COST-BENEFIT ANALYSIS OF FECAL SLUDGE TREATMENT INTERVENTIONS IN GHANA

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Academic Abstract

This paper provides an overview of excreta management processes across Ghana, both currently and from a historical perspective. We also conduct a cost-benefit analysis of several faecal sludge treatment technologies that could be deployed on a large scale across the country. The paper shows that all technologies examined – comprehensive treatment facilities, advanced stabilization ponds and resource recovery plants – would provide significant benefits with the potential to avoid 2-4 million cases of diarrhea and 300-600 associated deaths in the first year depending on the scale of implementation. Using cost data sourced from field investigations, we estimate the benefit-cost ratios for the investments between 3 and 6. These results are built on a number of assumptions and parameters, such as the reduction in disease and the ongoing operational profile of plants, the evidence for which is imprecise. Sensitivity analyses that account for some of this uncertainty show that benefits are still likely to exceed costs with a wider range between 2 and 8.

Policy Abstract

The Problem

In Ghana, the prevalence of onsite sanitation is more than 85%. This means that when the receptacles containing the faecal sludge are full they have to be collected and treated before discharging into the environment. Unfortunately, there are very few treatment plants available in the country and faecal sludge is mostly dumped into water bodies, drains, trenches, farms, bushes and other unauthorized places.

The danger of these practices is the pathogen load in human faeces. Poor end-of-pipe treatment poses a serious health challenge in the country. In 2017, it was estimated that there were 41 million cases of diarrhea and 7,300 related deaths in Ghana. A microbial risk analysis notes that 88% of diarrheal disease in Accra can be traced to poor sanitation, with only the remaining 12% to unsafe water. Another report indicated 75% of child deaths from cholera and diarrhea were the result of poor sanitation. Research had shown that the economic burden of diarrhea is considerable and one older estimate indicated that poor sanitation cost Ghana over $290 million in 2012, which at the time accounted for 1.6% of GDP.

Intervention 1: Comprehensive Treatment Plants

Overview

This intervention looks to build 18 treatment plants in major municipal and urban centers across the country, which would provide treatment services to some 6.8m people. This FSTP involves three stages called the primary, secondary and tertiary treatment. Modern technologies are employed in this type of intervention. The primary treatment includes the physical process of screening, grit removal and some sedimentation. The secondary treatment involves a physical phase separation to remove settleable solids and a biological process to remove dissolved and suspended organic loadings. The tertiary treatment is the final cleaning process that improves the wastewater quality before it is reused, recycled or discharged into the environment. Additionally the intervention involves the construction of a 2km access road and increased enforcement capacity to ensure trucks haul sludge to the plants for each site.

Implementation Considerations

The intervention would likely require collaboration between the public and private sector. Public-private partnership arrangements can be created that for example, mean that government provides some of the upfront capital and/or guarantees of enforcement, while the private sector operates and maintains the plants with payments based on meeting certain service standards. These arrangements would need to be negotiated on a case-by-case basis.

The calculations presented below assume that the failure rate is 5% in the second year, increasing by 5% every year before stabilizing at 50% after 10 years.

Costs and Benefits

Costs

The intervention is estimated to cost 642m cedi in upfront investment and ongoing maintenance and operations cost of around 97m cedi in the first year. Over a period of 15 years, with assumed failure rate noted above, the present value of costs is 1,349m cedi with around 48% being upfront investments in capital, and the remainder in operations and maintenance.

Benefits

The intervention would avoid around 2m cases of diarrhea and 329 associated deaths in the first year, with benefits decreasing proportionally to the assumed failure rate of plants. The total benefits of the intervention are estimated at 3,962m cedi over 15 years.

Intervention 2a and 2b: Resource Recovery plants (gas-to-energy and sludge-to-energy)

Overview

This intervention assumes the building of plants across 64 locations across Ghana serving 14m people. It is a two-ended approach in management of faecal sludge. One part is the treatment aspect it provides in receiving the sludge and the second aspect is the recovery of energy provides. The resource recovery systems are in two folds; Biogas to electricity and Sludge to electricity. Additionally the intervention involves the construction of a 2km access road for each site and increased enforcement capacity to ensure trucks haul sludge to the plants.

Biogas to Electricity

This intervention involves the generation of biogas from faecal sludge and subsequent conversion of the biogas to electricity. The plant would have three key stages, the primary treatment stage, secondary treatment stage and then the electrical power generation stage. The primary treatment includes the physical process of screening and grit removal. The secondary treatment involves an anaerobic digestion process which would generate the biogas from the sludge, the biogas is purified and subsequently stored. The third component receives the purified biogas and the chemical energy of the combustible gases is converted to mechanical energy in a controlled combustion system by a heat engine. This mechanical energy then activates a generator to produce electrical power.

Sludge to Electricity

This intervention involves the use of mechanically screened faecal sludge to produce electricity through approved gasification and incineration technology. The plant would have a drying bed for the receipt of the faecal sludge, the combustion chamber unit and the appropriate extension of the power to the grid or internal use. The process involves drying the sludge and gasifying it, thus using the gas for electricity production. The leachate from the drying beds are subsequently treated, disinfected and discharged as effluent.

Implementation Considerations

The interventions would likely require collaboration between the public and private sector. Public-private partnership arrangements can be created that for example, mean that government provides some of the upfront capital and/or guarantees of enforcement, while the private sector operates and maintains the plants with payments based on meeting certain service standards. These arrangements would need to be negotiated on a case-by-case basis.

The calculations presented below assume that the failure rate is 5% in the second year, increasing by 5% every year before stabilizing at 50% after 10 years.

Costs and Benefits

Costs

A summarized version of the costs is presented in the table below for both options across 64 locations in Ghana. The costs are relatively similar for both biogas to electricity and sludge to electricity options with expected CAPEX equal to 784m cedi and 737m cedi respectively. Total opex is GHS 104m and GHS 97m respectively in the first year, and decreasing proportionally with the assumed failure rate.

Over a 15-year period, the estimated costs are GHS 1,579 million and GHS 1,395 million respectively for biogas to energy and sludge to energy.

Costs of resource recovery options across 64 locations in Ghana

	Population served	Total capex (GHS, millions)	Total opex in the first year (GHS, millions)
Biogas to Electricity	13,994,704	784	104
Sludge to Electricity	13,994,704	737	97

Benefits

The intervention would avoid around 3.8m cases of diarrhea and 591 associated deaths in the first year, with benefits decreasing proportionally to the assumed failure rate of plants. The estimated benefits are GHS 7,485 million and GHS 7,451 million respectively, for BCRs of 4.7 and 5.3. There are some electricity produce benefits embedded in these figures, but the share of total benefits is negligible.

Intervention 3: Stabilization Ponds

Overview

This intervention assumes the building of ponds across 46 locations in Ghana that would serve 6.8m people. It involves the use of traditional waste stabilization ponds in handling faecal sludge. This typically involves anaerobic, facultative and maturation. But with the intervention a primary treatment where physical screening process, grit removal and some sedimentation would be introduced before the anaerobic process starts. A multiple stage maturation pond system would be introduced for effective disinfection. Additionally the intervention involves the construction of a 2km access road for each site and increased enforcement capacity to ensure trucks haul sludge to the ponds.

Implementation Considerations

The intervention would likely require collaboration between the public and private sector. Public-private partnership arrangements can be created that for example, mean that government provides some of the upfront capital and/or guarantees of enforcement, while the private sector operates and maintains the plants with payments based on meeting certain service standards. These arrangements would need to be negotiated on a case-by-case basis.

The calculations presented below assume that the failure rate is 5% in the second year, increasing by 5% every year before stabilizing at 75% after 5 years.

Costs and Benefits

Costs

The intervention is estimated to cost 298m cedi in upfront investment and ongoing maintenance and operations cost of around 35m cedi in the first year. Over a period of 15 years, with assumed failure rate noted above, the present value of costs is 926m cedi with around a third being upfront investments in capital, and the remainder in operations and maintenance.

Benefits

The intervention would avoid around 1.9 million cases of diarrhea and 263 deaths in the first year, with benefits decreasing proportionally to the assumed failure rate of plants. The total benefits of the intervention are estimated at 4,113m cedi over 15 years.

Summary BCR Table

Intervention	Benefit (GHS, millions)	Cost (GHS, millions)	BCR	Quality of Evidence
Comprehensive treatment plants	3,962	1,349	2.9	Limited
Stabilization ponds	4,113	926	4.4	Limited
Biogas to energy	7,485	1,579	4.7	Limited
Sludge to energy	7,451	1,395	5.3	Limited

INTRODUCTION

The National Environmental Sanitation Policy (2010) defines sanitation as developing and maintaining a clean safe and pleasant physical environment for all human settlements to promote the social, economic and physical well being of all sections of the population. Proper sanitation protects a community from diseases associated with poor waste management practices (Awuah, 2014). Even though sanitation is divided into three major components which are: solid waste management, liquid waste including human faeces management, and hygiene, the neglect of liquid waste management (particularly human faeces) has led to the separation of faecal sludge and hygiene as separate entities for attention. When the Millennium Development Goals were developed, sanitation was restricted to the provision of a safe toilet to the neglect of all other aspects of the sanitation chain including end-of-pipe treatment. Fortunately, The Sustainable Development Goals have incorporated end-of-pipe treatment within a broader scope at adequate sanitation.

This paper provides on overview of the excreta management technologies in Ghana, both currently and from a historical perspective. It also undertakes a cost-benefit analysis of several options for the management of faecal sludge from onsite sanitation systems in Ghana. Onsite sanitation systems are common practice in many developing countries because of the huge cost of transporting waste water through pipelines to central wastewater treatment plants. In Ghana, the prevalence of onsite sanitation is more than 85%. This means that when the receptacles containing the faecal sludge are full they have to be collected and treated before discharging into the environment. Unfortunately, there are very few treatment plants available in the country and faecal sludge is mostly dumped into water bodies, drains, trenches, farms, bushes and other unauthorized places.

The danger of these practices is the pathogen load in human faeces. Poor end-of-pipe treatment poses a serious health challenge in the country. In 2017, it was estimated that there were 41 million cases of diarrhea and 7,300 related deaths in Ghana (IHME, 2019). A microbial risk analysis by Labite et al. (2010), notes that 88% of diarrheal disease in Accra can be traced to poor sanitation, with only the remaining 12% to unsafe water. Most of the wastewater and faecal sludge treatment plants are non-functional, due to improper maintenance and inability to appropriately finance the costs of operations.

Faecal sludge treatment (FST) plants, when properly maintained and managed, can improve sanitation conditions and improve health outcomes in the serviced area. To do this however, will call for an evidence-based study to inform policy decisions including a closer look at costs and benefits.

Since 1995, several attempts have been made by the Government through the procurement of loans assisted by the World Bank to improve the living standards of communities by providing end-of-pipe technologies. Not much has been achieved due to lack of skilled technical and managerial labour and lack of resources for operation and maintenance of the facilities provided. Lack of proper institutional framework and non-implementation of national policies has played a major role in the collapse of these systems.

Against this backdrop, the broad objectives of this study are:

1. Examine the current toilet technologies in operation in Ghana and to determine how faecal sludge is managed when desludged (Section 2.2)
2. Provide extensive literature review on toilet technologies available, how faecal sludge has been managed over the years, cost of construction and the operation and maintenance costs (Section 2.3)
3. Undertake cost-benefit analysis of various faecal sludge management options (Section 3).

Our analysis indicates that all treatment technologies examined in this paper have the potential to generate significant health impacts in serviced areas. For example, if 18 comprehensive treatment plants (similar to the one currently operating in Lavender Hill, Accra) are constructed across the country in large cities and municipalities, it will improve sanitation conditions for 6.8 million people. We estimate that this would lead to a staggering 2m avoided cases of diarrhea and 329 avoided deaths per year, if all plants could be properly maintained and remain operational. The benefits in terms of avoided cost-of-illness and avoided mortality are worth around GHS 450m annually. Generating these benefits would require substantial initial and ongoing investment. These 18 plants would cost GHS 640m in upfront investment and GHS 107m annually in operations and maintenance. The cost-benefit analysis suggests a benefit-cost ratio of 3 at an 8% discount rate. The other technology options considered in this paper (stabilization ponds and two resource recovery options) have similar BCRs as comprehensive treatment plants.

Another important takeaway from this paper is that the available evidence to conduct cost-benefit analyses of FST technologies is very limited. The results presented in this paper, like all economic analyses, are based on a number of important assumptions and parameters. For many of these parameters precise estimates are unavailable. For example, while it is generally accepted that treating faecal sludge, instead of dumping it into the environment indiscriminately will improve health, there is substantial uncertainty on the magnitude of this impact (Mills et. al., 2018). Another key parameter is how many plants, once built, will continue operating into the future. Ghana has a history of FST treatment plants becoming non-operational due to failures mentioned above. While we account for this in our analysis, predicting the pathway of failure over 15 years is an imprecise exercise. For these reasons, readers should be cautious in interpreting the BCRs in this paper, particularly in comparing relative differences in the cost-effectiveness of the different treatment technologies. Instead, policy makers should interpret these findings as the plausible order-of-magnitude social return on investment from investing in FST technologies. It is likely that FST generates larger benefits than cost, with BCRs in the range of 2-8. More detailed, site-specific analyses should be conducted before policy makers actually construct individual FST technologies across Ghana.

EXCRETA MANAGEMENT IN GHANA

Excreta is a part of everyday life! Every adult human being produces on average 130 g of faeces and 1.4 L of urine every day (Parker et. al., 2015). Onsite sanitation systems (OSSs) are used to treat excreta and wastewater, either partially or fully, at the point of generation (Singh et. al., 2016). Most middle to low-income countries are dominated by OSSs (Parker et. al., 2015, Strauss, 2002) because they serve as a more economically sustainable option than alternatives (Dubber, 2014). In OSSs, faecal sludge (FS) accumulates over time, requiring periodic emptying of the tanks (Iwugo, 1981). FS collection and transport are mainly done by vacuum tankers (Boot, 2008, Koppelaar et. al., 2018, Mansour, 2017). Research has highlighted the possible emergence of business models from designing faecal sludge management systems around resource recovery which would in turn help ensure sustainable provision of adequate sanitation (Murray, 2010). But to date faecal sludge management (FSM) has not been given the needed attention in Africa (Bassan et. al., 2013, Baum, 2013, Ahmed et. al., 2019) making FSM difficult and cumbersome for states to manage (Owusu, 2013, Harada, 2008, Strande et. al., 2014, Ahmed et. al., 2018). Ghana is no exception. Most urban areas in Ghana are often faced with poor sanitation situations (Owusu, 2013, Ministry of Water Resources, Works and

Housing 2011) leading to faecal sludge management crises (Owusu, 2013). Lack of standardized methodologies for the quantification or characterization of FS has partly contributed to the crises (Niwagaba, 2014). In urban areas where the sanitation problem is the worst, it has been demonstrated that conventional sewer based solutions are five times more expensive than the faecal sludge management technologies in overall annualized capital and operating costs (Dodane, 2012). Environmental sanitation is an essential factor contributing to the health, productivity and welfare of the people of Ghana (Mara et. al., 2007). The WHO's 2006 guidelines for the safe use of wastewater, excreta and greywater constitute a tool for the preventive management of wastewater and provide clear guidance for decision-makers on wastewater application in different local contexts. The guidelines' primary purpose is to support the formulation of standards and government regulations regarding the use and management of wastewater, considering the specific aspects of every country (Mara et. al., 2007). Clearly, these guidelines and standards do not mention the criteria for the appropriate selection of interventions in application of the regulations regarding the use and the management.

The sanitation infrastructure of Ghana as in most sub-Saharan African countries is not properly developed. Lack of investment in wastewater and faecal sludge treatment plants in the cities of Ghana have overstretched the few available sanitation facilities, triggering pollution of nearby streams by large volumes of untreated or partially treated wastewater. Research has outlined the appropriate approach in curbing the problems to the establishment of treatment plants and resource recovery facilities (Ahmed et. al., 2018, Sagoe et. al., 2019, NESAP, 2010). The existence of the Lavender Hill Faecal Treatment Plant in Accra is an evidentiary symbol of this claim.

Faecal sludge (FS) generated in Ghana and many developing countries is mainly made up of public toilet sludge (PTS) and septage which are disposed of untreated and indiscriminately into lanes, drainage ditches, and open urban spaces (Owusu, 2013, Harada, 2008, Ministry of Water, Works and Housing, 2011, Ahmed et. al., 2018, Sagoe et. al., 2019, NESAP, 2010). These activities have been linked to unavailability of treatment plant and or dysfunctional facility for treatments or more commonly due to too long transportation time to the disposal site. There are very few faecal sludge treatment facilities available to treat the many tons of sludge generated and the old existing traditional waste stabilization ponds that are managing the sludge generated in the country are broken down (see Figure 1 and 2, DCE-KNUST, 2016). Most of these broken facilities had been turned to dumping sites for non faecal matter (Brook, 2012). The consequences of the dysfunctional facilities had contributed to the discharge of sewage into the Atlantic Ocean (DCE-KNUST, 2016, Awuah, 2008, Singh, 2016). The steps involved in the FSM chain include: collection, transportation, disposal, and treatment. Collection and transportation are the areas where Ghana had seen consistent improvement over the years (Boot, 2008, Muller, 1997, Schaub-Jones, 2005). Disposal and most importantly treatment are the areas where Ghana has seen a short fall, with high volumes of faecal sludge collected by vacuum tankers disposed on land and water bodies (Doku, 2003).

Figure 1: State of wastewater / faecal sludge treatment facilities in Greater Accra Region (DCE-KNUST, 2016)

Table 1: Waste water and fecal sludge treatment systems in Accra and Tema

LOCATION OF SYSTEM	TYPE OF FACILITY	YEAR	MANAGEMENT RESPONSIBILITY	FINANCING FOR O & M	CURRENT CONDITION
Accra Central Sewerage Scheme	*UASB-Trickling Filter/Secondary Clarifier/Sludge Beds	2000			Undergoing rehabilitation
37 Military Hospital	Trickling Filter/ Sedimentation	1972	Min. of Defence/ MoH	Govt Sub.	Non operational
University of Ghana (UG)	Trickling Filter+drain field	1967	Health Services, UG	Govt Sub.	Converted to a sewage transfer pumping station
Achimota School	Trickling Filter/Waste Stabilization ponds	1968	Ghana Edu. Service	Govt Sub	Converted to a sewage transfer pumping station
Burma Camp	Trickling Filter+Waste Stabilization Pond	1972	Ministry of Defence	Govt Sub	Damaged Filter Reconstruction
MATS, Teshie	Trickling Filter+Drain field	1972	Ministry of Defence	Govt Sub.	Damaged Filter Reconstruction
Labone Estates	Activated Sludge	1974	PWD	Sewer Tariff/ Gov	Damaged Filter/ Reconstruction
Ministries (Accra)	Activated Sludge	1972	PWD	Govt Sub	Damaged, Reconstruction
State House	Activated Sludge	1974	PWD	Govt Sub	Damaged, Reconstruction
Mental Hospital	Trickling Filter	1971	MoH/PWD	Govt Sub	Damaged, Reconstruction
Accra High School	Activated Sludge	1970	GES/PWD	Govt Sub.	Damaged, Reconstruction
Roman Ridge	Imhoff Tank	1973	PWD	Govt Sub	Non operational
Dansoman Estates	Communal Septic Tanks	1975	SHC/AESC Hydro	MWRWH/ Govt	3 out of 5 converted to sewage transfer pumping station
KorleBu Teaching Hospital	Imhoff Tank + Trickling Filter	1954	MoH/PWD	Govt Sub	Non operational
PRESEC School	Stabilization Pond	1976	GES/PWD	Govt Sub	Converted to a sewage transfer pump station
Teshie/ Nungua Estates	Trickling Filter	1977	SHC/AESC Hydro	MWH/Govt.	Damaged, need reconstruction
Trade Fair Site, Labadi	Trickling Filter	1972	PWD	MWH/Govt.	Damaged, need Reconstruction
Labadi Beach Hotel	Packaged Plant	1992	Beach Hotel Ltd	Hotel Tariff	Functional
Golden Tulip Hotel	Packaged Plant	1993	Golden Tulip Hotel	Hotel Tariff	Functional
Teshie-Nungua (Fertilizer)	FSTP	1994	AMA-WMD	AMA	Functional
Tema					
Planned Community &Industrial Estates	Chemical Treatment (1996 - , Aerated Lagoons)	1973	TemaDevp. Corp	Tariff/TMA	Non-functional. Outfall to SEA

Figure 2: State of wastewater / faecal sludge treatment facilities in Ashanti Region (DCE-KNUST, 2016).

Table 2: Wastewater / faecal sludge treatment facilities in Kumasi

LOCATION OF SYSTEM	TYPE OF FACILITY	YEAR	MANAGEMENT RESPONSIBILITY	FINANCING FOR O & M	CONDITION
Teaching Hospital/ City Hotel/4BN Barracks	Trickling Filter / Oxidation Pond (1962-)	1956	KATH/KMA	Min. of Health/Govt Subvention	Not operational
University Campus (KNUST)	Trickling Filter	1967	Health services (KNUST)	Govt. Subvention	Non-functional
Ahinsan/ Chirapatre/ Kwadaso Low-Cost Housing	Septic Tank-Filter Beds /Waste stabilization ponds (WSPs)	2002	KMA	KMA	Functional
Asafo	Waste Stabilization Ponds	1994	KMA/Contractor	KMA	Functional,
Asokore-Mampong Buobai	FSTP	2002	KMA	KMA	Non-functional
Oti/ Dompoase Landfill	Septic & Faecal Sludge Treatment Plan	2002	KMA	KMA	Non-functional primary settling ponds

For example, in the Cape Coast Metropolitan Assembly (CCMA), the authorities have acquired vast land at one of its communities called Nkanfoa, where both solid and liquid waste collected in the entire metropolis are partially managed. Specifically, this dumpsite serves the Cape Coast South District, Cape Coast North District, Elmina District, and the Cape Coast Metro. The Nkanfoa dumpsite is managed by the CCMA. The said dumpsite serves a total population of approximately 345,739 from the various districts and the metropolis.

Figure 3: A truck releases faecal sludge into the environment in Nkanfoa (source: Investigations by the authors)

At the dumpsite, a small section has been designated as a FS disposal point, where cesspit emptiers discharge FS directly onto the bare land (see Figure 3). As a result of the continuously discharging of the FS onto that particular portion, the area around it has turned into a wetland, which is expected to treat the FS. Nonetheless, owing to high volumes of FS and increasing pollutant loads, the wetland is observably weakened. Consequently, either partially-treated or non-treated FS eventually end up in nearby water bodies, posing public health risk to the people living around. Empirical data shows that there is repeated reports of enteric diseases such as diarrhea, typhoid, cholera, worm infestation among others (Cape Coast Metro Health Directorate, 2018).

It is imperative to note that the effect of this poorly treated waste has a nationwide implication, as successive governments inject huge sums of money into procurement of pharmaceuticals for the treatment of these preventable diseases. Again, because the FS is disposed of at the same area as the solid waste, periodic leveling of the solid waste by use of bulldozers has led to partial blockage of the wetland, resulting in backflow of a substantial quantity of the FS. Other key challenges worth mentioning have to do with unimaginable stench coupled with house flies, which have become an unbearable nuisance to members in the Nkanfoa community and its environs.

AN OVERVIEW AND HISTORY OF SANITATION INTERVENTIONS IN GHANA

During the Pre-colonial Era, traditional pit latrines were used. This involved trenches covered with wooden planks. The sites were far away from the community. When the trenches were full, the old one was covered with soil and the laterite or wooden structure was demolished and a new one was constructed in another place. The major problem associated with these pit latrines have been the dangers particularly at night time since the site becomes a breeding site for insects which in turn attracts snakes to such facilities.

In coastal areas, open defecation has often taken place along the beaches, with areas demarcated purposely for defecation. In landlocked areas, open defecation occurs in the bushes as cultural beliefs prevent faeces being collected in one place in some cultures. This practice had continued and currently in some of the remote regions in the country, open defecation is over 70% which is well above the nationwide open defecation average of 20% (Osumanu, 2019).

Bucket latrines were introduced during the colonial era prior to independence. Faecal sludge was collected daily and dumped in trenches further away from the communities. When the trenches got full, they were covered with soil and new trenches dug. The sites also became breeding grounds for several types of insects as with the traditional pits. Public toilet introduced during the colonial era (Aqua Privy) required the continuous application of water to the vaults. However, lack of water effectively made these dry toilets systems and produced a stench which compelled many people to abandon those places for open defecation in other places.

New onsite technologies were introduced in the early seventies such as the Kumasi Ventilated Pit (KVIP) latrine. The main aim was to reduce odour and insect breeding associated with the traditional pit latrines and to recover some nutrients for agriculture after stabilization and elimination of pathogens. The KVIP was designed for homes and institutions but because of lack of public toilet facilities many communities constructed KVIP for public areas such as Lorry station and market places. Some of the sanitary labourers who were responsible for the collection of the faecal sludge from bucket latrines dumped the faeces into the KVIP pits. This grossly defeated the purpose for which they were constructed. Some became holding tanks and instead of allowing the faecal sludge to stay for two years before desludging, the pits had to be desludged every week in some cases (Awuah, unpublished) and the weekly desludging practice is still ongoing (Ahmed et. al., 2019).

Septic tanks had been introduced before independence and the designs were very simple with only two chambers. The septage as they are called were dumped into special areas along the beach, on farms, trenches, bushes along the roads, rivers, streams and drains. Several designs are now being used without any supervision. Some have single chambers, other have two or more. There is no leaching field. Instead a soak away is connected to the last pit. The high rate of urbanization, lack of land availability has resulted in this type of design. There are no inspectors to check the construction as the Assemblies lack engineers with the requisite skills.

Many technologies have been introduced without any proper supervision. The following are the technologies being used today in the country.

1. Community Led Total Sanitation Program introduced by UNICEF/ Ministry of Sanitation and Water Resources/The Ministry of Local Government allowed individual homes to have their own type of pit latrines; with or without linings. Most are Mozambique type of Ventilated Improved Latrines.
2. Biofil Toilet Technology (BTT). The BTT is a blackwater treatment unit The technology uses aerobic processes for decomposition of faecal matter and other organic components. It has a porous composite filter (PCF) for rapid solid-liquid separation of blackwater. Solids remain in the box and are broken down by the action of earthworms and microbes. Effluent after solid-liquid separation is discharged into the sub-surface soil via a drain field (Figure 1). The poor pathogen and nutrient removal of this system call for further treatment in the form of a filter which some homes have incorporated in their systems.
3. Biodigestors toilets: is a biological system which employs anaerobic digestion as a means of treating FS and consequently producing biogas (Osei-Marfo, 2018). Three types are usually constructed in Ghana: fixed dome, floating drum and the Puxin design (Arthur et. al., 2011, Bensah, 2011). Benefits derived from biodigester toilets include waste treatment benefits (natural treatment process, reduce waste volume for transport, and nutrient recovery and recycling), energy benefits (sustainable energy source, direct replacement for non-renewable fossil fuel) and environmental benefits (odour

reduction, reduced pathogen levels, reduced greenhouse gas emissions and reduced mixing of gases to pollute the environment (Osei-Marfo, 2018, Bensah, 2011, Ahiataku-Togobo, 2016).

4. Septic tanks: It is an underground chamber made of concrete or fibre glass or plastic into which sewage flows for partial treatment through settling and anaerobic digestion where the effluent from the last chamber goes to a soak away pit or a drainage field. It can be two chambers or more. Recently in Ghana, some people have only one chamber with overflows leading into open nearby drains.
5. Clean team is a portable container which is filled with sawdust. The clean team staff collects the faecal sludge when it full and replace it with a new one. Because of the saw dust addition, the faeces do not smell. It can be placed in any part of the house.
6. Aqua privy: This toilet is for public use. The receiving pit is filled with water and subsequent top of water is done periodically to reduce odour and for ease of desludging. Unfortunately, due to lack of water and poor maintenance practices the pits are left like that without any top up. This has resulted in the strong malodorous gases in the chambers.
7. Pour flush: This toilet is generally used by households. The systems use small amounts of water to flush. Two pits are used. When is full it allowed to rest for a year or two before it is desludged.
8. Pungaluto. This is a septic tank but the tank is made of plastic.
9. Ecosan or ecological sanitation; This is a closed loop of sanitation here the human faeces are reused as soil conditioner. It is usually a dry toilet systems or compost toilet to be precise. The toilet is mixed with saw dust during its operation. Sometimes Urine diversion toilets are also known as ecosan.
10. Urine diversion toilets. These toilets divert urine into a separate receptacle and the faeces into another container. It is believed that the separation of urine from faeces will make it less odorous. The urine is store for three or more months and later used as a source of fertilizer.
11. Porta potty. This a toilet receptacle that has a toilet seat and receiving compartment at the base. It just like clean team. The toilet can then be taken to a treatment plant or into a septic tank after usage. Generally used for field trips.
12. Enviro Loo. It is dry water less sanitation system. This toilet depends on the movements of air and high heat absorbed by sunlight into the black box provided to reduce the volume of the faecal sludge to 5% of its original volume. The use of high water usage

as anal cleansing material and high patronage for public use could make this toilet nonfunctional.

13. Digni Loo: This is plastic toilet seat slab instead of wooden and concrete slab for use in the rural areas for pit latrines
14. Bore hole latrine. These are very deep and narrow pit latrines. They are never desludged. They take decades to become full and can be used in one's life time.
15. Sandplat: This is a pit latrine in sandy soil with no vent pipe. It is believed that the gases form the faeces will be absorbed by the sandy soil. This practice is not structurally good at the sand can cave in pose a great danger to life.

The purpose of outlining these public toilet technologies is to draw attention to how much has been invested in different onsite technologies and yet little has been seen in the areas of treating or handling of the faecal sludge generated from these technologies. Improper disposal of faecal sludge has been a growing problem in Ghana. In 2006, about 200,000 m^3 of FS was collected and dumped into the Atlantic Ocean without treatment (Boot, 2008), this figure however increased in 2010 to about 550,000 m^3 (Kopelaar, 2018). Current data indicate that these volumes grew again after 2010 (Ahmed et. al., 2019).

The country's development plans have not accounted for the proper treatment and disposal of faecal sludge from all the aforementioned onsite toilets. The Assemblies lack the technical know-how and allow under-resourced Environmental Health Officers to manage faecal sludge. The Sisai River in the Kumasi Metropolis for example has been a major dumping site because as one of the Environmental Officers said: 'We used to dump the faecal sludge into this river. We did not know where to take the faecal sludge and what to do with it' (Mr. Yaw Mensah, personal communication).

This has undoubtedly affected sanitation in Ghana. A study by Labite et al. (2010) identified that 88% of diarrhea related DALYs in Accra were attributable to poor sanitation. Another report indicated 75% of child deaths from cholera and diarrhea were the result of poor sanitation (Ghana MDG Report, 2015). Research had shown that the economic burden of diarrhea is considerable and that there is a need to alleviate some of these costs (Lorgelly et. al., 2008). One older estimate indicated that poor sanitation cost Ghana over $290 million in 2012, which at the time accounted for 1.6% of GDP (WSP, 2012). One way to alleviate some of these social, environmental and economic costs is to ensure proper faecal sludge treatment across the entire nation.

There is emerging evidence that these technologies can be built and maintained successfully in Ghana. A public-private partnership agreement between Sewerage Systems Ghana Ltd. and The Government of Ghana had led to the construction of a comprehensive faecal sludge treatment plant manned by competent staff and resources to operate and manage the facility for sustainability. The comprehensive FSTP has a capacity of about 2000 cubic metres a day and it currently serves Accra, Tema, some part of Eastern and Central regions of Ghana (Ahmed et. al., 2019, Ahmed et. al., 2018, Sagoe et. al., 2019).

COST-BENEFIT ANALYSIS

Against this backdrop, it is imperative that formal economic analysis is done to determine if the benefits of improving sanitation outweigh the costs and by how much. It is also important to determine if any technologies are superior in effectiveness relative to others in addressing the challenge.

In this section, we conduct a formal cost-benefit analysis of several options for faecal sludge management in Ghana. The options are:

- Comprehensive treatment plant
- Energy and resource recovery systems (two variants)
- Stabilization ponds

At the outset, it is important to highlight the broad assumptions and methods underpinning the cost-benefit analyses as a whole, before addressing the specifics of each intervention.

Costing approach

For each intervention, we first identified the feasible locations (cities, municipalities and towns) across each of Ghana's 16 regions where each option could be sited. These were based on straightforward criteria such as size of the population to be served, proximity to other (proposed) solutions, and availability of land (for stabilization ponds). For each site, population data was sourced from Ghana Statistical Service and it was assumed that each option would serve that population plus an extra 20% from surrounding areas. On the basis of the served population, we estimated the required treatment capacity using a relationship of 750 m3 sludge per day per 1 million people. This was based on capacity of the existing treatment facility at Lavender Hill and accounts for some population growth.

Initial investment costs for each treatment option were sourced from stakeholders and investment plans. Typically, the only available costing estimates were from large plants (those with capacity of 1000-1500 m3 per day), and so we adjusted costs proportionally downwards for those requiring smaller capacity. For each option we assumed some level of fixed costs regardless of plant size (USD 2m for comprehensive treatment plant; 1m USD for the resource recovery plants and USD 500,000 for the stabilization pond).

Annual operations costs were assumed to equal 12% of investment cost for plants situated inland, following a detailed investment and operations cost study of faecal sludge treatment in Senegal (Dodane et al. 2012). For plants situated near the coast we assumed double operations costs. We also assume operations costs rises with projected real GDP per capita growth.

We do not include the costs of trucks and other variables associated with desludging, since there is already a vibrant private market for removal of faecal sludge. We assume this will continue with the intervention, except that the trucks will transport waste to the treatment plant or stabilization pond instead of to the existing dumping sites. To increase the likelihood that this actually occurs, our cost estimates include the construction and maintenance of a 2km all-access road for each site as well as an increase in enforcement capacity of 5 full-time staff per 100,000 of population. The 2km road is assumed to cost USD 700,000 following another paper in the *Ghana Priorities* series examining road infrastructure (Graham et al. 2020) with a 12% p.a. assumed maintenance cost. Current sanitation enforcement capability in Ghana is 12 people per 100,000, so our assumption increases manpower by approximately 40%. Enforcement staff costs are assumed to be GHS 1500 per month, which is consistent with the urban sanitation paper in the *Ghana Priorities* series and based on interviews with health services officers (Dwumfour-Asare et al. 2020).

Estimation of baseline diarrhea incidence and mortality rates

Benefits for each treatment option were primarily reduction in diarrhea mortality and morbidity. This requires estimation of baseline diarrhea mortality and incidence. We stratified these measures by region and age group (0-4, 5-14, 15-49 and 50-69), which were estimated using the following approach.

The Demographic and Health Survey (DHS) conducted in 2014 provides regional estimates of U5 prevalence of diarrhea – and is the only regional level evidence we could identify for diarrhea. This data is combined with other broader information about U5 mortality rates at the regional level from MICS 2017/2018 and national level estimates of diarrhea incidence and mortality rates from Global Burden of Disease. This approach is admittedly imperfect, but in lieu of other data, it hopefully provides a reasonable (if somewhat imprecise) estimate of key regional level parameters.

Given the linear relationship between incidence and prevalence we can use regional level data on prevalence from DHS and national level data on incidence from GBD, to estimate regional level incidence. The equation is:

$$U5\ Incidence_j = \frac{U5\ Prev_j}{U5\ Prev_n} * U5\ Incidence_n \qquad (1)$$

where *j* subscript denotes a given region, and *n* denotes national level data. This equation assumes that if (say) regional prevalence is twice as high as national prevalence as measured by DHS, then regional incidence will be twice as high as national incidence as measured by GBD. The other underlying assumption is that the average length and frequency of diarrhea cases is equal across regions.

The Global Burden of Disease provides both incidence and deaths per year, allowing for the calculation of a case fatality rate (CFR) at a national level. For U5 this is 0.04%. To estimate regional CFRs we apply the following transformation using regional level U5 mortality rates:

$$U5\ CFR_j = \frac{U5\ MR_j}{U5\ MR_n} * U5\ CFR_n \qquad (2)$$

with subscripts as denoted above. This equation assumes that if (say) regional U5 mortality rate is twice as high as national U5 mortality rate, as measured by MICS, then the regional CFR from diarrhea should be twice as high as the national rate as estimated by GBD. This transformation assumes that the underlying risk factors of child mortality broadly affect diarrhea related mortality in an equivalent way. The estimate of regional level deaths is simply regional incidence multiplied by regional CFR.

To estimate parameters for the age group 5-14 we use national level relationships between U5 and these other age groups from GBD. We apply the following equation:

$$5 - 14\, Incidence_j = \frac{5-14\, Incidence_n}{U5\, Incidence_n} * U5\, Incidence_j \qquad (3)$$

According to GBD the incidence rate of diarrhea for 5-14 year olds is 53% of U5 incidence rate. Therefore the regional level incidence rate for 5-14 is simply 53% of the regional level incidence rate for U5 estimated from equation (1). We conduct similar transformations for the other age groups (15-49 and 50-69) using U5 incidence as the reference figure.

Lastly, we estimate CFRs for other age groups. As with U5, GBD provides national level CFRs from diarrhea for other age groups. To estimate regional level CFRs we use the following equation:

$$5 - 14\, CFR_j = \frac{U5\, MR_j}{U5\, MR_n} * 5 - 14\, CFR_n \qquad (4)$$

Ideally we would use the ratio of regional mortality rate to national mortality rates for the 5-14 age group. However, these data are unavailable. Instead we use the ratio of regional mortality to national mortality for U5. The idea behind this is that U5 figure captures the relative mortality risk for other age groups since it is influenced by the same factors at the regional level (poverty, health system coverage, rural / urban mix etc…).

Estimated incidence of diarrhea and mortality rates per region and age group are presented in the Table below.

Table 1: Estimated incidence of diarrhea and mortality rates per region and age group in Ghana

	Annual diarrhea incidence per person				Annual diarrhea related mortality per 1000 population			
Region	0-4 years old	5-14 years old	15-49 years old	50-69 years old	0-4 years old	5-14 years old	15-49 years old	50-69 years old
Greater Accra	1.37	0.73	0.77	0.83	0.31	0.01	0.02	0.13
Ashanti	2.67	1.42	1.50	1.62	1.53	0.06	0.11	0.65
Brong-Ahafo	3.22	1.71	1.80	1.95	0.91	0.03	0.07	0.39
Ahafo	3.22	1.71	1.80	1.95	0.91	0.03	0.07	0.39
Bono East	3.22	1.71	1.80	1.95	0.91	0.03	0.07	0.39
Central	1.64	0.87	0.92	0.99	0.55	0.02	0.04	0.23
Eastern	2.95	1.57	1.65	1.79	1.35	0.05	0.10	0.57
Northern	3.01	1.60	1.69	1.82	1.66	0.06	0.12	0.71
Savannah	3.01	1.60	1.69	1.82	1.66	0.06	0.12	0.71
North East	3.01	1.60	1.69	1.82	1.66	0.06	0.12	0.71
Upper East	2.26	1.20	1.26	1.37	0.70	0.03	0.05	0.30
Upper West	2.86	1.52	1.60	1.73	1.31	0.05	0.10	0.56
Volta	1.30	0.69	0.73	0.79	0.37	0.01	0.03	0.16
Oti	1.30	0.69	0.73	0.79	0.37	0.01	0.03	0.16
Western	1.28	0.68	0.72	0.77	0.34	0.01	0.03	0.15
Western North	1.28	0.68	0.72	0.77	0.34	0.01	0.03	0.15
All of Ghana	**2.20**	**1.17**	**1.23**	**1.33**	**0.90**	**0.03**	**0.07**	**0.38**

Source: Authors' calculations

Impact of each treatment option on diarrhea cases and mortality

While there is long-standing recognition of the importance of faecal sludge treatment on health outcomes, there is still limited evidence on the precise magnitude of impact. This is due to the difficulties of attributing causality from broad based infrastructure improvements, the multiple pathways of pathogen contamination, the possibility of threshold or non-linear effects, and site-specific idiosyncrasies that make generalization across different areas problematic (Mills et. al., 2018).

Notwithstanding these challenges, the limited existing evidence points towards an improvement of around 30% from sanitation interventions that remove pathogens from the environment. For example, Moraes et al. (2003) indicate a reduction of 22-60% in childhood diarrhea from sewerage in Brazil. A meta-analysis of predominantly household sanitation interventions notes an average reduction in diarrheal disease by 25%, increasing to 45% when coverage reaches 75% or higher (Wolf et al. 2018). That same study also noted a reduction in diarrheal disease of 17% from household sanitation interventions only and a 40% from sewer interventions. Unfortunately, there was no information on faecal sludge treatment interventions, though one might expect the impact to be lower than sewer interventions, but higher than household sanitation. One study documents that improved excreta disposal has the potential to reduce diarrhea morbidity by 36%, Esrey 1996. Lastly, a study by Labite et al. (2010) identifies that 88% of diarrhea related DALYs in Accra are attributable to poor sanitation, with 60% coming from exposure to open drains. Based on this, as well as reductions noted from other sanitation interventions, a 30% reduction associated with faecal sludge treatment seems reasonable.

We therefore adopt this parameter (30%) as an estimate of the **maximum possible diarrheal reduction** from faecal sludge treatment. The causal mechanism for this reduction is that once treated, faecal sludge (and the associated bacteria and pathogens) from onsite sanitation facilities do not end up in the environment via dumping grounds.

However, because treatment can only affect pathogen exposures that derive from machine based emptying and disposal via trucks, we adjust this parameter by a number of factors:

i. *the prevalence of open defecation* – clearly faecal matter that enters the environment directly cannot be affected by treatment plants. We source regional level open defecation rates from MICS (2017).
ii. *the prevalence of sewerage systems* – faecal matter that is transmitted via sewer is assumed to be treated regardless, and therefore unaffected by the intervention. We source regional level sewerage coverage rates from MICS (2017).
iii. *the prevalence of manual emptying* – faecal sludge that is emptied manually (i.e. requiring humans to lift the sludge) is at much higher risk of being dumped into the local environment as opposed to sludge that is emptied mechanically via vacuum trucks. Therefore, we conservatively assume all sludge that is emptied manually is not treated and will not be affected by the interventions. There are no regional level estimates for this parameter in Ghana, but two recent studies, one in Accra, and another in Kumasi suggest 10% and 11% of sludge respectively is emptied via manual methods (IWMI, 2015 and Furlong, 2015). We therefore reduce potential benefits by the midpoint of these values 10.5%. Note this value is applied after the first two steps, since this applies to the component of faecal sludge in onsite toilets only.

As an example of this calculation, in Greater Accra, 8% of households practice open defecation and 9% of households have sewer coverage (MICS, 2017). Additionally we assume 10.5% of faecal sludge is emptied manually. Therefore, the impact of faecal sludge treatment in Greater Accra is estimated as 30% * (1-8%-9%)*(1-10.5%) = 23%. Across regions the minimum impact is in the Upper East region and equals 9%. This is because two-thirds of households practise open defecation, and faecal sludge treatment cannot influence the pathogens coming from these households. The maximum impact across regions is estimated in Eastern region of 25%, where there is 11% prevalence of open defecation and 4% sewerage coverage. Estimated impacts across regions are presented in the Table below.

Unfortunately, there is insufficient information to determine specific impacts from each of the interventions. Therefore, all interventions are assumed to have the same impact on diarrheal disease.

Table 2: Impact of diarrheal disease from interventions by region

Region	Prevalence of open defecation (%)	Sewer coverage (%)	Impact on diarrheal disease from faecal sludge treatment
Greater Accra	8	9	23%
Ashanti	11	4	23%
Brong-Ahafo	17	0	23%
Ahafo	17	0	23%
Bono East	17	0	23%
Central	17	1	22%
Eastern	7	3	25%
Northern	57	0	12%
Savannah	57	0	12%
North East	57	0	12%
Upper East	67	0	9%
Upper West	52	0	13%
Volta	38	1	17%
Oti	38	1	17%
Western	16	1	23%
Western North	16	1	23%
All of Ghana	**22**	**2**	**21%**

Source: Authors calculations. Prevalence of open defecation and sewer coverage from MICS, 2017.

Welfare estimate of avoided case of diarrhea

The welfare impact from an avoided case of diarrhea is assessed using the cost-of-illness approach following *Ghana Priorities* guidelines (Wong and Dubosse, 2019). The only study we could identify that estimates the cost of illness of diarrhea in Ghana is Aikins et al (2010). That study estimated an average cost of treatment for diarrhea of USD 4.10 for outpatient cases (2004 figures). Using the appropriate inflation and exchange rate adjustments this equals GHS 57. These represent only direct medical costs and do not include the cost of patient or caregiver time.

For estimates of inpatient costs, we adopt costs from WHO-Choice database. For tertiary level care the figure is GHS 7.7 per day in 2005 figures, we roughly corresponds to GHS 100 per day in 2018 figures. For an average inpatient case of 5 days, the cost is GHS 500.

To these we add the cost of patient or caregiver time for each age-group. We estimate average duration of each diarrhea episode using Global Burden of Disease data. These equal around 5 days for all age groups, though are slightly higher for U5s (5.5 days). Productivity losses are assumed to be 50% of national average wages for 15-49 year olds following *Ghana Priorities* guidelines. For 5-14 year olds and 50-69 year olds productivity losses are 25% of national average wages. This accounts for the likely lower wage rates for these age groups. For 0-4 we assume no productivity loss since we assume each 0-4 year old requires a caregiver at all times, regardless of whether they are suffering from diarrhea or not. See Table 3 below for an overview of parameters used.

Table 3: Parameters used to estimate cost-of-illness per case of diarrhea by age group

	Days per case	Productivity loss per case	Cost per case (no treatment seeking)	Cost per case treated (outpatient)	Cost per case (inpatient)
Cost per case of diarrhea U5	5.5	0	0	57	500
Cost per case of diarrhea 5-14	5.1	64	64	122	565
Cost per case of diarrhea 15-49	5.0	128	128	185	628
Cost per case of diarrhea 50-69	5.2	64	64	123	566

The calculation also requires estimates of treatment seeking rates for each age group, and how many cases, conditional upon seeking treatment progress to severe cases requiring inpatient care. MICS (2017) provides regional level data of treatment seeking rates for U5 for each region. For the other age groups there is a dearth of information on treatment seeking behaviour. One study from Ghana indicates that 15% of individuals aged 10 and above sought treatment as a first option for diarrhea and more severe symptoms (such as blood in stool) (Danso-Appiah et al. 2004).

To estimate the number of cases, conditional on seeking treatment that progress to severe cases, we adopt parameters from Radin et al. (forthcoming), following the systematic review by Lamberti et al. (2012). Specifically, we assume 40% of treatment seeking cases in U5 require inpatient treatment. For the other age groups, it is assumed 7% of cases (i.e. 1% out of 15%) require inpatient treatment broadly following Lamberti et al. (2012).

Region specific costs per case of diarrhea are presented below in Table 4. These represent the weighted average cost accounting for the different rates of no treatment, outpatient and inpatient treatment and the unit cost of each from Table 3.

Table 4: Cost per episode of diarrhea avoided by region (all figures in cedis)

Region	Treatment seeking rate for diarrhea U5 (%)	Treatment seeking rate for diarrhea (all other age groups)	Cost per episode of diarrhea U5	Cost per episode of diarrhea 5-14	Cost per episode of diarrhea 15-49	Cost per episode of diarrhea 50-69
Greater Accra	18	15	42	78	141	79
Ashanti	30	15	70	78	141	79
Brong-Ahafo	51	15	119	78	141	79
Ahafo	51	15	119	78	141	79
Bono East	51	15	119	78	141	79
Central	32	15	75	78	141	79
Eastern	36	15	84	78	141	79
Northern	39	15	91	78	141	79
Savannah	39	15	91	78	141	79
North East	39	15	91	78	141	79
Upper East	51	15	119	78	141	79
Upper West	59	15	138	78	141	79
Volta	38	15	89	78	141	79
Oti	38	15	89	78	141	79
Western	37	15	87	78	141	79
Western North	37	15	87	78	141	79
All of Ghana	**36**	**15**	**84**	**78**	**141**	**79**

Source: Authors' calculations

Welfare estimate of avoided mortality

Estimation of the welfare impact of mortality avoided follows *Ghana Priorities* standardized assumptions and is based on guidance provided by Robinson et al. (2019). Each life year lost is valued at 1.2x GDP per capita in the initial year rising to 1.6x GDP per capita in 2030. For each death avoided we estimate the years of life lost (YLLs) based on Ghana life tables and taking the midpoint of each age group range. These correspond to 65.5 years, 59.6 years, 39.9 years and 17.2 years per death avoided for 0-4 year olds, 5-14 year olds, 15-49 year olds and 50-69 year olds respectively.

Accounting for imperfect maintenance, reduced lifespan of plants and improper dumping of sludge into the environment

The discussion in Section 2.2, Figure 7 shows that historically faecal sludge treatment options have consistently suffered from poor maintenance and inability to finance and continue operations. This has meant that plants tend to remain operational much less than the actual feasible operating life of each facility. Additionally, the intervention assumes that trucks will actually deliver faecal sludge to the plant or pond. However, if haulage times are significantly longer and the truck operators do not respond to enforcement, then the faecal sludge will be deposited into the environment as before with no benefits.

To account for these potential sources of failure, we assign a cumulative failure rate over time to each intervention option. For comprehensive treatment and for resource recovery options, the assumption is 0%, 5% increasing over time by 5% per year, until 50% stabilizing at that level thereafter. In other words, by year 10 only half the plants are assumed to be operational. Benefits and operating costs are reduced by the cumulative failure rate over the feasible operating lifetime (15 years). Investment costs are of course unaffected by the failure rate since they are incurred upfront. For stabilization ponds the failure rate assumption is 0%, 5%, increasing by 5% per year before stabilizing at 25%. This implies that only 3 in 4 ponds remain operational after five years. Stabilization ponds have a lower failure rate than the other two interventions because technical knowledge required to operate and maintain them are lower.

INTERVENTION ONE: Comprehensive Faecal Sludge Management in Ghana

Description of Intervention

This intervention involves a holistic approach in the treatment of faecal sludge comprehensively (Figure 4 and 5). It requires the building of Comprehensive Faecal Sludge Treatment Plants (FSTP). This FSTP involves three stages called the primary, secondary and tertiary treatment. Modern technologies are employed in this type of intervention. The primary treatment includes the physical process of screening, grit removal and some sedimentation. The secondary treatment involves a physical phase separation to remove Settleable solids and a biological process to remove dissolved and suspended organic loadings. The tertiary treatment is the final cleaning process that improves the wastewater quality before it is reused, recycled or discharged into the environment.

The cesspit trucks are expected to have different tank volumes generally between 10-20 m^3 (NESSAP, 2010, Atwi, 2009, Chowdhry, 2012). An automatic card-authorization system is used to reject non faecal matter or hazardous waste coming to the plant. After the use of the card dedicated to each truck, an automatic valve opens which enables unloading the content of the tank. About 8 -10 vehicles are allowed to simultaneously unload by gravity to an underground reinforced concrete receiving chamber. The maximum allowed volume is 560 cubic meters per hour. There is a stone catchment pit planned into the receiving chamber, from this the remaining robust wastes can be removed. The septage flows towards the next step gravitationally which involves mechanical pre-treatment as faecal matter in Ghana contains high level of foreign matter loads (Ahmed et. al., 2018). The mechanically treated septage arrives into a main buffer basin, which also serves as a lifting pump station. The main purpose of this basin; to equalize the quality of the hauled and pre-treated septage, to ensure the optimal and economical operation time of the primary clarifier. After the primary clarification stage, the feed goes to the biological treatment stage which make use of multiple Anoxic, Anaerobic and Aerobic stages to ensure the organic and nutrients loadings are reduced to the expected EPA guidelines. This is based on the comprehensive characteristics of faecal sludge studied in Ghana (Ahmed et. al., 2019). The secondary clarifiers receive the feed from the biological last stage of biological treatment processes to separate the activated sludge from the treated wastewater. Disinfection of the effluent water is going to be ensured by UV and/or NaOCl dosing. The use of chlorination has tendency to increase the conductivity and minimal dosing has been advised by research (Ahmed et. al., 2019). Sand and carbon filtration is used to ensure efficient removal odour, metals and other pollutants to ensure the water is safe for reuse in the plant. All odour emitting sources of the treatment process are placed in closed buildings, from where the polluted air is removed and treated. All generated sludge in the treatment process are pumped to sludge thickening basin where they subsequently pressed. The pressed sludge is used for biochair (charcoal), activated carbon and also can serve as feed to the proposed plant for processing of the sludge to electricity.

This intervention is to be implemented in the large urban areas in Ghana (Regional Capitals). The areas targeted for this intervention are Tema Metropolis, Cape Coast metropolis, Effutu Municipal, Adansi North, Kumasi Metropolis, Sunyani Municipal, New Juaben Municipal, Tamale Metropolis, Sekondi/Takoradi Metropolis, Bolgatanga, Wa, Ho Municipal, Bunkprugo-Yunyoo, Nkwanta South, Sawla-Tuna-Kalba, Asunafo North, Sefwi Wiaso and Techiman Municipal. All the sixteen regions in Ghana were considered. Cumulatively, a total of about 6.8 million people will be reached by the intervention.

This intervention can be implemented by the state government through the Ministry of Sanitation and Water Resources. However, private sector participation is recommended in the implementation of the intervention. International donors and NGOs can also play a role in the implementation scheme. There are plans in place to implement sanitation levy in the country and it may be used to partly support such an intervention.

Figure 4: Overview of Comprehensive FSTP for Kumasi by PURECO of Hungary

Figure 5: Overview of Comprehensive FSTP by EMO of France

Cost of comprehensive FST

In Ghana the only comprehensive FSTP is in Greater Accra Region. The investment cost was USD 40 million for a 2000 cubic meters per day capacity in James Town owned by Sewerage Systems Ghana Ltd. Another one in Adjen Kotoku with daily capacity of 1000 cubic meters has an investment capital of about 15 million USD. A 1000 cubic meters comprehensive FSTP being built in Kumasi with a treatment capacity of 1000 cubic meters per day also has an initial cost of 10.5 million Euros. A proposal from EMO to build a comprehensive FSTP in Ghana also has a price of about 9.5 million Euros for a 1000 cubic meters per day.

Based on these figures we estimate that comprehensive FSTP with treatment capacity of 1,000 cubic meters per day requires USD 20 million in investment, USD 2m of which is assumed to be fixed costs. Plants of lower or greater capacity would therefore cost less or more based on the formula USD 2m + USD 18,000 per m^3. An overview of proposed sites and associated costs are presented below.

Table 5: Proposed sites of comprehensive treatment plants with associated capex and opex costs

Location	**Region**	**Population Served**	**Capex Cost (GHS millions)**	**Opex Cost (GHS millions)**
Tema Metropolis	Greater Accra	432,994	39.0	9.5
Cape Coast Metropolis	Central	223,391	26.1	6.4
Effutu Municipal	Central	98,411	18.4	4.5
Adansi North	Ashanti	155,759	21.9	2.7
Kumasi Metropolis	Ashanti	2,515,264	167.3	20.4
Sunyani Municipal	Brong-Ahafo	183,080	23.6	2.9
New Juaben Municipal	Eastern	271,675	29.1	3.5
Tamale Metropolis	Northern	330,437	32.7	4.0
Sekondi/Takoradi Metropolis	Western	873,498	66.2	16.1
Bolgatanga	Upper East	192,080	24.2	2.9
Wa	Upper West	155,627	21.9	2.7
Ho Municipal	Volta	262,380	28.5	3.5
Bunkprugu-Yunyoo	North East	182,084	23.5	2.9
Nkwanta South	Oti	173,510	23.0	2.8
Sawla-Tuna-Kalba	Bono East	148,478	21.5	2.6
Asunafo North	Savannah	185,366	23.7	2.9
Sefwi Wiawso	Ahafo	218,028	25.8	3.1
Techiman Municipal	Western North	217,842	25.8	3.1
TOTAL	GHANA	6,819,905	642	97

Source: Author’s calculations

We estimate that building 18 comprehensive treatment plants around Ghana would serve 6.8 million people at a cost of GHS 642 million, with ongoing operations costs of GHS 97m initially (this figure assumes 5% failure rate).

The estimated benefits of the intervention are presented below. Based on the assumptions presented in Section 3.0.3 these investments would avoid 1.9 million cases of diarrhea and 329 deaths annually if all plants are functioning.

Table 6: The estimated benefits of the intervention for the various regions in Ghana.

Location	**Region**	**Cases of diarrhea avoided per year (thousands)**	**Deaths avoided per year**
Tema Metropolis	Greater Accra	80.7	7
Cape Coast Metropolis	Central	49.0	6
Effutu Municipal	Central	21.6	3
Adansi North	Ashanti	57.9	12
Kumasi Metropolis	Ashanti	934.2	195
Sunyani Municipal	Brong-Ahafo	80.0	8
New Juaben Municipal	Eastern	118.1	20
Tamale Metropolis	Northern	70.0	14
Sekondi/Takoradi Metropolis	Western	151.7	15
Bolgatanga	Upper East	23.4	3
Wa	Upper West	34.9	6
Ho Municipal	Volta	34.0	3
Bunkprugu-Yunyoo	North East	38.5	8
Nkwanta South	Oti	22.5	2
Sawla-Tuna-Kalba	Bono East	64.8	7
Asunafo North	Savannah	39.2	8
Sefwi Wiawso	Ahafo	95.2	10
Techiman Municipal	Western North	37.8	4
TOTAL	GHANA	1,954	329

Source: Authors' calculations

The total costs and benefits of the intervention are presented below at 5%, 8% and 14% discount rate. Note that these values assume a large cumulative failure rate as presented in Section 3.0.6. The central estimate is a cost of GHS 640 million and a benefit of GHS 1401 million, for a BCR of 2.2.

Table 7: BCR of comprehensive faecal sludge treatment plant.

Intervention	**Discount Rate**	**Benefit (millions, cedi)**	**Cost (millions, cedi)**	**BCR**
Comprehensive Faecal Sludge Treatment Plant	5%	4933	1563	3.2
	8%	3962	1349	2.9
	14%	2751	1071	2.6

INTERVENTION TWO: Energy/Resource Recovery Systems

Description of Intervention

This intervention is a two-ended approach in management of faecal sludge. One part is the treatment aspect it provides in receiving the sludge and the second aspect is the recovery of energy provides. The resource recovery systems are in two folds; Biogas to electricity and Sludge to electricity.

Biogas to Electricity

This intervention involves the generation of biogas from faecal sludge and subsequent conversion of the biogas to electricity. The plant would have three key stages, the primary treatment stage, secondary treatment stage and then the electrical power generation stage. The primary treatment includes the physical process of screening and grit removal. The secondary treatment involves an anaerobic digestion process which would generate the biogas from the sludge, the biogas is purified and subsequently stored. The third component receives the purified biogas and the chemical energy of the combustible gases is converted to mechanical energy in a controlled combustion system by a heat engine. This mechanical energy then activates a generator to produce electrical power. The power can be used internally or put on the national grid (see Figure 6).

Figure 6: Overview of the Biogas to Electricity intervention; this is being used at Lavender Hill FSTP

Sludge to Electricity

This intervention involves the use of mechanically screened faecal sludge to produce electricity through approved gasification and incineration technology. The plant would have a drying bed for the receipt of the faecal sludge, the combustion chamber unit and the appropriate extension of the power to the grid or internal use. The process involves drying the sludge and gasifying it, thus using the gas for electricity production. The leachate from the drying beds are subsequently treated, disinfected and discharged as effluent (see Figure 7).

Figure 7: Overview of the Sludge Biomass to Electricity

These interventions are to be implemented in the urban areas in Ghana and some Municipalities where feasible. Again, the plants dual purpose of existence also would generate electricity equivalent to about 3,064,840 Kwh each year (Biogas to electricity) and about 574,658 Kwh each year (Sludge to electricity) based on the estimated sludge to be generated from the implemented areas. The areas targeted for this intervention are Tema Metropolis, Cape coast metropolis, Effutu Municipal, Adansi North, Kumasi Metropolis, Sunyani Municipal, New Juaben Municipal, Tamale Metropolis, Sekondi/Takoradi Metropolis, Bolgatanga, Wa, Ho Municipal, Bunkprugo-Yunyoo, Nkwanta South, Sawla-Tuna-Kalba, Asunafo North, Sefwi Wiaso, Techiman Municipal, Ada west, Ashaiman Municipal, Agona west Municipal, Ajumako-Eryan-Essiam, Assin Central, Twifo-Heman-Lower Denkyira, Asokore Mampon, Atwoma Kwanwoma, Mampon Municipal, Sekyere central, Berekum Municipal, Dormaa central Municipal, Jaman North, Birim North, Birim Municipal, Fanteakwa, Karaga, Nanumba north, Sagnerigu Municipal, Yendi, Ahanta West, Nzema East, Wassa Amenfi West, Bawku, Garu Tempane, Talensi, Jirapa, Lawra, Sissala East Akatsi south, ketu south North Tongu, Chereponi Mamprusi East,Biakoye, Krachi East, Bole Gonja Central Asutifi South, Tano North, Aowin, Bia west, Sefwi Bibiani-Ahwiaso Bekwai, Atebubu Amantin, Kintampo North Municipal, Pru and Nkoranza South. All the sixteen regions in Ghana were considered. Cumulatively, a total of about 14 million people would be reached by the intervention in the country.

This intervention can be implemented by the state government through the Ministry of Sanitation and Water Resources. As before, the private sector, international donors and NGOs are recommended to assist in implementation.

Costs and Benefits of Resource Recovery of Biogas to Electricity Plant

Ghana has several systems producing electricity from biogas. A private company called Safi Sana uses faecal sludge and vegetable to produce biogas which is converted electricity. Research has indicated that the initial cost of the plant is about USD 2.8 million USD (Sagoe et. al., 2019). The comprehensive faecal sludge treatment plant in Jamestown, Accra has a biogas to electricity component which is estimated to cost USD 8.5 million. We therefore, estimate the investment cost of biogas to electricity plant with a capacity of 1,500 cubic meters to be around 10 million USD, with a fixed cost component of 1m USD.

With Sludge Biomass to Electricity, no such technology exists in Ghana, however based on a proposal submitted to Sewerage Systems Ghana Ltd. by Egnedol and other information gathered on Egnedol technology on gasifying biomass to electricity, the investment cost is estimated at USD 5 million for a 1000 cubic metres sludge biomass to electricity plant, with a fixed cost component of 1m USD.

A summarized version of the costs is presented in Table 8 for both options across 64 locations in Ghana. The costs are relatively similar for both biogas to electricity and sludge to electricity options with expected CAPEX equal to GHS 784m and GHS 737m respectively. Total opex is GHS 104m and GHS 97m respectively per year.

Table 8: Costs of resource recovery options across 64 locations in Ghana

	Population served	Total capex (GHS, millions)	Total opex (GHS, millions)
Biogas to Electricity	13,994,704	784	104
Sludge to Electricity	13,994,704	737	97

The estimated benefits of the intervention are presented in Table 9. Based on the assumptions presented in Section 3.0.3 these investments would avoid 3.8 million cases of diarrhea annually and 591 deaths per year if all plants are functioning. Additionally, the interventions would provide 3million kWh (biogas) or 574,000 kWh (sludge) per year.

Table 9: Benefits from resource recovery options across 64 locations in Ghana.

	Cases of diarrhea avoided in the first year (millions)	Deaths avoided in the first year	kWh produced in the first year
Biogas to Electricity	3.8	591	3,064,840
Sludge to Electricity	3.8	591	574,658

The total costs and benefits of the intervention are presented below at 5%, 8% and 14% discount rate. Note that these values assume a large cumulative failure rate as presented in Section 3.0.6. The central estimate is a cost of GHS 1,579 million and GHS 1,395 million respectively for biogas to energy and sludge to energy. The estimated benefits are GHS 7,485 million and GHS 7,451 million respectively, for BCRs of 4.7 and 5.3. The value of electricity generated is assumed to be GHS 1.32 per kWh following Quartey and Ametorwotia (2017). The value of electricity is less than 1% of the benefit in both cases.

Table 10: BCR for Resource recovery.

Intervention	**Discount Rate**	**Benefit (GHS, millions)**	**Cost (GHS, millions)**	**BCR**
Biogas to Energy	5%	9315	1822	5.1
	8%	7485	1579	4.7
	14%	5200	1262	4.1
Sludge to Energy	5%	9273	1610	5.8
	8%	7451	1395	5.3
	14%	5176	1114	4.6

INTERVENTION THREE: Stabilization Pond Systems for Remote Areas and / or villages

The intervention involves the use of traditional waste stabilization ponds in handling faecal sludge. This typically involves anaerobic, facultative and maturation. But with the intervention a primary treatment where physical screening process, grit removal and some sedimentation would be introduced before the anaerobic process starts. A multiple stage maturation pond system would be introduced for effective disinfection (see Figure 8).

Figure 8: Overview of the stabilization pond with primary treatment and multiple facultative pond

This intervention is to be implemented in the district capitals and / or remote areas or villages. The areas targeted for this intervention are Ada west, Ashaiman Municipal, Agona West Municipal, Ajumako-Enyan-Essiam, Assin Central, Twifo-Heman-Lower Denkyira, Asokore Mampon, Atwoma Kwanwoma, Mampon Municipal, Sekyere central, Berekum Municipal, Dormaa central Municipal, Jaman North, Birim North, Birim Municipal, Fanteakwa, Karaga, Nanumba north, Sagnerigu Municipal, Yendi, Ahanta West, Nzema East, Wassa Amenfi West, Bawku, Garu Tempane, Talensi, Jirapa, Lawra, Sissala East Akatsi south, ketu south North Tongu, Chereponi Mamprusi East,Biakoye, Krachi East, Bole Gonja Central Asutifi South, Tano North, Aowin, Bia west, Sefwi Bibiani-Ahwiaso Bekwai, Atebubu Amantin, Kintampo North Municipal, Pru and Nkoranza South. All the sixteen regions in Ghana were considered. Cumulatively, a total of about 6.8 million would be reached by the intervention in the country.

Costs and Benefits of Stabilisation Pond

Steiner (2012) has estimated some cost associated with treatment technologies including stabilization ponds but is based on the total solids (TS) of the FS. Several stabilization ponds exist in Ghana and is one of the most used technologies since the inception of the country. Based on these available data, this work estimated the cost of a Modified traditional stabilization ponds in Ghana to include a primary treatment before the first pond and multiple facultative pond an initial capital cost of USD 5 million for a capacity of 600m^3 per day, with a fixed cost component of USD 500k.

For the establishment of stabilization ponds across 46 locations in Ghana the expected capex cost is GHS 298m while annual opex is GHS 35m. The intervention is expected to avoid 1.9 million cases of diarrhea per year and 263 deaths if all ponds are functioning.

The total costs and benefits of the intervention are presented below at 5%, 8% and 14% discount rate. Note that these values assume a cumulative failure rate as presented in Section 3.0.6. The central estimate of cost is GHS 926m, while benefits are estimated at GHS 4,113 for a BCR of 4.4

Table 10: BCR for Stabilisation pond.

Intervention	**Discount Rate**	**Benefit (GHS, millions)**	**Cost (GHS, millions)**	**BCR**
Stabilization Pond	5%	5248	1089	4.8
	8%	4113	926	4.4
	14%	2737	720	3.8

Discussion of results and conclusion

The results indicate that all treatment technologies have the potential to deliver large benefits to Ghana, with all options avoiding millions of diarrhea cases per year and hundreds of associated deaths. Looking across the interventions the BCRs are quite similar, with comprehensive treatment plants having a BCR of 2.9 at the low end and sludge-to-energy plants yielding a BCR of 5.3 at the high end (see Table 11).

We caution against putting too much weight on to the relative differences of these technologies in terms of BCR. As indicated in Section 3, the key parameters upon which the BCRs are based are estimated imprecisely. We assume a 30% maximal reduction in diarrheal disease from the interventions (which is then tempered by coverage of sewerage, open defecation and manual emptying) but this estimate is imprecise. Additionally, the pathway of failure is also estimated with likely error. So while point estimates are relatively high for sludge-to-energy and relatively low for comprehensive treatment plants, it is likely that the plausible range of BCRs overlap.

Table 11: Summary of costs and benefits at different discount rates

Intervention	Discount Rate	Benefit (GHS, millions)	Cost (GHS, millions)	BCR	Quality of Evidence
Comprehensive Faecal Sludge Treatment Plant	5%	4,933	1,563	3.2	Limited
	8%	3,962	1,349	2.9	
	14%	2,751	1,071	2.6	
Stabilization Pond	5%	5,248	1,089	4.8	Limited
	8%	4,113	926	4.4	
	14%	2,737	720	3.8	
Biogas to Energy	5%	9,315	1,822	5.1	Limited
	8%	7,485	1,579	4.7	
	14%	5,200	1,262	4.1	
Sludge to Energy	5%	9,273	1,610	5.8	Limited
	8%	7,451	1,395	5.3	
	14%	5,176	1,114	4.6	

To determine the impact of uncertainty we also present aggregate BCRs at an 8% discount rate across several scenarios. These assume:

1. No failure
2. Failure happens twice as fast and twice as large (i.e. increase in failure at 10% per year, rather than 5% and settles at an equilibrium failure twice as large)
3. Diarrhea impact is 50% larger than expected (i.e maximal diarrhea reduction is 45%)
4. Diarrhea impact is 50% lower than expected (i.e. maximal diarrhea reduction is 15%)
5. Investment and maintenance costs are 25% larger than expected

Investment and maintenance costs are 25% lower than expected.

The results of these sensitivity analyses are presented in Table 12 below.

Table 12: Sensitivity analysis

	BCR for Comprehensive	BCR for Stabilization Pond	BCR for Biogas to energy	BCR for Sludge to Energy
Central	2.9	4.4	4.7	5.3
No failure	3.4	4.8	5.5	6.2
Failure is twice as fast and large	2.5	3.7	4.0	4.5
Diarrhea impact +50%	4.4	6.7	7.1	8.0
Diarrhea impact -50%	1.5	2.2	2.4	2.7
Costs +25%	2.3	3.6	3.8	4.3
Costs -25%	3.9	5.9	6.3	7.1

Source: Authors' calculations. Note: All figures assume 8% discount rate

The results of the sensitivity analysis show that the BCRs remain within a relatively tight range of 1.5 to 8.0. The BCRs appear to be most sensitive to the impact of plants on diarrheal disease. Importantly, the BCRs overlap to a substantial degree making clear cut inferences regarding the most superior technology from a cost-benefit perspective challenging. Nevertheless it appears that the BCRs for all interventions are greater than 1, demonstrating that faecal sludge treatment does not destroy social welfare, even with high failure rates. We suggest that policy makers in Ghana, if they decide to proceed with faecal sludge treatment technologies do more detailed site-specific studies to ascertain more precise benefits to costs.

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GHANA PRIORITIES

The Ghanaian economy has been growing swiftly, with remarkable GDP growth higher than five per cent for two years running. This robust growth means added pressure from special interest groups who demand more public spending on certain projects. But like every country, Ghana lacks the money to do everything that citizens would like. It has to prioritise between many worthy opportunities. What if economic science and data could cut through the noise from interest groups, and help the allocation of additional money, to improve the budgeting process and ensure that each cedi can do even more for Ghana? With limited resources and time, it is crucial that focus is informed by what will do the most good for each cedi spent. The Ghana Priorities project will work with stakeholders across the country to find, analyze, rank and disseminate the best solutions for the country.

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