as well as in the hydrogeology (there is a higher water table in Dakar, as opposed to Accra, which infiltrates the tanks), all of which can affect FS composition (Dodane et al. 2012).

Understanding the collection of FS is also essential to the design of the FSTPs, including likely extreme values in peak periods, which might be certain days of the week, particular months or climatic seasons. As West Africa did not have long experience in FS treatment, such background information for designing the FSTPs was often not available prior to the construction of the first treatment systems. Therefore, designs were mostly based on small-scale prefeasibility studies, which built on estimates from basic mathematical models and on global knowledge to attempt to give a fair idea of the volume distribution of FS as well as its quality. Moreover, insufficient data available at the time of design have

FIGURE 6. THE FS TREATMENT PROCESS AT EKPÈ, BENIN.



[4] A planned rehabilitation project, supported by the African Water Facility/African Development Bank, could not be executed owing to disagreement among the parties to the PPP. However, the government was able to raise resources with the World Bank to establish a new septage treatment plant on a nonprivate site (see https://www.afdb.org/en/documents/document/benin-grand-nokoue-septage-management-improvement-project-public-private-partnership-pcr-99788).

generated additional uncertainty concerning the final performance of the FSTPs.

Apart from FS volume, its quality (for example solid and water contents, degree of stabilization) matters for plant design. For example, total solids will inform on the materials that could be available for composting while the degree of stabilization will clarify if FS can be fed directly to a drying bed, or a settling pond should be considered first. Finally, for any compost production, the high variability in the compost nutrient content has to be addressed to give customers a quality guarantee.

Since FSTPs have now been running for some time, it has become important to analyze their performance and to compile adequate knowledge to ensure designs of future plants are more robust. Some of the identified gaps could be addressed through relevant policies to ensure the FSTPs continue to operate under the best possible conditions.

4.1 Methodology

4.1.1 Collection of FS Volume Data

Data collection focused on the volumes and quality of the collected FS, as they have implications for plant capacity, area needs (for example via drying beds) and technology choice, as well as the financial analysis of an optional co-composting unit similar to the one tested in Greater Accra.

For Ouagadougou, only two FSTPs were considered, i.e. Zagtouli and Kossodo. Data were obtained from the National Utility for Water and Sanitation in Burkina Faso (ONEA) database. The volumes of FS were sourced from the monthly and daily reports produced on site and used for the monitoring of the two FSTPs. At each facility, the volume of FS was calculated from the differential weight of the trucks coming to discharge the FS. In rare instances where the weight bridge was not functioning (due to a power failure or technical hitch), data were estimated by the operator from the truck's volumetric capacity.

At Zagtouli, the time period chosen was from October 2014 (the date of plant commissioning) to December 2016. At Kossodo, the data were collected from September 2014 (commissioning of the plant) to July 2015 and from November 2015 to December 2016. Kossodo FSTP was closed from August 2015 to October 2015 due to restoration work on the access road to the plant.

In Greater Accra, FS volumes were obtained from municipal records and included monthly and daily monitoring reports for each site. In particular, the Accra Metropolitan Assembly (AMA) database provided information on the Lavender Hill site while for Nungua Farms, records from Tema Metropolitan Assembly (TMA) were considered. Monthly records were obtained for 7 years of operation, from 2010 to 2016, while daily records were obtained for 2015 only. Data for November and December 2016 (Lavender Hill) and from November 2015 to February 2016 (Nungua Farms), were not available during the preparation of the document. The more recently established FSTPs in Accra by Sewerage Systems Ghana Limited were only commissioned towards the end of 2016, and therefore were not considered in the study (SSGL 2019).

In Benin, data were collected from the SIBEAU database. The volumes of FS were obtained from the monthly monitoring and operation reports of Ekpè FSTP over a period of 6 years of operation (from 2011 to 2016).

To analyze the effects of parameters such as workday, calendar month and season on the volume of FS received at each facility, STAT-ease Design Expert 10.0® software was used. For other tests, we considered the least significant difference (LSD) to compare means and Tukey's Student Range. Results at 5% ($p<0.05$) were considered as statistically significant.

4.1.2 FS Sampling for Laboratory Analysis

Sampling intervals: Samples were collected from trucks serving OSS in HH and institutions (including public toilets [PT]).

- In Burkina Faso, the sampling was conducted in July 2016 over 2 weeks; four samples of each source (HH, PT) were collected in the first week and one of each source in the second week. The sampling was carried out on Tuesday and Thursday during the first week and on Monday of the second week at Kossodo FSTP. At Zagtouli FSTP, sampling was done on Wednesday, Friday and Saturday during the first week and ended on Tuesday of the second week.
- In Ghana, the sampling was conducted over 3 weeks at each FSTP. Two samples of each source (HH, PT) were collected in the first and second weeks and one of each source in the third week. The sampling was undertaken on Mondays at Lavender Hill and on Wednesdays at Nungua Farms during August 2015.
- For Benin, samples were collected from Ekpè FSTP over 5 days (from 7 to 12 May 2015). The sampling was conducted manually on 50 trucks (10 trucks day^{-1}) from various origins (Cotonou, Sèmè-Podji, Abomey-Calavi and surroundings) and randomly from all kinds of OSS. The sampling was performed in the morning or early in the afternoon and the sampling time varied between 2 and 3 hours each day.

Sludge capture: For each FS truck in Greater Accra and Ouagadougou, an equal volume (3 l) of sludge was collected

with a bucket during the following points of discharge: the beginning (when valves were opened), the middle and at the end of discharge when pressure was low. In Ekpè, from each FS truck, an equal volume (2 l) of sludge was collected using a bucket (0.5 l) at the beginning when valves were opened, 1 l at the middle of discharge; and 0.5 l at the end of discharge when pressure was getting low. These three fractions were mixed to give a fair idea of the composition of FS in that truck.

For each truck from which FS was sampled in Ghana and Burkina Faso, information on the source of FS (pit latrine, septic tank, domestic HH or institutions, such as offices) and the estimated amount that was discharged at the FSTP was collected through interviews with the truck drivers.

Sample compositing: Equal volumes of FS from three different trucks at the Nungua Farms, Lavender Hill and Kossodo sites and two different trucks at Zagtouli (given the reduced number of trucks visiting this plant), either from HH or PT, were mixed for each source into a composite sample.

In total, 10 composite samples at each location, Nungua Farms, Lavender Hill, Ekpè, Kossodo and Zagtouli, were obtained (five from HH and five from PT/offices; except in Ekpè). The composite samples reflecting the contents of 60 (Ghana) and 50 (Burkina Faso, Benin) FS trucks were each packaged in containers of 1 l and sent for analysis. In Benin, the 50 samples were merged to obtain 20 (4 day^{-1}).

Laboratory analysis: The results obtained are listed below.

- In Ghana, analyses of total coliforms (TC) and *E. coli* concentrations were done at the IWMI laboratory. Analysis of pH, electrical conductivity (EC), TS, suspended solids (SS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), ammonia (NH_4-N), nitrate (NO_3-N) and organic carbon (to calculate organic matter [OM]) was conducted by the Water Research Institute of the Council for Scientific and Industrial Research. Total nitrogen (TN), total phosphorus (TP) and total potassium (TK) were analyzed by Ecolab, University of Ghana.

- In Burkina Faso, helminth eggs, fecal coliforms (FC), TC, *E. coli*, TN and TK concentrations were analyzed by the Laboratory of Water, Decontamination, Ecosystem and Health (LEDES) at the International Institute for Water and Environmental Engineering (2iE) in Ouagadougou. Analysis of pH, EC, TS, SS, BOD, COD, ammonia (NH_4-N), nitrate (NO_3-N) and TP was done by the Laboratory of Analysis of Quality and the Environment (LANE) also located in Ouagadougou.

- In Benin, all parameters were analyzed at the Laboratory of Sciences and Water Technologies (LSTE) in Abomey-Calavi. To validate these results, samples were also analyzed by the laboratory of the Public Health Directorate, which is under the purview of the Ministry of Health, Benin.

All parameters were measured three times from the same sample and data reported were averages of the three values.

4.2 Discharged FS Volumes at FSTPs

4.2.1 Ouagadougou

For the receiving chambers at the FSTP, truck volume and frequency are important: At Zagtouli, it was established that the average volume of FS was 8.7 m^3 truck^{-1} while at Kossodo, the average volume was statistically higher at 10.5 m^3 truck^{-1} (see Annex 1, Table A1). As the two plants are in the same country, the difference is probably not due to the size of the trucks but rather to the filling rates of the trucks visiting the different treatment stations. This could be linked to the social status of the communities served by the plants and should be investigated further. In general, higher filling rates should be promoted as they correlate with lower cost of transportation of the waste, which could mean increased affordability.

On the other hand, the amounts of FS received at both facilities were not significantly affected by the calendar day, months or seasons over the period of observation.

The monthly volume of FS collected between September 2014 and December 2016 at Kossodo FSTP was 6,582 m^3 while at Zagtouli it was significantly less (2,315 m^3). The average volume of FS collected and transported over the period to those FSTPs in Ouagadougou was 8,108 m^3 month^{-1}. Since the commissioning of the FSTPs, 22,891 trips by vacuum trucks had been received at both FSTPs. The average number of trips for each working day was 25 at Kossodo (which has a more central location) versus 10 at Zagtouli, leading to a total of up to 35 trips workday^{-1} for the entire city on a normal day (i.e. when both FSTPs were in operation).

Truck operator services are offered 5 to 6 days a week (Zoungrana et al. 2011). The average amount of FS collected for each working day between Monday to Saturday in 2015 was 237 m^3 at Kossodo while at Zagtouli, it was 87 m^3 (Figure 7). City-wide, FS volume collected and received at the FSTPs was 324 m^3 workday^{-1}. Based on the average values, the highest volume of FS collected at both facilities was recorded on Mondays (377 m^3), the lowest being on Wednesdays and Fridays.

FS volumes collected at each FSTP during the rainy season were 14 or 26% higher in Ouagadougou than those measured during the dry season, but the differences were not statistically significant. The average amount of FS discharged at Kossodo from September 2014 to December

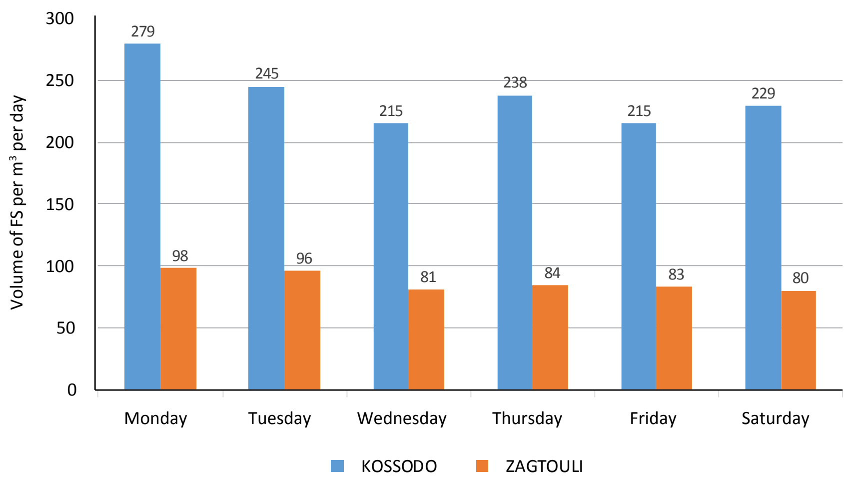
2016 during the rainy season was 7,742 ± 3,069 m^3 $month^{-1}$; while the volume of FS discharged during the dry season was 6,130 ± 3,283 m^3 $month^{-1}$. This was similar to Zagtouli FSTP (on average, 2,529 ± 542 m^3 $month^{-1}$ and 2,225 ± 648 m^3 $month^{-1}$ for the rainy and dry seasons respectively).

For design plans, extreme values also matter. The highest monthly amounts of FS discharged at both facilities from 2014 to 2016 were registered in October 2016 at Zagtouli and at Kossodo, i.e. following the rainy season and were 75 to 100% higher than the average values for the period. However, the lowest processed FS amounts (excluding periods of shutdown) were 35 and 65% lower than the average, respectively. The reasons for these observations are diverse (for example more holidays in December), but the important message is that FS volume variation must be factored into the design of the FSTPs to ensure that the treatment remains acceptable at all times.

4.2.2 Greater Accra

For Lavender Hill, municipal records showed an average volume of 9.7 m^3 FS $truck^{-1}$ while for Nungua Farms this figure was 13.2 m^3. Figure 8 shows the trend of the average volume of FS discharged daily (Monday to Sunday) at FSTPs in Greater Accra during 2015. The average amount of FS collected in Lavender Hill for each working day was 852 m^3 while in Nungua Farms this was 216 m^3. The amount of FS collected increased from Monday to Thursday with the statistically lowest volumes collected on Sundays.

FIGURE 7. DAILY VOLUMES OF FS RECEIVED IN 2015 AT THE FSTPs IN OUAGADOUGOU, BURKINA FASO.



Overall average (m^3 $workday^{-1}$)	
KOSSODO	237+/- 116
ZAGTOULI	87 +/- 35
IN TOTAL	324 +/- 31

Between 2010 and 2016, the average volume of FS discharged monthly at Lavender Hill was 27,285 ± 1,781 m^3, while at Nungua Farms it was statistically lower (4,183 ± 654 m^3). Hence, the total amount of FS collected in Greater Accra every month was 31,468 ± 2,435 m^3 and 377,615 ± 12,137 m^3 annually, assuming no discharge elsewhere.

Monthly differences were not statistically significant under consideration of the lowest and highest loads, for example January 2016 and 2015 at Lavender Hill (16,393 and 45,396 m^3, respectively) or in August and June 2016 at Nungua Farms (558 and 10,534 m^3, respectively). Seasonal effects (rainy season, dry season) were also not statistically significant.

4.2.3 Grand Nokoué

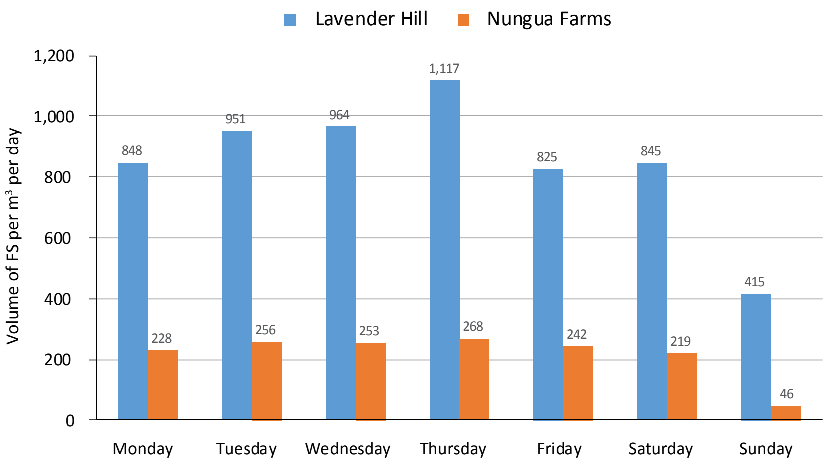
The average volume of FS for each truck was 8.6 m^3 over the entire period considered but seems to have been declining over recent years (around 9.0 in 2010 versus 8.1 in 2016). Figure 9 shows the trend of the average volume of FS discharged from Monday to Saturday at the FSTP at Ekpè, Grand Nokoué during 2016. The average amount of FS sent to the FSTP was 382 m^3 $workday^{-1}$. The statistically highest volumes of FS for 2016 were registered on Mondays and Tuesdays (average 421 and 418 m^3 $workday^{-1}$, respectively) and the lowest statistically significant volume on Saturdays (303 m^3 $workday^{-1}$).

The average volume of FS collected monthly at Ekpè during the analyzed six years of operation was 10,525 ± 676 m^3 $month^{-1}$ showing limited variation without any significant difference. The same applies to seasonal variations. Monthly extremes ranged from 3,046 m^3 in December 2012 (probably due to a partial plant closure) to 13,666 m^3 in July 2011.

4.2.4 Annual Trends

Over 7 years, certain trends of FS discharge at the FSTPs were observed. These reflect in part the dynamic between population growth and the provision of sanitation services but are also influenced by plant breakdown/renovation or the opening of alternative plants.

FIGURE 8. DAILY VOLUMES OF FS RECEIVED IN 2015 AT THE FSTPs IN GREATER ACCRA, GHANA.

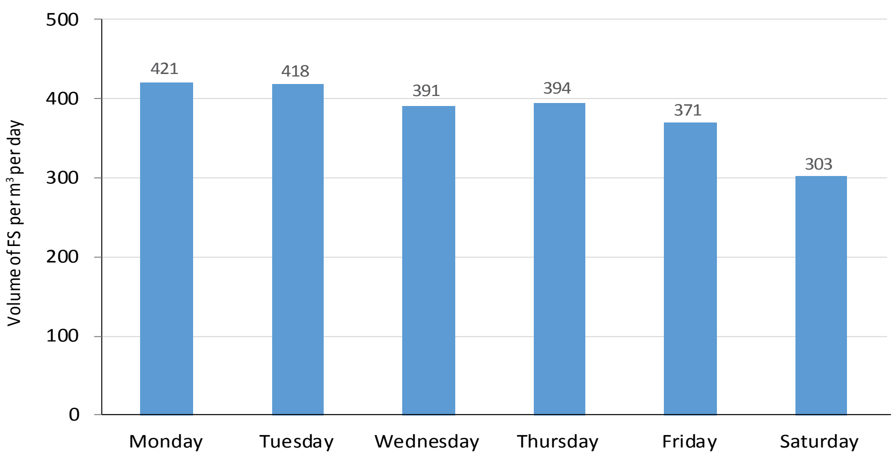


Overall average (m^3 $workday^{-1}$)	
LAVENDER HILL	852 +/- 135
NUNGUA FARMS	216 +/- 45
IN TOTAL	1,068 +/- 175

For Ouagadougou, Figure 10 shows a continuous increase in the annual amount of FS discharged at the newly constructed FSTPs and of the ratio of the volume of FS collected to the population of the city. This indicates not only the collection of more FS but also that collection has kept pace with population growth – there was a statistically significant improvement in the sanitation situation (by 86%) between 2015 and 2016. There are no data on how much informal discharge in the environment has decreased. In 2006, at least seven uncontrolled sites were identified where FS from the city was being dumping without treatment and with little control (Ouedraogo 2006).

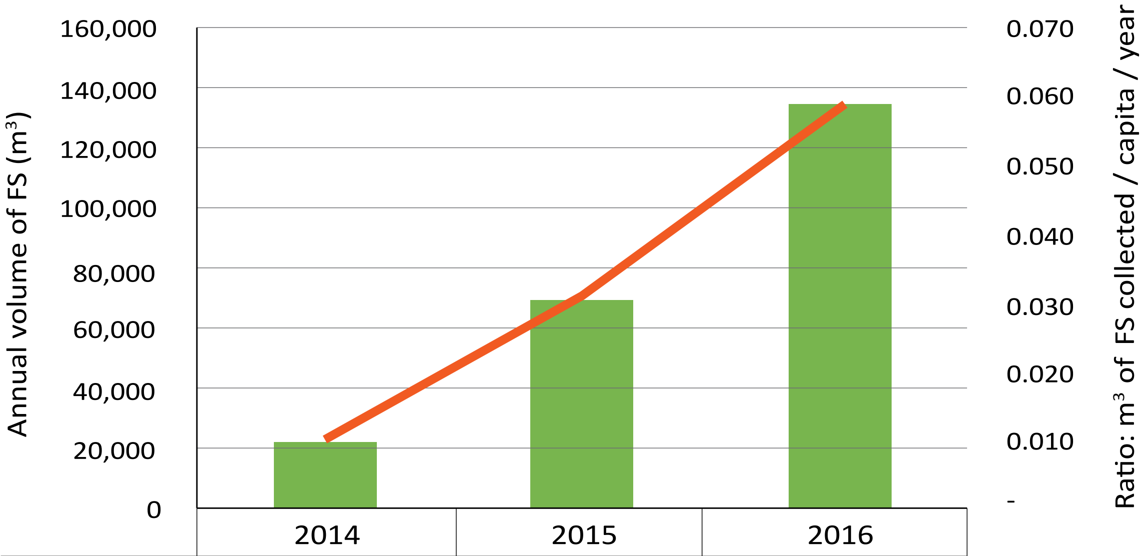
In Greater Accra, the annual volume of collected FS remained in the same range (ca. 370,000-410,000 m^3 $year^{-1}$) between 2010 and 2015 but decreased in 2016 when the rehabilitated Mudor plant (and other initiatives) started operations in the second part of the year (Figure 11). Given the population increase in this period, an increase in the FS volume delivered to the FSTPs was expected. However, Accra grows far more horizontally than vertically and septic trucks at the city margin will seek other alternatives to inner-city traffic and loss of time and income. The FS collection rate $capita^{-1}$ was 0.08 to 0.10 m^3, higher than Ouagadougou, but (even disregarding 2016), appears to be declining, which is concerning.

FIGURE 9. DAILY VOLUMES OF FS RECEIVED IN 2016 AT THE FSTP IN GRAND NOKOUÉ, BENIN.



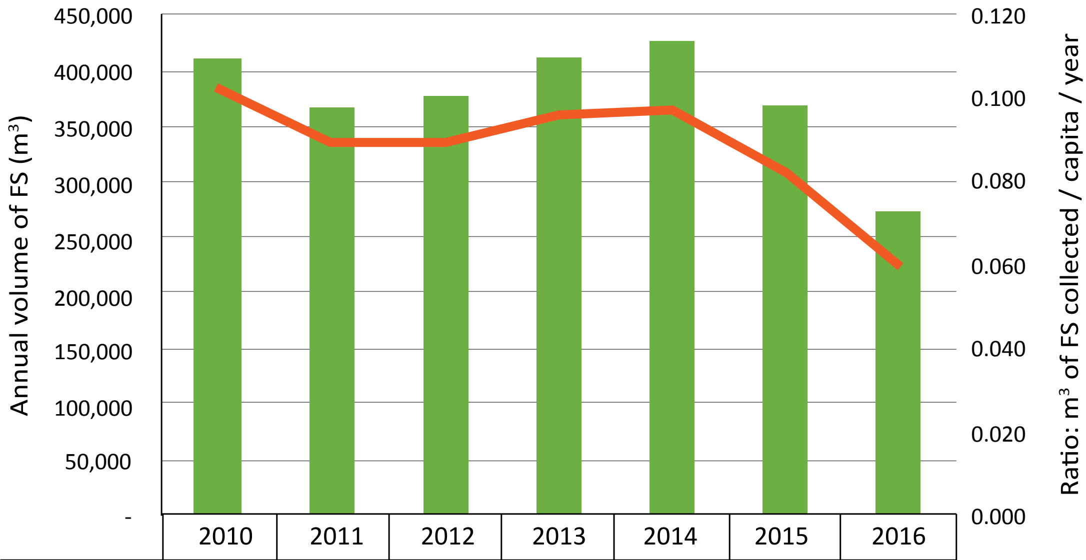
Overall average (m^3 $workday^{-1}$)	382 ± 68

FIGURE 10. ANNUAL VOLUMES OF FS (M^3 $YEAR^{-1}$) COLLECTED AND TREATED AT THE FSTPs AND AVERAGE AMOUNT OF FS COLLECTED AND TREATED $CAPITA^{-1}$ $YEAR^{-1}$ IN OUAGADOUGOU, BURKINA FASO.



	2014	2015	2016
FS (m^3)	22,657	69,532	134,854
Ratio	0.011	0.032	0.059

FIGURE 11. ANNUAL VOLUMES OF FS (M^3 $YEAR^{-1}$) COLLECTED AND PARTIALLY TREATED AT THE FSTPs AND AVERAGE AMOUNT OF FS COLLECTED AND TREATED $CAPITA^{-1}$ $YEAR^{-1}$ IN GREATER ACCRA, GHANA.

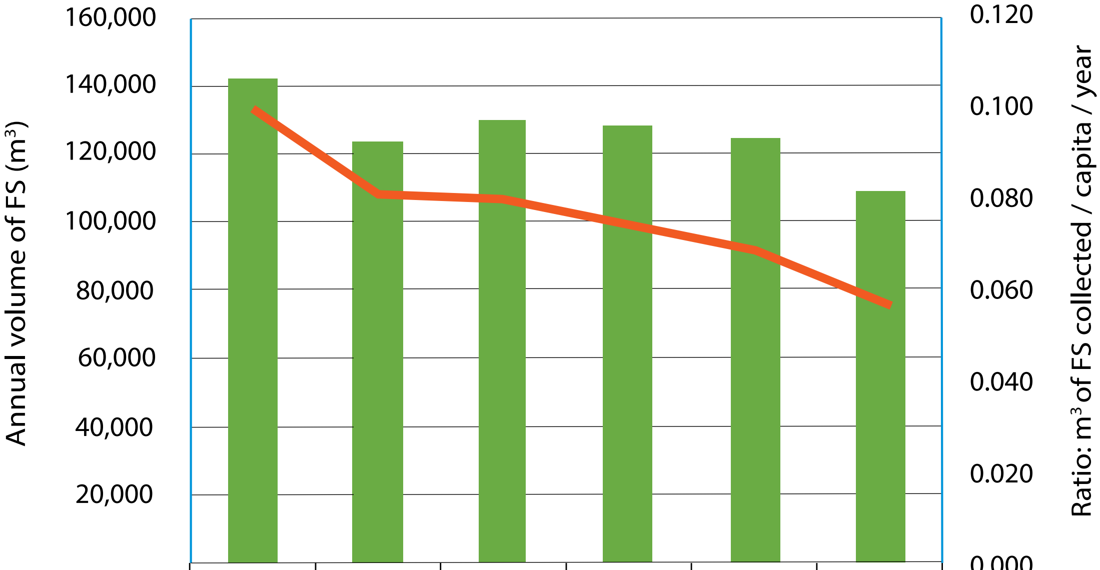


	2010	2011	2012	2013	2014	2015	2016
FS (m^3)	411,463	366,155	377,116	412,227	425,890	367,781	273,437
Ratio	0.103	0.089	0.090	0.097	0.098	0.083	0.060

Figure 12 shows a declining trend for Ekpè, similar to Greater Accra, although the variations in the collected FS volume appeared limited from 2012 to 2015. In 2016, only 76% of the FS collected in 2011 was sent to the FSTP. This corresponded to the lowest fraction over the study period. Simultaneously, the ratio of volume (m^3) of FS treated capita^{-1} year^{-1} declined from 0.099 in 2011 to 0.056 in 2016. This represented a 43% reduction and has been attributed to the combined effects of a reduction in collected FS volumes and population increase in the target area.

To generate the ratio of FS collected/treated capita^{-1} presented in Figures 10, 11 and 12, it was assumed that the population serviced by the different FSTPs was comparable to the administrative boundaries as defined in this report. However, particularly for Greater Accra and Grand Nokoué, the administrative boundaries may not align with the economic area of operation of the trucks. Therefore, the rates capita^{-1} city^{-1} shown in Figures 10 to 12 are only indicative for trends within each geographic area and should not be compared across city regions.

FIGURE 12. ANNUAL VOLUMES OF FS (M^3 YEAR^{-1}) COLLECTED AND PARTIALLY TREATED AT THE FSTP AND AVERAGE AMOUNT OF FS COLLECTED AND TREATED CAPITA^{-1} YEAR^{-1} IN GRAND NOKOUÉ, BENIN.



	2011	2012	2013	2014	2015	2016
FS (m^3)	142,816	123,438	130,032	128,194	124,302	108,989
Ratio	0.099	0.080	0.079	0.073	0.067	0.056

4.3 Physical and Chemical Characteristics of FS

At the studied FSTPs, apart from volumetric data, no regular (monitoring) data were collected, such as on the origin of the FS or on its quality. An analysis is, however, important for the treatment as different physical and chemical characteristics can have implications for the design of the FS drying, treatment as well as composting and reuse processes. Bassan et al. (2013b) reported, for example, that the FSTP in Zagtouli was designed based on literature values to treat 125 m^3 day^{-1} with a TS load of 21,000 mg l^{-1} resulting in 48 drying beds, each with a surface area of 128 m^2. Follow-up studies, before the plant's inauguration, on the characterization of the FS revealed that TSS were much lower and the plant was overdesigned by a factor of at least two, which has financial implications. On the other hand, the plant was able to treat 250 m^3 day^{-1} (Bassan et al. 2013b) and more FS could be directed to it, especially given the high load reported above at Kossodo.

Tables 4 to 6 present the results of characterization of raw FS for the three locations. Although there are some trends in view of FS origin and FSTP, variations were generally high and statistically significant differences should be treated with caution. The pronounced difference between Accra's HH and institutional sources in view of TS, OM and COD for example (Table 5) is noteworthy. The higher solid content of institutional FS than HH FS could theoretically result from less water use (like in single pit latrines) but is probably due to a higher desludging frequency (resulting in less stabilized FS) of institutional rather than HH-based systems.

Another observation relates to the lower biodegradability (wider COD to BOD ratio) of the Greater Accra FS compared to the FS sampled in Ouagadougou (Table 4). The ratio was 1.9 to 2.1 in Ouagadougou, around 4.2 in the Grand Nokoué area and 4.8 to 6.8 in Greater Accra. The lower biodegradability of FS across Accra could be the result of the sludge generally being stored longer compared to storage in Ouagadougou.

For the assessment of co-composting options, it is important to note the high average solid content of FS in Ekpè (Table 6) as this has significant implications not only for the amounts of additional organic waste needed and co-compost which can be produced, but also the related space requirement and so forth. An explanation for the high TS and TSS content might be the relatively high solid waste and sand content of pits, especially in coastal Cotonou and Porto-Novo (pS-Eau 2004). Consequently, it was noted that TP and TK were higher in FS from Ekpè compared to FS from the other locations. However, the TN and NO_3-N were lower and higher than those in Greater Accra FS, which is consistent with the previous remark and potentially indicates a higher level of stabilization. Nevertheless, the TS and TSS in Ekpè remained lower than those at the institutional FS in Greater Accra, the institutions being known for their low residence time and water use.

In general, and as also reported, for example from India (Jayathilake et al. 2019), most parameters varied significantly, from one region to another and within the same region. This variability is an important factor, which must be managed to enable the smooth operation of an FSTP (Bassan et al. 2013a; Nikiema et al. 2017). It will be important to 'guarantee' a defined nutrient content if the FS is transformed and marketed as compost. To buffer variations in quality, Nikiema et al. (2020) recommended to either present labels with nutrient ranges on compost bags and/or to enrich the compost with key nutrients (NPK) to achieve constant percentages. However, this requires compost analysis for each batch and higher production costs.

Source: IWMI

TABLE 4. AVERAGE CHARACTERISTICS OF DIFFERENT TYPES OF FS IN OUAGADOUGOU.

FSTP	Origin	pH	Conductivity	TSS	TS	COD	BOD	NO_3-N	NH_3-N	OM	TN	TP	TK	*E. coli*	FC	Helminths
		pH unit	µS cm^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	*E+05 CFU 100 ml^{-1}*	*E+05 CFU 100 ml^{-1}*	Egg/l^{-1}
Kossodo	HH	8.6	1,053	1,801	2,974	939	502	63.2	28.7	15,640 ± 8,084	430 418	44.1	644.4	13±22	16.2±26.8	2,139 ±1,786
	Institution	8.4	1,940	2,631	4,458	1,319	640	93.3	48.8	16,908 ±14,063	640 121	68.4	587.8	7.1±10.7	10±14	981 ±561
Zagtouli	HH	8.4	1,236	2,165	3,157	976	454	78.2	36.9	13,900 ±13,915	596 369	61.2	733.5	1.1±1.2	0.6±0.3	817 ±670
	Institution	8.3	1,981	3,004	5,256	1,614	640	94.5	56.6	5,780 ±2,295	672 425	82.4	680.2	0.7±0.5	1.3±1.4	1,572 ±1,234

TSS: Total suspended solids; TS: Total solids; COD: Chemical oxygen demand; BOD: Biological oxygen demand; N: Nitrogen; NO_3: Nitrates; NH_3: Ammonia; OM: Organic matter; TN: Total nitrogen; TP: Total phosphorus; TK: Total potassium; FC: Fecal coliforms.

TABLE 5. CHARACTERISTICS OF DIFFERENT TYPES OF FS IN GREATER ACCRA.

FSTP	Origin		pH	Conductivity	TSS	TS	COD	BOD	NO_3-N	NH_3-N	OM	TN	TP	TK	*E. coli*	TC
			pH unit	µS cm^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	*E+05 CFU 100 ml^{-1}*	*E+05 CFU 100 ml^{-1}*
Lavender Hill	HH	Av.	7.5	6,326	3,723	7,103	9,378	1,969	2.1	529	5,502	1,320	176	196	52.8	1,517
		SD	0.2	3,127	3,028	5,153	8,212	1,493	1.5	233	4,624	239	124	137	25.6	1,202
	Institution	Av.	7	9,628	22,447	29,727	20,953	3,331	2.8	797	21,060	3,008	856	258	331	1,517
		SD	0.3	1,269	20,096	26,090	13,561	2,326	3.4	191	14,844	1,932	679	121	277	1,202
Nungua Farm	HH	Av.	7.5	3,331	2,643	4,789	6,935	1,278	2.5	1,572	4,788	1,720	146	92	10.0	273
		SD	0.1	1,748	1,702	1,275	2,618	408.5	2.5	1,752	1,683	1,635	67	34	2.5	335
	Institution	Av.	7.7	9,388	21,621	34,230	28,248	4,164	5.2	1,304	13,400	10,410	414	620	34.0	170
		SD	0.3	8,728	13,748	12,232	12,395	1,083	5.6	293.8	2,966	11,396	298	342	20.4	154

Av: Average; SD: Standard deviation; TSS: Total suspended solids; TS: Total solids; COD: Chemical oxygen demand; BOD: Biological oxygen demand; N: Nitrogen; NO_3: Nitrates; NH_3: Ammonia; OM: Organic matter; TN: Total nitrogen; TP: Total phosphorus; TK: Total potassium; FC: Fecal coliforms.

TABLE 6. CHARACTERISTICS OF FS IN EKPÈ FSTP.

FS samples	pH	Conductivity	TSS	TS	COD	BOD	NO_3-N	TN	TP	TK	FC
	pH unit	µS cm^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg N l^{-1}	mg N l^{-1}	mg l^{-1}	mg N l^{-1}	*E+05 CFU 100 ml^{-1}*
Average	7	3,207	17,792	19,680	21,757	5,198	82.2	950.5	489.3	868.9	120.8
SD	0.7	1,484	8,998	9,937	16,016	3,199	49.5	352.6	208.7	352.8	101.7

Av: Average; SD: Standard deviation; TSS: Total suspended solids; TS: Total solids; COD: Chemical oxygen demand; BOD: Biological oxygen demand; N: Nitrogen; NO_3: Nitrates; NH_3: Ammonia; OM: Organic matter; TN: Total nitrogen; TP: Total phosphorus; TK: Total potassium; FC: Fecal coliforms.

4.4 Discussion

FSM is a challenge in many West African cities, ranging from overstretched or missing collection and treatment infrastructure to the lack of viable solutions to manage FSM by-products, which accumulate on site. To better understand the current status of FSM, particularly collection and treatment, the study looked at the following different aspects:

4.4.1 FS Collection Trends

In the sampled cities, the raw FS sent to the FSTPs was transported by FS vacuum trucks. There was some variation between weekdays, for example with lower collection rates on weekends. This could be related to normal business hours (in institutions for example) but also influenced by cultural factors. Especially in Accra, which has a high share of Christians, large parts of Sunday are reserved for church service by both service providers and HH. The recorded daily discharge rates are, however, important information for the FSTP to understand the frequency of arriving trucks, related parking space requirements, peak desludging rates and overall volumes to be prepared for.

The analysis of variations over the year was catalyzed by Bassan et al. (2013a) who indicated that in the rainy season, rainwater or groundwater could intrude into the septic tanks and pits, resulting in more frequent emptying. This could, for instance, be an issue in Cotonou and Sèmè-Podji where the groundwater level during the rainy season is close to the surface (0-4.5 m [maximum]) (SEURECA 2016). However, our data could not confirm a statistically significant impact of the calendar month or season for any FSTP on the FS volumes recorded.

The analysis also showed the impact of location. Where septic tanks are emptied by private companies, the number of HH served each day determines the profit. Obviously, FSTPs within HH vicinity are preferred as they minimize transport costs and time, as observed in Greater Accra and Ouagadougou. A related factor is the quality of the FSTP access road. In a study by Anaglate (2013), conducted during the rainy season for the Nungua Farms FSTP in Greater Accra, it was established that FS collected during rainy days was only half of the volumes collected during nonrainy days. This was because truck operators would reduce operations when it rained and red clay roads became a risk, but they would catch up on their rounds during nonrainy days.

The development of collected FS volumes at the FSTPs is expected to increase over time with population growth. However, this appears to be confounded by (i) the limits of some of the FSTPs, which have reached their capacity; (ii) the capacity of truck operators (usually small and micro-enterprises) to serve all HH with their aging (second-hand) truck fleet; (iii) the truck operators' decisions on where to desludge (for example informally) to save costs; and (iv) HH decisions not to engage with an (expensive) truck operator but to manage the FS informally. Except in Senegal, private sector incentives for investment in FS collection that can help to increase the truck fleet are not offered within the West African region (Mbeguere 2014).

4.4.2 Treatment Capacity and Performance

Waste stabilization ponds are the dominant treatment process for FS in West Africa. These pond systems involve the use of settling ponds and/or sand drying beds to isolate solids and stabilization ponds for the removal of dissolved organic matter in wastewater. With only a limited number of FSTPs in the region, it is however no surprise that their capacities are usually (over)stretched, although data on treatment performance are rare. For example, in Benin, the privately owned FSTP at Ekpè was expected to receive only the trucks of the SIBEAU company (about five a day) but eventually was asked to also accommodate other truck operators in the Grand Nokoué area. Between 2008 and 2010 this resulted in up to 80 trucks a day, exceeding on average 2.65 times the design capacity with severe consequences for the water retention time and treatment quality (Hounkpe et al. 2014). However, the alternative would have been for the truck operators to illegally desludge or to stop their service. Only 20 years after the start of the Ekpè FSTP, funding for one of two new FSTPs has been allocated (World Bank 2016) and construction has started. To meet the regional FS treatment needs, more FSTPs are needed, but also incentives, higher capacities and laboratories to improve performance monitoring (Murray and Drechsel 2011).

4.4.3 Discharging Preferences

Not all generated FS is collected in West Africa and not all collected FS is treated. For example, in Dakar, Senegal, only 25% of the generated 6,000 m^3 of FS is collected and ends up in treatment plants (Mbeguere et al. 2011). In Ghana, until recently, nearly 90% of the FS collected in Greater Accra did not undergo any treatment before being dumped officially on Accra's beach (Lavender Hill) due to the dearth of functional FSTPs. Another key reason for FS collection without proper discharge at designated FSTPs is economic, i.e. the transportation distance between HH and the few existing FSTPs. With increasing distances (the urban boundary also has to be addressed), fewer HH are being served every day while fuel costs rise, unless the truck operator finds an alternative (informal) dumping site in the proximity of the served community. Where truck drivers are not monitored, they might opt for the least costly option in terms of truck operations, saving on fuel, time and tipping fees. Zoungrana et al. (2011) reported that fuel can constitute over 50% of the septic truck running costs in Burkina Faso and the truck accounts for 78% of the total business operational costs. To partially address these issues, cities such as Ouagadougou have opted for the construction of multiple decentralized (small) treatment systems to reduce travel distance to each of them. However, this type of solution is usually more costly.

Thus, while in Ouagadougou, both FSTPs (Kossodo and Zagtouli) have, according to the design, a FS treatment capacity of 125 m^3 day^{-1}, the Kossodo FSTP is overexploited and Zagtouli is underexploited. The reason being that the Kossodo FSTP has a more favorable geographical location, close to the city center, where most HH have high incomes and rely on septic tanks. These HH likely empty their septic tanks more often because of their larger water consumption (Nikiema et al. 2017). The plant is also easy to access, well equipped and well known, compared to other FSTPs in town. This is in line with the study of Hawkins and Muxímpua (2015) who indicated that the frequency of emptying the septic tank and the truck rotation depend on the population, the travel distance and the living standard. The same observation is pertinent to Accra, where Lavender Hill is close to the city center with good access roads, receiving most of the FS, while Nungua farms has a more complicated and muddy access road.

5. CO-COMPOSTING POTENTIAL OF FS

To avoid long trips to an FSTP, some truck drivers serve farmers who appreciate the low-cost farm-gate delivery of nutrient-rich 'manure'. In countries such as Ghana, Burkina Faso, Mali or Benin, it has been reported that farmers pay truck drivers for the FS, which is changing the 'tipping fee' from expenditure to revenue (Bolomey 2003; Asare et al. 2003; Koanda 2006). If done during the dry season, this practice might not pose any danger because longer FS exposure to the sun will kill pathogens. However, when done during the growing season, such practices could represent a potential health hazard if the workers and/or harvested crop parts make contact with the raw FS (Keraita et al. 2014). The practice might have its roots in the manual emptying of pits and local reuse as manure. In 2006, still 23% of all (mostly manually collected) FS in Ouagadougou was recycled in local farms (Koanda 2006).

However, potential reuse risks can be avoided through the destruction of pathogens. RRR processes, such as co-composting, will not only turn the largest by-product, the generated FS, into a resource but also provide farmers with valuable nutrients and organic matter. To better understand the quantities, qualities and costs associated with FSM and RRR, the study looked at the possibility of an additional fecal sludge + other municipal organic waste co-composting unit. The proposed scenario was analyzed to understand the related implications of the introduction of RRR in terms of staffing, area needs, finance and so forth.

In this section, the potential of introducing FS co-composting at the existing FSTPs in Burkina Faso and Benin is assessed, following a model similar to the one already implemented near Nungua Farms, Ghana, and operated by Jekora Ventures Ltd. (see Nikiema et al. 2020).

To generate the financial models for Burkina Faso and Benin, we adopted a scenario replicating the experience of the co-composting facility at Nungua Farms FSTP in Ghana using similar design factors and processes (Armah 2016; Nikiema et al. 2020). For the co-composting process, apart from FS, food waste and sawdust were used as the main additional organic waste sources. For other data, like infrastructure and operational costs as well as assumptions on annual sales and likely revenues, see Tables A5 to A9 in Annex 2. The @RISK® software was used to run the financial simulations.

5.1 Treatment and Recycling Potentials

Table 7 shows the total amount of FS and other organic waste materials required for the proposed co-composting processes in Ouagadougou and in Cotonou. These volumes consider the FS characteristics and estimated dewatering performance.

Priority should be given to sorted organic waste, which requires less labor for preprocessing and results in lower co-compost production cost. In addition, wastes that are easily biodegradable should be chosen, ideally with a relative wide carbon to nitrogen ratio to balance the narrow one of FS. In our scenarios, we considered a mix of 80% municipal organic solid waste and 20% sawdust (shares in the total mass).

Composts and co-composts produced may be sold in their original form or after enrichment with plant nutrients to increase and/or guarantee the compost nutrient value. This 'fortification' can be done with industrial fertilizer, rock phosphate or urine for example. In our scenarios, ammonium sulfate, typically the cheapest mineral nitrogen source, was used to enrich the nitrogen content of the compost to 3% in mass.

Finally, Table 7 presents the amounts of co-compost products that could be obtained. There is potential to produce 537 MT $year^{-1}$ at Kossodo while at Zagtouli, the amounts can range between 198 and 240 MT $year^{-1}$ for the current and design capacities, respectively. At the larger FSTP in Ekpè, the potential rises to 4,500 MT $year^{-1}$. This is mainly due to the 10 times higher TS content in the FS (Table 6), leading to higher amounts of dewatered FS available for co-composting. However, the high sand level in the Ekpè FS will cause challenges for compost quality and (if desired) the machinery for processing compost into pellets (Nikiema et al. 2020).

TABLE 7. RAW MATERIALS AVAILABLE OR NEEDED FOR THE COMPOSTING PROCESS.

	Unit	Kossodo	Zagtouli[d]		Cotonou
			Actual capacity	Design capacity	
Total amount of FS treated[a]	m^3 $year^{-1}$	102,799[b]	32,055[b]	39,000	108,989
Amount of sorted solid waste required[c]	MT $year^{-1}$	725	267	324	6,075
Total products	**MT $year^{-1}$**	**537**	**198**	**240**	**4,500**
Compost (nonenriched)	MT $year^{-1}$	372	137	167	3,118
Compost enriched with ammonium sulfate[e]	MT $year^{-1}$	165	61	74	1,381

[a] The total volumes of FS considered were taken from Section 4.2. They correspond to the volume of FS received at each treatment plant for 2016.

[b] From empirical sources, HH FS corresponds to 70% of the FS collected at the site; public toilets account for 30% of the FS collected at the site.

[c] The amount of sorted organic solid waste should correspond in mass to three times that of the dewatered FS produced. As in Ekpè the TS content is about 10 times higher than in Kossodo, also the amount of solid waste can be increased correspondingly.

[d] The scenarios were obtained for the current and designed capacities in Zagtouli. This is because, based on data collected for 2016, the treatment plant at Zagtouli was not yet operating at full capacity.

[e] We assumed that part of the co-compost product could be enriched with minerals to enhance the compost quality. The percentage of co-compost going through this extra process was triangulated to between 0 and 50% with an average at 30%. The rest of the compost would be sold as regular compost.

5.2 Land Requirements

The land requirements for the various additional plant components of a co-composting station at FSTPs are presented in Table 8. To integrate them in the FSTPs of Kossodo and Zagtouli, about 0.4 and 0.2 hectares (ha) are required, respectively. In the case of Ekpè, the additional land requirement for processing the indicated compost amounts rises to 2 ha. This extensive land area may be difficult to source in an urban set up. To reduce the land requirement, it is possible to consider more intensive composting processes (for example aerated windrow composting or in-vessel composting) but these scenarios also require higher investment costs, which were not investigated in detail in this study. As the Ekpè FSTP is already overloaded, the operators should also consider decentralized alternatives. This could offer potentially better outreach to compost users as well as reduced transport distances and costs for septic trucks, possibly translating into more HH being served. However, these scenarios can also translate into higher investment costs.

TABLE 8. KEY LAND REQUIREMENT COMPONENTS (M^2) FOR EACH SITE.

	Unit	Kossodo	Zagtouli		Cotonou (Ekpè)
			Actual capacity	Design capacity	
Solid waste sorting bay	m^2	209	77	94	1,747
Composting platform	m^2	1,206	443	539	10,100
Machinery room and storage	m^2	316	153	169	1,904
Office, toilets and showers for men and women	m^2	50	40	40	75
Maximum requirement	ha	0.4	0.2	0.2	2

Note: The land requirement shown corresponds to the effective area. This means that space for walkways, cleaning and so forth should also be considered in addition. Typically, a 25% addition for each unit could accommodate these extra areas. Access roads should also be arranged separately.

5.3 Investment (Capital) Costs

The extra infrastructure shown in Table 8 implies additional costs (Table 9). The construction costs were derived from actual construction costs in Ghana in 2016. To integrate recycling at the FSTP of Kossodo, at least EUR 234,000 are required while for Zagtouli, the minimum requirement is EUR 111,000. In the case of Cotonou, the minimal investment cost calculated amounted to EUR 1.46 million. These investment costs assume in all cities that parts of the needed equipment are already available, such as treatment facilities for FS leachate, which can also absorb leachate from the composting area.

TABLE 9. ESTIMATED CONSTRUCTION COSTS (EUR) AT EACH SITE.

Location	Kossodo	Zagtouli		Cotonou
		Actual capacity	Design capacity	(Ekpè)
Solid waste sorting bay	16,836	6,203	7,572	140,728
Composting platform	75,241	27,659	33,651	630,023
Machinery room and storage	43,810	21,212	23,430	263,968
Office	13,335	10,668	10,668	20,002
External services (including walls, fences)[a]	11,794	5,458	6,250	21,364
Contingency (10%)	26,178	11,506	13,237	187,470
Subtotal: construction	*187,193*	*82,705*	*94,808*	*1,324,328*
Engineering and construction supervision (15%)	28,079	12,406	14,221	82,136
Solar panels for office lighting only	2,000 to 10,000 (average at 5,000)			10,000
Office furniture and equipment/tools for the co-compost plant	13,800	10,400	10,800	44,500
TOTAL	**234,072**	**110,511**	**124,829**	**1,460,964**

[a] Minimal external services, such as fences, have been considered, but not the construction of roads, which is more expensive and much be calculated on a case-by-case basis.

Depending on the compost volume and particular market demands, additional machinery may be required such as a mechanical sieve, a grinder, a mixer (if enrichment is done) or a pelletizer. Details of machine capacities required (MT hr^{-1}), under the scenario described so far, are shown in Table 10. Most of this equipment could be sourced locally, apart from the pelletizer, which involves advanced technology and is better obtained from specialized companies. The cost of securing this equipment will vary, depending on manufacturers, designs, materials used for their fabrication and capacity. Prices could range from EUR 10,000 for a basic set of machinery to EUR 100,000 for a larger imported set (Nikiema et al. 2020).

TABLE 10. TYPES OF MACHINERY AND THEIR MINIMUM CAPACITY IN METRIC TONS PER HOUR, REQUIRED AT EACH SITE.

Equipment[a]	Kossodo	Zagtouli		Cotonou
		Actual capacity	Design capacity	(Ekpè)
Sieve	0.32	0.12	0.14	2.70
Grinder	0.23	0.08	0.10	1.89
Mixer	0.10	0.04	0.04	0.84
Bagging unit	0.33	0.12	0.15	2.73
Pelletizer (optional)	0.00	0.00	0.00	0.00

[a] The capacities of the equipment will change if a higher volume of enriched products is to be produced, compared to our tested scenario.

5.4 Production and Marketing (Operational) Costs

Based on the experience of the plant in Ghana, Table 11 presents the operational costs and revenues as calculated for the three projected FST-cum-co-composting plants in Ouagadougou and Cotonou. These costs increase annually due to inflation, fuel and salary increases, among other factors. The cost items considered included labor, marketing, sales and distribution, transportation of products, utilities, inputs (such as ammonium sulfate), insurance of the plant and equipment, annual write-off, depreciation of equipment and furniture as well as estimated legal and registration charges for the co-compost products.

The estimated co-compost production costs for each tonne of compost reflect economies of scale (EUR 159.4, EUR 125.0 and EUR 81.6 for Zagtouli, Kossodo and Ekpè, respectively).

The co-compost plants will generate profits from sales of their products, i.e. co-compost and/or enriched co-compost (and possibly compost pellets). To set the sales cost point for the compost, the current sales price for a comparable product in each location was used. To set the price of enriched compost, which has no comparable product in Burkina Faso or Benin, a 65% increase of the sales price for the regular co-compost was used due to the additional production costs (for example mineral fertilizer and electricity for extra processing). In Ghana, previous research has shown that an increase in production cost, for switching from regular compost to enriched compost, could reach 100% and our lower cost assumption should be considered optimistic. Another assumption is that the enriched compost will only be produced based on market demand and acceptance of a premium price. Table 11 shows the results, assuming – on average – a 70 to 30% share of normal to enriched co-compost.

The total tipping fees collected at the FSTPs in Ouagadougou and Cotonou ranged from EUR 0.46 to EUR 0.75 m^{-3} for FS. This income should ideally cover the operational FS treatment costs (which in pond-based systems are relatively low) and in addition support parts of the composting process. As composting sanitizes the sludge, it eliminates the need for safe disposal at a landfill (and thus saves on related costs).

Different possible scenarios (see Annex 2, Table A9) show that in comparison with possible revenues from compost sales, tipping fees will only (need to) finance about 10% of the composting process (Table 11).

Table 11 presents the annual profit or loss, which could be experienced by each of the three co-composting plants. From this analysis, it appears that the plants in Kossodo, Cotonou/Ekpè and Zagtouli could reach the break-even point after 5, 7 and 8 years of operation, respectively. To cover for the losses that the co-compost plants will experience before they break even, an operational subsidy will be required. Compared to compost sales, the average tipping fee could cover 8 to 15% of the revenues (Ouagadougou) while in Ekpè the share is much lower (2 to 3%) due to the relatively low number of trucks needed for the much higher co-compost production per cubic meter of (high density) FS processed.

TABLE 11. TOTAL COSTS AND REVENUES (IN EUR) INCURRED FROM FS CO-COMPOST OPERATIONS.

	Revenue item	Year 1	Year 2	…	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Kossodo	Total cost	67,181	63,802	…	81,810	87,831	92,739	98,138	104,077	110,609
	Total revenue	34,227	43,467	…	77,211	89,191	98,110	107,921	118,714	130,585
	(Share of) tipping fees	5,140	5,654	…	7,525	8,278	9,106	10,016	11,018	12,120
	Sales of products	29,087	37,813	…	69,686	80,913	89,005	97,905	107,696	118,465
	Profit or loss	(32,954)	(20,335)		(4,598)	1,360	5,371	9,783	14,637	19,976
Zagtouli (design capacity)	Total cost	34,364	32,523	…	41,267	44,206	46,637	49,311	52,252	55,487
	Total revenue	14,959	19,057	…	34,022	39,328	43,261	47,587	52,346	57,581
	(Share of) tipping fees	1,950	2,145	…	2,855	3,140	3,455	3,800	4,180	4,598
	Sales of products	13,009	16,912	…	31,167	36,188	39,807	43,787	48,166	52,983
	Profit or loss	(19,405)	(13,467)		(7,246)	(4,877)	(3,375)	(1,723)	94	2,094
Ekpè	Total cost	366,974	389,834	…	502,601	538,165	564,260	592,963	624,537	659,268
	Total revenues	184,318	238,523	…	436,512	506,351	556,986	612,685	673,953	741,348
	(Share of) tipping fees	5,449	5,994	…	7,979	8,776	9,654	10,619	11,681	12,850
	Sales of products	178,868	232,529	…	428,533	497,574	547,332	602,065	662,272	728,499
	Profit or loss	(182,656)	(151,311)		(66,089)	(31,815)	(7,274)	19,722	49,416	82,080

5.5 Bridging the Financial Gap for Operation and Maintenance

Table 12 presents the net present values (NPV) and returns on investment (ROI) for the tested scenarios in Kossodo, Zagtouli and Ekpè. For Kossodo, it shows that there is a comfortable 73% chance for the business to be profitable. This is the highest probability obtained in our study. However, as for many waste-based compost plants, the potential ROI considering composting only are rather low, around 30% on average, making full (operational and eventually capital) cost recovery unlikely within the stations' life time unless under very optimistic scenarios. However, partial recovery could be considered an important step towards reduced dependency on subsidies, which remains 'business as usual' in the waste and sanitation sectors.

TABLE 12. NPV AND ROI FOR THE TESTED SCENARIOS IN KOSSODO, ZAGTOULI AND COTONOU.

	Kossodo (actual capacity)	Zagtouli (design capacity)	Cotonou (actual capacity)
Mean NPV	EUR 60,941	EUR (6,696)	EUR 1,315
Mean ROI	30%	-8%	4%
Probability (NPV > 0)	73.3%	41.2	48.2

Setting up a recycling plant in Zagtouli would result in a negative NPV of -EUR 6,696, largely due to its relatively lower capacity. The recycling plant in Ekpè is expected to perform slightly better than the one in Zagtouli (Table 12) but may face space availability challenges, as mentioned previously. In addition, marketing such large amounts of compost from one location might be challenging without additional investments, for example, in a partnership with a fertilizer company. Except for Kossodo, the ROI for Ekpè and Zagtouli is almost zero for the first 10 years. Key factors likely to influence the financial performance of the plants are shown in Table 13. The table also draws from IWMI experiences with other composting stations across the subregion (Drechsel et al. 2010; Danso and Drechsel 2014) which indicated that professional market analyses are crucial, especially where subsidies might not last. The market analysis should also look beyond agriculture at other possible market segments, such as housing (real estate) and landscaping, as well as competing products. Another lesson is, that within the agriculture sector, the lowest transaction costs are associated with larger customers, such as outgrower companies and industrial crop plantations that can buy in bulk and often also provide their own transport. The study also stressed the benefits of effective project partnerships linking public and private sectors (such as for compost marketing or with particular buyers through contractual purchase agreements).

Source: IWMI

TABLE 13. FACTORS THAT INFLUENCE THE FINANCIAL PERFORMANCE OF FS CO-COMPOSTING BUSINESSES.

Factor	Notes
Market analysis	A detailed market study is required to identify premium customers with high willingness and ability to pay for a safe quality compost, as well as large customers who might expect discounts but can take large amounts of different quality (such as for landscaping) and year round (such as real estate). The analysis should look at existing comparable products on the market to understand customer expectations and to verify the willingness-to-pay results.
Competition	Competition can be addressed through good marketing of a better product. Setting a cost-recovering price will not always work. Indeed, a local competitor with a lower-priced product that is better promoted or already a trusted brand will generate potentially negative rivalry. Subsidized compost production by competitors can severely undermine fair competition. Also, low-quality products and poor marketing (common among many government compost stations) are severe obstacles to cost recovery.
Compost price adjustments	In the Ghanaian FS recycling plant, the compost sales price was set at a low value in the first year to encourage customers to test and adopt it. Subsequent increase should allow for the attainment of a reasonable (cost-covering) level. However, cost increase can be hard to implement.
Location	Authorities have often limited choice in selecting ideal locations for treatment plants. Transport costs to and from the plant for inputs and outputs (waste/FS versus compost) can greatly determine the success or failure of a business, especially if there are competing plants or shops that are better located. Partnerships can partially address geographic disadvantages – for example a fertilizer distributor could support decentralized marketing. Compost prices can also vary among geographies: In Ouagadougou, which has lower rainfall, poorer soils and suboptimal biomass production, compost is rare and can be sold for a higher price than in Cotonou, for example.
Staff capacity	The FSTP/compost station should either have staff trained in business development, including market analysis and product marketing, or link with partners who are professional in this regard. Most government plants lack the respective staff mix or partnerships. Under an ideal scenario, sales should be aligned with compost production, targeting a high turnover in the storage room.
Tipping fees	Tipping fees are an important revenue stream for the FS treatment process. In our calculations, they can additionally add about 10% of the total revenues which are dominated by compost sales. Depending on alternative desludging options, and enforced legislation against wild dumping, the fees could be increased although the truck operators would probably transfer any increase to the served HH.
Staff versus electricity cost	The proposed composting process cited here is highly manual and so supports employment (see Section 5.6); this means it is not constrained by machinery that breaks down, low institutional capacities and regional power supply challenges. Thus, a decision regarding the pros and cons of manual labor versus electricity (machinery) costs will have to consider more than just monetary values.
Cultural perceptions	While compost is generally well accepted, the addition of treated FS could be a concern for some sectors, like vegetable farming or those relying on export. Such concerns must be addressed through safety controls, product quality monitoring and sensitive marketing/branding.

5.6 Benefits Generated

Assuming a farm application rate of 10 MT ha^{-1} for basic (nonenriched compost), we established that the co-composts produced through FS recycling can be used to fertilize 70 ha $year^{-1}$ from the Kossodo FSTP, 25-31 ha $year^{-1}$ from the Zagtouli FSTP and in Cotonou, up to 588 ha $year^{-1}$ could be fertilized. The potential is therefore not negligible, especially where alternative organic fertilizers are rare or expensive. Positive impacts can be expected for farmers and consumers who benefit from increased agricultural productivity. In Ghana, revenue increase for maize farmers using co-compost compared to those using inorganic fertilizer reaches 40-50% (IWMI, unpublished data). In addition, jobs are created as shown in Table 14. In Ouagadougou, up to 47 new jobs could be created while for Cotonou, the number rises to 184 people. Many of these jobs do not require a prequalification and can directly benefit unemployed youth and women.

TABLE 14. STAFF REQUIREMENTS AT THE RECYCLING PLANTS, CLASSIFIED ACCORDING TO SKILLS OR PROCESSING TASKS.

Classification skill^{-1}					
Job classification	**Position**	**Kossodo**	**Zagtouli**		**Cotonou**
			Actual capacity	**Design capacity**	
• Group 1: High skills (positions can also be combined)	Manager, marketing manager (if not outsourced), finance officer	2	1	1	5
• Group 2: Moderate skills	Manager, marketing officer, accountant, technician for machinery (if applicable), M&E	5	2	2	28
• Group 3: Low initial skills	Laborers	17	6	8	133
• Group 4: No special skills	Security guards, loading of trucks with products	7	5	5	18
Classification according to processing task					
Staff required for sorting solid waste		1.2	0.4	0.5	10.0
Staff required for turning compost		11.9	4.4	5.3	99.6
Staff required for final processing and bagging of compost		6.0	2.0	3.0	45.0
Staff required for administration, M&E and marketing		4.0	2.0	2.0	11.0
Staff required for loading, delivery, etc.		3.0	2.0	2.0	7.5
Staff required for security		4.0	3.0	3.0	11.0
TOTAL STAFF		**31**	**14**	**16**	**184**

The addition of a formal FS recycling process is recommended for any new FSTP. To achieve this, early planning is needed due to the additional space and budget requirements. In our scenarios, the highest implementation potential was identified for the FSTP at Kossodo in Burkina Faso. Comparing the extra costs and benefits, it would take at least 5 years to break even. Only then, any revenues from compost sale could help to sustain the operation of the FSTPs and contribute, for example, to the monitoring of treatment quality as this will also affect compost marketing. Other – not counted – benefits are the reduction of the sludge disposal costs, the reduced volume and disposal costs of the co-composted municipal organic waste, and related greenhouse gas emissions, and the creation of jobs and a safe organic fertilizer that will help farmers to produce more food. Thus, the planning for RRR should look at economic benefits and not only financial cost recovery. As for any business, the success of RRR will also depend on many factors, such as the need for a professional market analysis, strategic partnerships and sound marketing skills which consider cultural perceptions and the competitive landscape.

6. CONCLUSIONS

In West Africa, as for the rest of SSA, much of the urban or rural population does not have access to adequate basic sanitation. Apart from toilet access, there is also the need to safely manage the waste generated from toilet use. In this region, sewer systems' coverage in urban areas is limited to 12% of the total urban population and such systems are only found in selected large and well-planned urban areas. Low coverage is partly attributable to the challenges related to sewer design, costs and management. Even the efforts undertaken in recent years to increase decentralized sewer coverage struggled to succeed because, for example, many HH decide against a connection owing to high connection fees, usually required as up-front payment, lack of incentives for HH to connect and other constraints.

There are also enormous challenges associated with the treatment of collected wastewater. Consequently, notable volumes of raw or slightly treated sewage are commonly discharged into the sea or rivers. In West Africa, the highest sanitation coverage (85%) is achieved through OSS (42% for septic tanks and 58% for pit latrines or other OSS), which allow for storage and (pre-) treatment of human excreta within the plot occupied by a dwelling or its immediate surroundings. As with sewers, the OSS sector faces challenges related to the removal of FS from OSS and its transport to the site of treatment/disposal. Indeed, indiscriminate dumping is still happening in many cities while treatment performance at designated dumping sites can also be suboptimal.

This report has attempted to close some data gaps in the commonly grey area of FSM in West Africa, focusing on the examples of Ouagadougou, Greater Accra and the Grand Nokoué area. The selected three urban regions include the capital cities of Burkina Faso, Ghana and Benin. In Ouagadougou (n=3), Grand Nokoué (n=1) and Greater Accra (n=3) different numbers of official FSTPs are in operation. Over the years, most FSTPs have relied on the use of waste stabilization ponds for treating FS. In Accra, this trend changed recently when (also in response to increasingly limited space) other technologies, including one UASB, have been commissioned (SSGL 2019).

In general, the FS received at FSTPs is being transported by means of FS vacuum trucks and such service is offered 5 to 7 days each week. Truck operators operate within an economic area, which may not necessarily align with the administrative boundaries. There is some variation related to the daily volumes of FS received at the FSTPs (Table 15), with lower collection rates towards weekends, for example. Overall, the collected FS volumes were not significantly affected by calendar days, months or seasons over our period of observation. Nevertheless, we noted that the Kossodo FSTP in Ouagadougou received 26% more FS each month during the rainy seasons than over the dry seasons while the difference was only about 14% for the Zagtouli FSTP and negligible for the other locations. Between 2014 and 2016, the maximum annual volume of FS collection capita^{-1} and discharge at designated sites was approximately 0.06 m^3 in Ouagadougou, 0.10 m^3 in Greater Accra and 0.08 m^3 in Grand Nokoué. Except for Ouagadougou, these volumes have been trending towards decreased amounts.

TABLE 15. FS COLLECTION AND TREATMENT IN OUAGADOUGOU, GREATER ACCRA AND GRAND NOKOUÉ.

	Average volume collected (m^3 month^{-1})	Volume collected (m^3 capita^{-1} year^{-1})[a]	Days with maximum collection compared to the average	Days with minimum collection compared to the average	Rainy season impact	Number of workdays week^{-1}
Ouagadougou	8,108	0.06	Mondays (average + 16%)	Wednesdays and Fridays (average – 27%)	14-26% higher	5 or 6
Greater Accra	31,468	0.08-0.10	Thursday (average + 30%)	Sundays (average – 57%)	1% higher	7
Grand Nokoué	10,525	0.06-0.07	Mondays and Tuesdays (average + 10%)	Saturday (average – 21%)	2% higher	6

[a] This calculation assumes that the administrative area corresponds to the area covered by the FSTP. While this could be true for a circular city such as Ouagadougou, it may not be accurate for other city regions where transport distances might render certain city parts uneconomical to service.

Our analysis of FS characteristics shows that although there are some trends in view of FS origins and FSTPs, variations were generally high and statistically significant differences should be treated with caution. The pronounced difference between Accra's HH and institutional sources in view of TS, OM, COD, for example, is notable. Another observation relates to the lower biodegradability of the Greater Accra FS with COD to BOD ratios of 1.9 to 2.1 in Ouagadougou, around 4.2 in the Grand Nokoué and 4.8 to 6.8 in Greater Accra.

Our study also explored the potential for building a circular economy business around the FSTPs constructed in West Africa. For that purpose, we assessed the potential of introducing FS co-composting at the existing FSTPs in Burkina Faso and in Benin, following a business model similar to the one already implemented near Nungua Farms in Greater Accra, Ghana, and operated by Jekora Ventures Ltd. We found that about 750 MT and 4,500 MT of co-compost could be generated respectively at the two regions each year. This would in addition enable about 1,000 MT and 6,000 MT of organic solid wastes to be processed. Integration of co-composting would require some land and finances in the order of at least EUR 235,000 and EUR 125,000 for FSTPs in Kossodo and Zagtouli, respectively. The high land requirement to run the same model at the Grand Nokoué site could be a constraint.

The co-composts produced through FS recycling could be used to fertilize 70 ha $year^{-1}$ from the Kossodo FSTP, 25 to 31 ha $year^{-1}$ from the Zagtouli FSTP and up to 588 ha $year^{-1}$ in Grand Nokoué. The potential is therefore not negligible, especially where alternative organic fertilizers are rare or expensive. In Ouagadougou, up to 47 new jobs could be created while for Cotonou, the number rises to 184 people. Many of these jobs do not require a prequalification and can directly benefit unemployed youth and women.

To cover the estimated co-compost production costs (EUR 82 to EUR 159 MT^{-1}), compost sales will have to carry 90% of the compost production costs, while tipping fees are needed to cover the FS treatment costs and only a smaller share (6 to 10% on average) could support additional resource recovery.

Factors that influence the financial performance of the FS co-composting businesses relate to market potential (demand, competition, cultural perception and price) which is affected, *inter alia*, by the location of the plant and the type of process in place. For Kossodo, there is a comfortable 73% chance for the business to be profitable. This is the highest probability obtained in our study. However, as for many waste-based compost plants, the potential returns on investment are rather low, around 30% on average, making a full (operational and eventually capital) cost recovery unlikely within the stations' life time unless under very optimistic scenarios. However, a partial recovery could be considered an important step towards a reduced dependency on subsidies, which remains business as usual in the waste and sanitation sectors.

As a way forward to this study, the potential RRR opportunity for Kossodo FSTP calls for more detailed studies to confirm the actual market demand around this site and eventually to explore real implementation. For the other two FSTPs, there is a need to address the current operational challenges, which may help to improve the business potential compared to what was observed in the current work.

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ANNEXES

Annex 1: Volumes of FS Collected at the Studied FSTPs.

Tables A1 to A5 show the monthly FS collection data from the stations in Ouagadougou, Accra, Cotonou and Abomey-Calavi.

TABLE A1. AVERAGE VOLUME PER TRIP IN OUAGADOUGOU, 2014-2016.

	Average volume of FS collected trip^{-1} (m^3 trip^{-1})	
Months	**Kossodo**	**Zagtouli**
October 2014	10.2	9.4
November 2014	10.8	9.1
December 2014	9.7	9.1
January 2015	9.6	7.4
February 2015	10.1	9.4
March 2015	9.3	9.3
April 2015	10.1	8.7
May 2015	9.3	8.7
June 2015	16.3	8.8
July 2015	10.3	8.8
November 2015	10.6	9.2
December 2015	10.7	8.1
January 2016	10.6	8.1
February 2016	10.4	8.4
March 2016	10.0	8.5
April 2016	10.5	9.1
May 2016	10.3	9.0
June 2016	10.5	8.5
July 2016	10.2	9.0
August 2016	10.5	8.6
September 2016	10.4	8.2
October 2016	10.7	8.4
November 2016	10.4	8.4
December 2016	10.7	9.4
Average	**10.5**	**8.7**
Standard deviation	**1.3**	**0.5**

Source: Tanoh 2016, updated.

TABLE A2. MONTHLY VOLUMES OF FS COLLECTED AT EACH FSTP IN OUAGADOUGOU, 2014-2016.

Month/Year	Kossodo		Zagtouli		All combined (total)		All combined (average)	
Parameter	FS volume	Trips	FS volume	Trips	FS volume	Trips	FS volume	Trips
Unit	m^3 $month^{-1}$	Number $month^{-1}$	m^3 $month^{-1}$	Number $month^{-1}$	m^3 $month^{-1}$	Number $month^{-1}$	m^3 $month^{-1}$	Number $month^{-1}$
September 2014	2,971	292	N/A[b]	N/A[b]	2,971[c]	292[c]	N/A[a]	N/A[a]
October 2014	5,514	542	1,591	170	7,105	712	3,553	356
November 2014	5,407	502	2,331	255	7,738	757	3,869	379
December 2014	3,330	342	1,513	166	4,843	508	2,422	254
January 2015	5,395	560	1,571	212	6,966	772	3,483	386
February 2015	4,085	405	1,993	213	6,078	618	3,039	309
March 2015	4,396	473	2,106	226	6,502	699	3,251	350
April 2015	7,417	736	1,950	223	9,367	959	4,683	480
May 2015	7,458	799	2,178	249	9,636	1,048	4,818	524
June 2015	8,121	497	2,077	236	10,198	733	5,099	367
July 2015	4,460	435	2,217	251	6,677	686	3,338	343
August 2015	N/A[a]	N/A[a]	2,510	295	2,510[c]	295[c]	N/A[a]	N/A[a]
September 2015	N/A[a]	N/A[a]	2,092	235	2,092[c]	235[c]	N/A[a]	N/A[a]
October 2015	N/A[a]	N/A[a]	2,533	286	2,533[c]	286[c]	N/A[a]	N/A[a]
November 2015	816	77	1,843	201	2,659	278	1,329	139
December 2015	2,373	222	1,944	239	4,317	461	2,158	231
January 2016	3,176	299	1,712	212	4,888	511	2,444	256
February 2016	4,876	471	2,443	292	7,319	763	3,660	382
March 2016	5,787	578	2,171	255	7,958	833	3,979	417
April 2016	7,041	672	2,130	235	9,171	907	4,586	454
May 2016	7,173	695	1,877	208	9,050	903	4,525	452
June 2016	7,596	725	2,015	238	9,611	963	4,806	482
July 2016	9,569	941	2,769	308	12,338	1,249	6,169	625
August 2016	9,869	944	2,811	325	12,680	1,269	6,340	635
September 2016	11,609	1,113	3,743	454	15,352	1,567	7,676	784
October 2016	13,382	1,249	4,043	480	17,425	1,729	8,713	865
November 2016	10,531	1,010	2,844	339	13,375	1,349	6,688	675
December 2016	12,190	1,136	3,497	373	15,687	1,509	7,844	755
TOTAL	**164,542**	**15,715**	**62,504**	**7,176**	**227,046**	**22,891**		
Monthly average	**6,582**	**629**	**2,315**	**266**	**9,039[d]**	**908[d]**		
Monthly SD	3,246	305	634	76	3,799[d]	371[d]		
RS average	**7,742**	**707**	**2,529**	**293**				
RS SD	3,069	307	582	74				
DS average	**6,130**	**598**	**2,225**	**254**				
DS SD	3,283	308	648	75				

Note: DS = dry season; RS = rainy season.

[a] The FSTP at Kossodo was closed because of ongoing restoration works. Heavy trucks and rains had damaged the FSTP access road. Consequently, no FS was delivered to the FSTP during that period.

[b] The FSTP at Zagtouli was not yet in operation.

[c] Only one plant in operation during this month.

[d] In calculating these values, we did not consider the monthly average marked.

Source: Tanoh 2016, updated.

TABLE A3. MONTHLY VOLUME (M³) OF FS COLLECTED IN GREATER ACCRA BETWEEN 2010 AND 2016 AT NUNGUA FARMS AND LAVENDER HILL.

Months	FS volumes $year^{-1}$ and treatment plant $year^{-1}$														For all years (2010-2016)		
Years	2010		2011		2012		2013		2014		2015		2016		FSTP		All FSTPs
FSTP	1[a]	2[b]	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
January	31,525	2,429	30,322	2,112	26,326	2,323	30,681	5,768	28,702	8,118	45,396	6,666	16,393	4,569[c]	29,906	4,569	34,475
February	28,111	1,188	25,860	1,478	27,247	2,152	29,575	4,990	26,898	6,930	26,869	6,851	18,391	3,931[c]	26,136	3,931	30,067
March	30,545	2,389	27,878	2,693	26,268	3,524	29,042	5,465	29,857	7,762	29,129	6,811	19,575	2,798	27,470	4,492	31,962
April	30,507	1,069	25,715	2,891	25,404	4,528	30,342	5,069	26,112	1,544	24,134	7,498	18,343	7,564	25,794	4,309	30,103
May	33,630	1,465	29,284	1,162	28,955	3,709	23,658	8,435	28,877	673	26,277	6,085	20,225	9,966	27,272	4,499	31,771
June	33,019	1,307	30,807	845	31,981	3,947	31,583	5,742	29,556	5,504	28,169	4,052	17,412	10,534	28,932	4,562	33,494
July	34,367	1,307	30,953	2,033	29,886	5,174	31,535	9,319	30,953	5,148	30,206	4,884	15,472	9,951	29,053	5,402	34,455
August	34,096	1,861	34,561	488	27,655	4,554	31,632	8,039	32,757	8,303	24,434	7,511	16,975	558	28,873	4,473	33,346
September	34,018	1,624	31,991	2,627	23,251	3,815	28,169	6,376	32,456	7,313	15,860	5,042	15,811	226	25,936	3,860	29,796
October	32,854	1,822	23,358	1,241	29,216	4,858	16,713	5,280	32,262	6,758	18,255	6,666	11,941	462	23,514	3,869	27,383
November	34,018	2,059	27,975	1,320	26,966	4,897	26,685	4,475	29,537	6,943	19,274	3,330[c]	27,409[c]	286	27,409	3,330	30,739
December	34,484	1,769	26,093	2,468	26,956	3,524	28,625	5,029	28,848	4,079	17,712	2,904[c]	27,120[c]	554	27,120	2,904	30,024
Average $month^{-1}$	32,598	1,691	28,733	1,780	27,509	3,917	28,187	6,166	29,735	5,756	25,476	6,207	17,054	4,290	27,285	4,183	31,468
SD $month^{-1}$	2,003	448	3,179	795	2,273	964	4,293	1,567	2,095	2,507	7,912	1,171	2,372	4,610	1,781	654	2,435
RS average	33,066	1,315	28,685	1,790	28,115	3,881	27,000	7,815	30,036	3,618	23,817	5,987	16,534	8,199	26,750	4,658	31,408
RS SD	1,380	307	3,410	814	3,194	1,216	5,850	1,646	2,393	1,529	5,660	1,322	2,843	3,517	5,312	2,749	3,508
DS average	32,130	1,933	28,782	1,775	26,903	3,488	29,373	6,708	29,433	6,145	27,136	6,685	11,889	5,168	26,521	4,557	31,078
DS SD	2,530	486	3,256	904	534	1,264	1,718	1,658	1,926	1,996	9,954	115	9,276	2,290	6,681	2,153	6,571
Total $year^{-1}$	**391,174**	**20,289**	**344,797**	**21,358**	**330,111**	**47,005**	**338,240**	**73,987**	**356,815**	**69,075**	**305,715**	**62,066**	**170,538**	**42,899**	**327,415**	**50,200**	**377,615**
GRAND TOTAL	**411,463**		**366,155**		**377,116**		**412,227**		**425,890**		**367,781**		**213,437**		**377,615 ± 12,137**		

Note: RS = rainy season; DS = dry season.

[a] Lavender Hill; [b] Nungua Farms; [c] The amounts of FS in November and December 2016 at Lavender Hill and for November 2015 to February 2016 for Nungua Farms were extrapolated from the previous years to obtain the yearly volume.

TABLE A4. MONTHLY VOLUME OF FS COLLECTED IN COTONOU/ABOMEY-CALAVI FROM 2011 TO 2016.

Years	2011	2012	2013	2014	2015	2016	*For all years (2010-2016)*	
Months							**Average**	**SD**
January	10,308	10,666	10,850	9,388	10,114	9,784	10,185	546
February	11,006	11,504	10,012	9,688	12,662	8,894	10,628	1,365
March	12,858	11,832	11,080	10,214	10,182	9,594	10,960	1,217
April	11,086	10,462	11,042	10,704	9,464	8,920	10,280	890
May	11,538	6,776	11,380	10,632	9,116	8,534	9,663	1,861
June	12,416	11,468	11,118	10,066	10,328	9,878	10,879	973
July	13,066	12,968	12,598	11,468	10,818	10,124	11,840	1,223
August	12,666	10,102	11,338	11,498	10,012	9,820	10,906	1,119
September	12,230	11,346	11,196	11,150	10,392	3,337	9,942	3,288
October	11,580	11,556	11,808	11,196	10,682	10,110	11,155	646
November	11,258	11,712	8,736	10,554	10,216	9,954	10,405	1,047
December	12,804	3,046	8,874	11,636	10,316	10,040	9,453	3,420
Average month^{-1}	11,901	10,287	10,836	10,683	10,359	9,082	10,525	N/A
SD month^{-1}	889	2,733	1,122	736	863	1,886	N/A	1,712
RS average	11,882	10,898	11,125	10,824	10,145	8,694	10,595	N/A
RS SD	712	1,962	1,185	476	628	2,443	N/A	1,678
DS average	11,928	9,430	10,431	10,485	10,657	9,626	10,426	N/A
DS SD	1,189	3,633	1,002	1,032	1,126	439	N/A	1,784
Total year^{-1}	142,816	123,438	130,032	128,194	124,302	108,989	126,295	10,974

N/A: Not applicable.

RS = rainy season; DS = dry season

Annex 2: Assumptions for the Financial Analysis of FS Co-composting at Existing FSTPs in Ekpè and Ouagadougou.

Raw Materials

Apart from FS, we considered the use of food waste and sawdust as the main additional organic waste sources for the co-composting process (Table A5). For FS in Kossodo and Zagtouli, we assumed that HH FS represented 70% of the total FS collected.

TABLE A5. RAW MATERIAL REQUIREMENTS.

Category	Parameter	Minimum	Maximum	Average	Moisture content
Dewatered FS	Solids recovered in drying beds	60% of TS or 65% of TSS	95% TS or TSS	70% TS or 85% TSS	65%
Other organic waste inputs	Food waste	70%	100%	80%	40-70% (50% average)
	Sawdust			Balance	10-40% (20% average)
Concentration of N in co-compost	Before enrichment	1.0% N	2.2% N	1.5%	30%
	After enrichment			3%	30%

Products

We assumed that the main outputs of the plants were (co-)compost, enriched (co-)compost and, exceptionally, (co-)compost pellets (Table A6).

TABLE A6. ASSUMED CO-COMPOSTING PRODUCTS.

Category	Parameter	Minimum (%)	Maximum (%)	Average (%)
Products	Compost	50	100	70
	Enriched compost	0	50	30
	Pellets		Optional	
Process	Loss of mass during composting	40	50	45
Process	Enrichment	Done with ammonium sulfate to attain 3% N in the product		

Investment Costs

Data in Table A7 were used to establish construction costs. These unit costs were derived from the recent construction of a similar plant in Ghana (Armah 2016).

TABLE A7. COSTS PER CO-COMPOSTING UNIT (METER, SQUARE METER OR CUBIC METER).

Description	Rate unit^{-1} (€)	Unit
Office building	266.69	m^2
Solid waste sorting area	80.55	m^2
Composting area	62.38	m^2
Pelletization unit and storage area	138.64	m^2
Channel	33.96	m
Pond	11.52	m^3
External works (wire mesh fence with a height of 2.5 m)	40.43	m
Ground works	11.52	m^2

Drying beds, the mixing chamber and most of the external works were not considered as part of the investment required because the existing plants already produced dewatered FS which could feed the proposed co-compost plant. In addition, we considered that (except for pelletizing) no electricity was consumed in the processing of compost or enriched compost. One hundred percent of the electricity for office operations was generated by solar panels. The installation cost was €5,000 on average for Ouagadougou and €10,000 on average for Cotonou.

Production Costs

The key general assumptions on production and cost factors are presented in Table A8. The lifecycle of the project was taken as 15 years; but this could last much longer.

TABLE A8. ASSUMED PRODUCTION COST FACTORS.

Parameters	Minimum (%)	Maximum (%)	Average (%)
Depreciation of machinery			10[a]
Depreciation of office equipment			20[b]
Depreciation of building construction			5[c]
Inflation	5	20	10
Inflation for production cost	3	15	10
Discount factor	7	15	12
Fuel and transportation cost for products			€0 (product only sold at plant gate)
Electricity consumed			No electricity consumed for compost/enriched compost production. Use of solar panels for office needs.
Telephone, supplies, postage, etc. $year^{-1}$	EUR 100	EUR 500	EUR 200
Compost certification $year^{-1}$	EUR 0	EUR 500	EUR 200
Company registration $year^{-1}$	EUR 0	EUR 500	EUR 200
O&M cost for machinery			5.0% of investment cost
O&M cost for office equipment			2.0% of investment cost
O&M cost for building			0.5% of investment cost
Vehicle insurance			Not applicable
Employee insurance and benefits			Included in the salary rates
Machinery, fire and theft insurance	1% of value	5% of value	3% of value
Write-off of sales	3% of total revenues	7% of total revenues	5% of total revenues
Staff salary group 1: high education	EUR 200	EUR 400	EUR 300
Staff salary group 2: moderate education	EUR 150	EUR 400	EUR 250
Staff salary group 3: low education	EUR 90	EUR 150	EUR 120
Staff salary group 4: no education	EUR 50	EUR 100	EUR 75
Engineering, design, construction supervision	5% of total construction cost	15% of total construction cost	10% of total construction cost
Price of ammonium sulfate MT^{-1} for Year 1	EUR 150	EUR 300	EUR 200
Cost of waste collection	EUR 0	EUR 0	EUR 0
Cost of unit bag, used to package 50 kg of compost	EUR 0.2	EUR 0.5	EUR 0.3
Advertisement cost: Years 1,2	1% of revenues	3% of revenues	2% of revenues
Advertisement cost: Years 3,4	0.5% of revenues	2% of revenues	1% of revenues
Advertisement cost: Years 5-10	0.1% of revenues	1% of revenues	0.5% of revenues

[a] Standard deviation taken at 1%.

[b] Standard deviation taken at 2%.

[c] Standard deviation taken at 0.5%.

Revenues

Table A9 presents assumptions on the percentage of each product sold annually and on the sales price.

TABLE A9. ASSUMPTIONS FOR REVENUE ESTIMATION.

Category	Parameter	Minimum (%)	Maximum (%)	Average (%)
Percentage of FS-based co-compost products sold				
	Year 1	50	80	55
	Year 2	60	90	65
	Year 3	70	95	75
	Year 4	70	95	85
	Year 5	80	100	90
	Years 6-10	85	100	95
Co-compost sales price for Year 1	Burkina Faso	0.06	0.13	0.08[a]
	Benin	0.05	0.08	0.06[b]
Enriched co-compost sales price for Year 1	Burkina Faso	0.10	0.20	0.14
	Benin	0.08	0.20	0.10
Sales	Annual sales price increment		10% increase year^{-1}	
Revenue	Tipping[c] fee FS m^{-3}	EUR 0	EUR 0.25	EUR 0.05

[a] Taken to be similar to existing, similar organic products; CFA 1,500 30 kg bag^{-1}; EUR 1.00 = CFA 656.

[b] Taken to be similar to existing, similar organic products; CFA 1,500-2,000 50 kg bag^{-1}; EUR 1.00 = CFA 656.

[c] The total tipping fees are ideally covering FS treatment plus parts of FS dewatering, drying beds' leachate treatment and composting. What is considered here is only a share of the overall tipping fee already collected (EUR 0.46 to EUR 0.75 m^{-3} of FS) assuming that other revenue streams (compost sales, limited subsidies) cover the remaining operational costs of the compost production.

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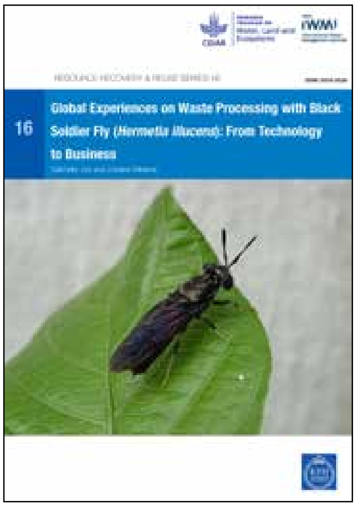

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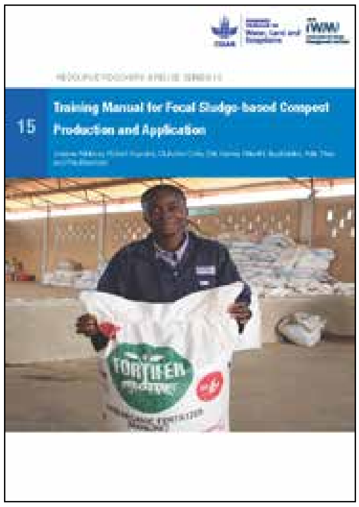

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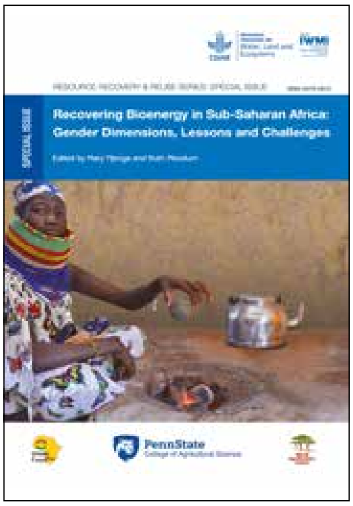

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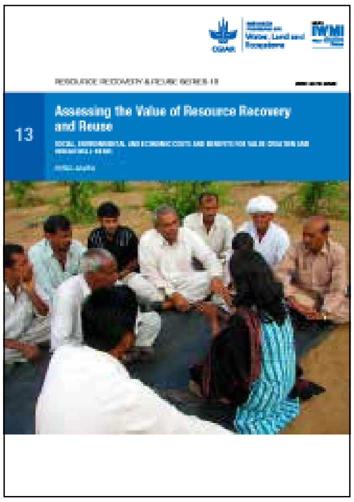

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RESEARCH PROGRAM ON Water, Land and Ecosystems

LED BY: IWMI International Water Management Institute


Source: IWMI

CGIAR Research Program on Water, Land and Ecosystems

The **CGIAR Research Program on Water, Land and Ecosystems (WLE)** is a global research-for-development program connecting partners to deliver sustainable agriculture solutions that enhance our natural resources – and the lives of people that rely on them. WLE brings together 11 CGIAR centers, the Food and Agriculture Organization of the United Nations (FAO), the RUAF Global Partnership and national, regional and international partners to deliver solutions that change agriculture from a driver of environmental degradation to part of the solution. WLE is led by the International Water Management Institute (IWMI) and partners as part of CGIAR, a global research partnership for a food-secure future.

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CGIAR Research Program on Water, Land and Ecosystems (WLE)
International Water Management Institute (IWMI)
127 Sunil Mawatha, Pelawatta
Battaramulla, Sri Lanka
Email: wle@cgiar.org
Website: wle.cgiar.org
Thrive Blog: wle.cgiar.org/thrive

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