Performance Evaluation of Fecal Sludge Treatment Plant at Khulna City and Proposal for Sustainable Development

by

Fatima Naznin

A thesis submitted in partial fulfillment of the requirements for the degree of
Master of Science in Civil Engineering

Khulna University of Engineering & Technology
Khulna 9203, Bangladesh

December, 2017

Performance Evaluation of Fecal Sludge Treatment Plant at Khulna City and Proposal for Sustainable Development

A thesis report submitted to the Department of Civil Engineering in Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh in partial fulfillment of the requirements for the degree of

"Master of Science in Civil Engineering"

Supervised by:
Dr. Khondoker Mahbub Hassan
Professor
Department of Civil Engineering,
KUET,
Khulna – 9203

Prepared by:
Fatima Naznin
Roll no: 1501565
Department of Civil Engineering,
KUET,
Khulna – 9203

Department of Civil Engineering
Khulna University of Engineering & Technology
Khulna - 9203, Bangladesh
26th December, 2017

Declaration

This is to certify that the thesis work entitled "Performance Evaluation of Fecal Sludge Treatment Plant at Khulna City and Proposal for Sustainable Development" has been carried out by Fatima Naznin in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

Dr. Khondoker Mahbub Hassan	Fatima Naznin
(Supervisor)	Roll No: 1501565
Professor	
Department of Civil Engineering	
KUET, Khulna - 9203	

Approval

This is to certify that the thesis work submitted by Fatima Naznin entitled "Performance Evaluation of Fecal Sludge Treatment Plant at Khulna City and Proposal for Sustainable Development" has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh on 26th December, 2017.

BOARD OF EXAMINERS

1. __________________________ Chairman (Supervisor)
   Dr. Khondoker Mahbub Hassan
   Professor, Department of Civil Engineering
   Khulna University of Engineering & Technology, Khulna-9203

2. __________________________ Member
   Head, Department of Civil Engineering
   Khulna University of Engineering & Technology, Khulna-9203

3. __________________________ Member
   Dr. Quazi Hamidul Bari
   Professor, Department of Civil Engineering
   Khulna University of Engineering & Technology, Khulna-9203

4. __________________________ Member
   Dr. Md. Saiful Islam
   Professor, Department of Civil Engineering
   Khulna University of Engineering & Technology, Khulna-9203

5. __________________________ Member (External)
   Dr. M. Ashraf Ali
   Professor, Department of Civil Engineering
   Bangladesh University of Engineering and Technology
   BUET, Dhaka-1000

Acknowledgement

First of all, I would like to express my earnest gratitude to Almighty Allah (swt) for being generous to give me the strength and ability to accomplish this thesis work.

The author would like to mention the name of thesis supervisor Professor Dr. Khondoker Mahbub Hassan, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Khulna, with high respect for his expert guidance, demonstrative encouragement and productive suggestions. Without his constant supervision, valuable advices and suggestions from time to time, I would not have been able to complete the whole thesis in a right manner.

The author thankfully acknowledged the financial support provided by "KCC FSM Scholarship Program".

Honest gratitude is extended to all of the faculty members of the Department of Civil Engineering for their thoughtful advice, support and encouragement during the research meetings. The same goes for all the members and friends in the department for their kind co-operation. The author would like to show gratitude to the lab assistants of Environmental engineering lab at Civil engineering Department in KUET for their sincerest cooperation.

Last but not least, deepest gratitude is expressed to author's parents, whose moral support and inspiration gave her the strength to complete this study.

Abstract

Bangladesh strides successfully towards full sanitation coverage which contributing to healthier life for every citizen. However, there is typically no management system in place for the accumulated fecal sludge in various containments connected to toilets. FSM (fecal sludge management) is a relatively new field, however, it is currently rapidly developing and gaining acknowledgement. Containment, emptying, transport, treatment and reuse are the basic elements of FSM. The present study is related to treatment part of FSM. Khulna the third largest city in Bangladesh having more than 1.5 million populations where people predominantly depend onsite sanitation technologies. There was no designated disposal site for collected fecal sludge and emptier had been habituated to discharge in nearby lowlands, water bodies or in drains which ultimately pollutes the environment and poses serious threat to human health. So, to fix up the situation, with the financial assistance of SNV Netherlands, Khulna city corporation (KCC) decided to establish a fecal sludge treatment plant (FSTP) at Rajbandh within the municipal landfill site boundary. The FSTP was built on a passive landfill site adopting the constructed wetlands (CW) treatment technology. This study aims at evaluating the treatment efficiency of Khulna FSTP and identifying the difficulties in operation and maintenance (O&M) at the field level and giving proposals for sustainable development.

In FSTP treated effluent, the BOD values were found to be varied from 16 mg/L to 25 mg/L while the allowable disposal limit is 40 mg/L for inland surface water bodies (ECR'97, Bangladesh)**.** Total suspended solids (TSS) concentrations were observed in the range of 30~80 mg/L which is within the allowable limit of 100 mg/L. The nitrate and phosphate concentrations in treated effluent were always found to be far less than the acceptable limit. Escherichia coli (E.coli) in final effluent never exceeded 100N/100ml while the acceptable limit is 1000N/100ml. This study also focuses on operation and maintenance (O&M) issues. Field monitoring focused on various critical intervention issues such as: adjustment of water levels, maintenance of flow uniformity, vegetation management, odor control and maintenance of berms. Finally, some constitutive recommendations have been made for the FSTP which would ensure its long-term sustainability.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 Background

The need of fecal sludge management (FSM) draws an attention and simultaneously it is achieving acknowledgement for pursuing sustainable solution around the world. As per agenda of Sustainable Development Goals (SDGs) declared where includes a goal to ensure availability and sustainable management of water and sanitation for all. Fecal sludge management in a city area specifically includes fecal sludge emptying and haulage, treatment, and reuse (Koné and Peter, 2008). In 2015 it is estimated that 2.4 billion people globally still use unimproved sanitation facilities in addition to Southern Asia owns the highest population of 953 million who have no sanitation access (World Health Organization WHO, 2015). The majority of the world's open defecators (64%) live in South Asia. The proportion of people who practice open defecation has dropped by 32 percentage points, from 68 percent in 1990 to 36 percent in 2015, a faster rate of reduction than in any other region (UNICEF, 2016). The fallen rate of open defecation is really noteworthy but sustained use of these latrines as well as the need for provision of sustainable services of pit emptying, transportation for safe disposal and treatment of waste will be undertaken confidently. Many cities continue to experience population growth that far exceeds the ability and resources of local authorities to extend coverage of infrastructure or provide adequate levels of sanitation services. The majority of the urban population living in low income settlements use some form of on-site sanitation but many of these facilities are rudimentary and poorly maintained (Luthi, 2011). The sanitation scenery in cities of developing countries merely shows different type onsite sanitation system (OSS) used but it follows informal services for excreta disposal which includes either manual or mechanical emptying. While latrines may be "improved" per WHO/UNICEF Joint Monitoring Program (JMP) definitions of "hygienic separation of human excreta from human contact", the inevitable need for emptying creates the potential for a significant risk to public health. Not only is contact with human excreta unavoidable during manual emptying, the fecal sludge itself is often disposed – even in the case of mechanical service providers – directly into the environment without treatment. This can result in communities that have made progress in increasing access to improved sanitation seeing the benefits of this progress negated by the fact of living in and around fecal sludge that has merely moved from their toilets to their immediate environment (BBS, 2011).In developing country cities, inadequate fecal sludge management generates significant negative public health and environmental risks. This practice of dumping emptied sludge in nearby open drain or water-body ultimately regenerates the risks of fecal matter re-enter into the domestic environment. Poorer groups along with children more prone to waterborne diseases who mostly dwell in unsafe environment are most sufferer of this; however, the risk remains also high for those who practice safe sanitation (Opel, 2011). According to WHO, diseases transmitted through human waste contaminated water include diarrhea, cholera, dysentery, typhoid and hepatitis and cause 115 deaths every hour in Africa alone. Of the roughly 2 million people that die every year from diarrheal diseases, most of them are children under the age of five. Most deaths from diarrhea occur among children less than 2 years of age living in South Asia and sub-Saharan Africa. From 2000 to 2015, the total annual number of deaths from diarrhea among children under 5 decreased by more than 50 per cent – from over 1.2 million to half a million (UNICEF, 2016). To unimpeded the progression and improve the situation constructive concern should be employed not only for stopping open defecation but also safe disposal of excreta. So, the increasing demand associated with FSM advances to ensure safe and viable solution for future.

Over the last 15 years, the thinking of engineers worldwide has started to shift, and people are starting to consider onsite or decentralized technologies as not only long-term viable options, but possibly the more sustainable alternative in many ways compared to sewer-based systems which are prohibitively expensive and resource intensive. In urban areas, it has been demonstrated that, depending on local conditions, the cost of FSM technologies are five times less expensive than conventional sewer-based solutions (Dodane et al., 2012). For every $1 invested in water and sanitation, an average of at least $4 is returned in increased productivity (Hutton, G. 2012). For example, a 2012 report published by the World Health Organization (WHO) estimates that poor sanitation and hygiene in many countries translates into a global economic loss of roughly $260 billion annually. In places such as Afghanistan, the Lao People’s Democratic Republic and Sri Lanka, poor sanitation and hygiene cost their economies as much as 6 per cent of gross domestic product (GDP) every year. For achieving universal sanitation coverage it would require incremental capital costs of $217 billion over the five-year period. The provision of urban sanitation dominates funding requirements, making up almost 60% of the need (Chowdhary and Kone, 2012).

Bangladesh has virtually eliminated open air defecation, bringing it down to only 1% of its population who do not have access to indoor toilet facilities. According to JMP, in 2015 Bangladesh has made good progress towards MDG (Millennium Development Goals) target. Open defecation has been reduced to only 1%, a milestone change from 42% in 2003. Improved sanitation coverage is 61%, an increase of 28% since 2003. Still 28% people are sharing latrines and 10% people are using unimproved latrines. As Bangladesh makes huge strides towards achieving MDG, virtually the entire country has been brought under the sanitation umbrella. In taking on SDGs, Bangladesh will have the opportunity to draw strength from being a star performer of the MDGs. The government allocated BDT 30.7 billion (USD 390 million) in the country's water and sanitation section in the 2012-13 fiscal year, BDT 28.24 billion (USD 360 million) in the 2013-14 fiscal year and BDT 41.13 billion (USD 526 million) in 2014-15 (SACOSAN- VI, 2016). The rapid increase of fixed-place defecation has created a new challenge for fecal sludge management in Bangladesh. Nearly 34.2% of the total population lives in urban areas (Worldometers, 2017). With the increase in sanitation coverage in urban areas using septic tanks and pit latrines, it is expected that fecal sludge volume will increase considerably within a few years. If collection and disposal systems are not in place, serious environmental degradation and associated health risk will increase" (Rahman, 2009). In the city, this challenge is terrible due to factors like high population density, rapid and unplanned growth, inadequate service provisions and so on. Most of dwellers in urban areas using predominantly on-site technologies have no attention to desludge their containment with a regular interval; moreover they rely only on the manual process of emptying operated by sweepers. On the other hand, rests are mainly emptied manually by "sweepers" (Courilleau and Cartmell, 2010) who often do not have any capacity to transport emptied sludge to a safe or designated place for disposal. In recent days, sweepers are declining in number as they are opting for safer, less stigmatized livelihoods. So, most city resident are habitual to connect their tanks directly to drains and local line-agencies have been unable to regulate pollution effectively thus accumulated sludge overflows into nearby drains and low-lying lands which causes dangerous impacts on public health and environment. A recent gap analysis report says, “With sewerage system (only in parts of Dhaka city) and septic tanks (largely used in urban centers) discharging into open water bodies, the urban scenario falls far behind hygienic sanitation coverage in true sense” (Opel, 2011).

Most of the cities in Bangladesh, including the third largest Khulna (Islam, 2012), have no designated dumping sites or treatment facilities for fecal sludge despite acute sanitation challenge. Khulna is one of the most climate vulnerable cities in the world (Haque et al., 2014) having a population over 1.5 Million (KCC website, 2015) has no sewer network. The household sanitation covers up to 99% by mostly onsite technologies which includes 61.7% septic tanks and 38.3% pits (FSM Survey, 2014). Like other local context, in the city of Khulna the disposal of fecal sludge is unusual as most are directly connected to surface water drains or water bodies consequently accumulated sludge overflows into nearby drains and low-lying lands which causes dangerous impacts on public health and environment. Failure to provide long term household sanitation and FSM solution risks undermining any progress made through increased toilet access alone. In this circumstances, Khulna City Corporation (KCC) carries out such a reliable solution-‘fecal sludge treatment plant’ (FSTP) which would enable to flourish the fecal sludge management (FSM) more firmly than before. Fecal sludge treatment plant is one kind of treatment plant where collected fecal sludge from septic tanks and pits are treated and finally its effluent is discharged into environment satisfying the disposal standards. In this viewpoint, the present study aims at inspecting the performance of the newly built FSTP with regards to treated effluent quality along with its operation and maintenance (O & M).

1.2 Objectives of the study

The target of this study is to evaluate the performance of Khulna FSTP which confirms the influent and effluent water quality characteristics and eventually the treatment efficiency along with suggestive proposals by identifying the difficulties in operation and maintenances. The objectives are precisely noted below:

a) To determine the treatment efficiency of Khulna FSTP and its effluent quality.

b) To provide recommendations for sustainable development of the FSTP based on field monitoring and mitigation measures of identified difficulties in operation and maintenance (O & M).

1.3 Structure of the dissertation

The study has been represented in seven several chapters encompassing different aspects of this study (Figure 1.1). The chapters gradually reveal the present global situation of FSM in sanitation sector, its significance, FSM progress in Bangladesh and eventually a holistic view of fecal sludge treatment plant in Khulna including its construction, performance evaluation, operation and maintenance (O&M) and proposal for sustainable development for its long term function.

Chapter-1 gives a general explanation of existing sanitation statuses throughout the world and Bangladesh, achievement of sanitation coverage and practices of in Bangladesh. In national level, an effort to build a FSTP for progression of FSM by KCC.

Chapter-2 comprises of a comprehensive literature review covering ecal sludge-its quantification, characteristics, and factors having impact on variability of it. Then it also elaborates about FSM- existing sanitation system in Bangladesh and its achievement, target of FSM and technologies applied to FS treatment. Finally, approaches of FS treatment in Khulna city has been mentioned.

Chapter-3 contains elaborate description of field survey and sample collection, analytical methods and experimental procedures employed in this study along with the fundamental principles underlying those. It also shows entire view of Khulna FSTP where plot of establishment, location, design configuration are included. Treatment mechanism, feeding options and vegetation management of planted constructed wetland are explained. Again site preparation, feeding option and sludge removal of pilot scale sludge drying bed are illustrated in this chapter.

Chapter-4 delivers laboratory test results on various physical, chemical and microbial parameters and solids concentration of influent and effluent collected from Khulna FSTP. Samples collected in dry and wet season to comprehend variation between test results.

Chapter-5 deals with operation and maintenance in which several operational activities at different levels of Khulna FSTP are described. It also narrates practice of maintenance followed in pond components. Finally, proposals have been outlined for sustainable development addressing the basic considerations of design, operation and maintenance.

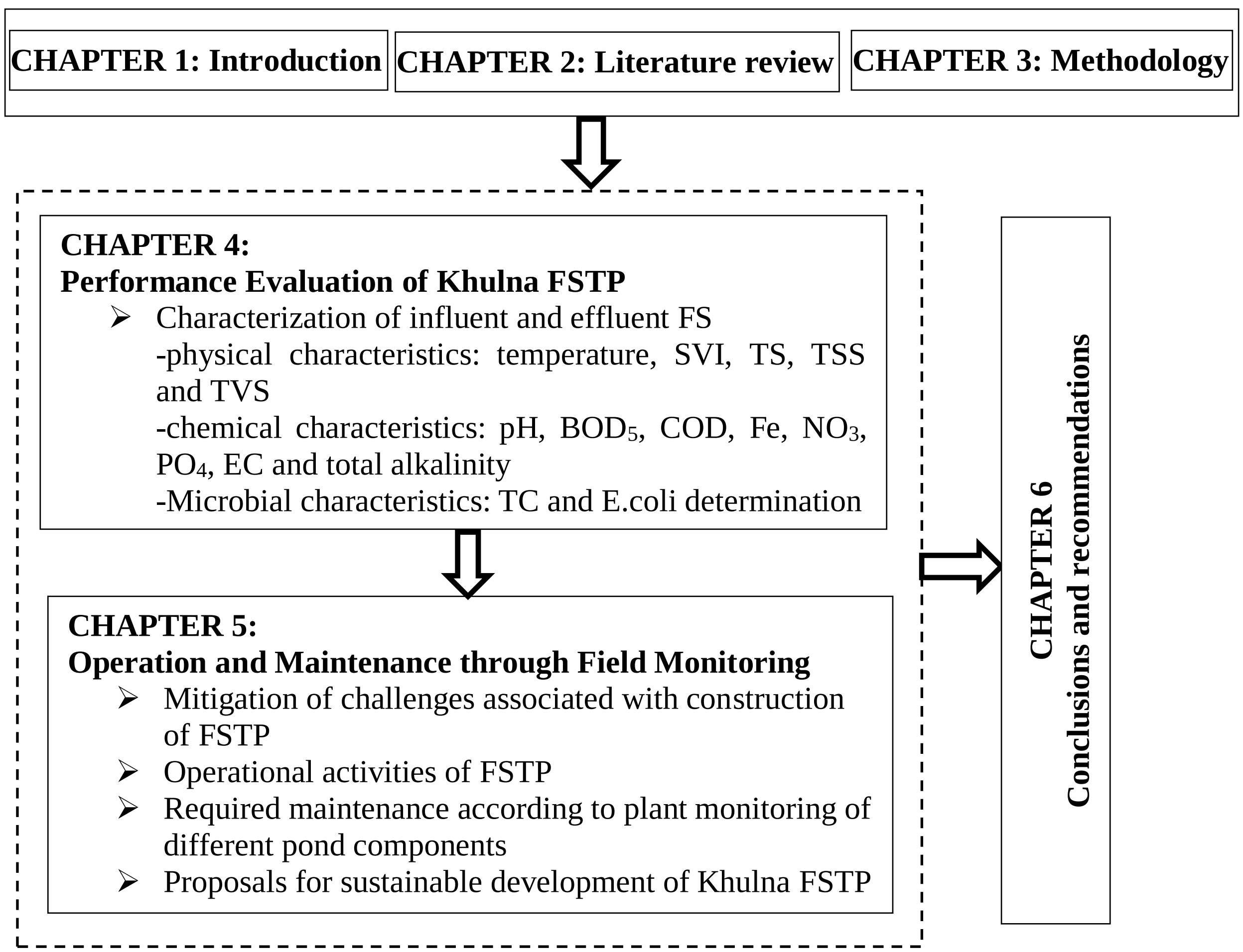


Figure 1. 1 Structure of the dissertation.

Chapter-6 draws final conclusions based on rational outcomes of performance evaluation and thorough findings from field monitoring and also provides a few recommendations for future related studies.

There are two specific objectives in this study, which were outlined earlier in section 1.2 in this chapter. The first objective is addressed in chapter 4. The second objective is elucidated in chapter 5. Chapter 5 describes on operation and maintenance of FSTP through field monitoring and illustrates proposals for sustainable development of this plant. Based on the investigations in the earlier chapters, finally, overall conclusions and recommendations are provided in chapter 6.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1 General

For conveying a theoretical base of the study this chapter is arranged so as to the reviews summarize and evaluate this relevant literature. The chapter discusses primarily about fecal sludge-what it is, its generation sources, volume, physical nature and how to manage. It also focuses on global need of FSM-its aspects, purposes, procedures, goals and so on; which is relatively new field though its potentiality is emerging rapidly. The challenges of controlling the pollution through fecal sludge disposal and what type of solution eligibly satisfied is overviewed. The fundamentals of fecal sludge treatment plant (FSTP) along with its operation and maintenance is outlined.

2.1.1 Fecal sludge

Fecal sludge (FS) is raw or partially digested, a slurry or semisolid, and results from the collection, storage or treatment of combinations of excreta and blackwater, with or without greywater. It comes from onsite sanitation technologies, and has not been transported through a sewer. Examples of onsite technologies include pit latrines, unsewered public ablution blocks, septic tanks, aqua privies, and dry toilets. In many cities, a mixture of these technologies often exist side-by-side, and there is generally a prevalence of different technologies in different geographical regions. For example, in Bangkok, Thailand; Dakar, Senegal; Hanoi, Vietnam, and Buenos Aires, Argentina septic tanks are the predominant form of onsite FS containment technology; whereas in Kampala, Uganda; Nairobi, Kenya; and Dares Salaam, Tanzania, various types of pit latrines are the predominant form of FS containment technology (e.g. improved and unimproved private latrines, shared and public latrines). The quantity and characteristics of FS also depends on the design and construction of the sanitation technology, how the technology is used, how the FS is collected, and the frequency of collection. All of these variables results in a significant difference in FS characteristics within cities, and within the same type of containment technology in different locations (Strande, *et al.*, 2014).

2.1.2 Human excreta

The amount of feces and urine produced per capita per day may vary for different regions. Reasons for this can be different dietary habits and climate conditions. The amount of feces produced ranges from 69 - 520 g/cap·day, while the urine production ranges from 845 - 1200 g/cap·day (Aalbers, 1999).

2.1.3 Quantification of fecal sludge

However, no proven methods exist for quantifying the production of FS in urban areas, and the data collection required in order to accurately quantify FS volumes would be too labor intensive, especially in areas where there is no existing information. There is therefore a need to develop methodologies for providing reasonable estimates. Due to the variability of FS volumes generated it is important to make estimates based on the requirements specifically for each location and not to estimate values based on literature. Two theoretical approaches that have been developed are the Sludge Production Method, and the Sludge Collection Method, depending on whether the goal is to determine total sludge production, or the expected sludge loading at a treatment plant.

Table 2. 1Reported fecal production rates

Location	Wet weight (g/person/day)
high income countries[1]	100-200
low income countries, rural[2]	350
low income countries ,urban[2]	250
China[3]	315
Kenya[4]	520
Thailand[5]	120-400

(Source: Strande, et al., 2014)

[1]Lentner et al. (1981); Feachem et al. (1983); Jönsson et al. (2005); Vinnerås et al. (2006), [2]Feachem et al. (1983), [3]Gao et al. (2002), [4]Pieper (1987), [5]Schouw et al. (2002)

2.1.3.1 Sludge production method

The sludge production method for estimating FS quantities starts at the household level with an estimate of excreta production (i.e. feces and urine), the volume of water used for cleansing and flushing and in the kitchen, and accumulation rates based on the type of onsite containment technology. The quantity of feces produced on a daily basis can vary significantly based on dietary habits. The frequency of fecal excretion is on average one stool per person per day, but can vary from one stool per week up to five stools per day (Lentner *et al*., 1981; Feachem *et al*., 1983).

In addition to the volume of excreta generated daily, FS accumulation depends on time and spatial habits that influence where people use the toilet, such as work schedule, eating and drinking habits, patterns of societal cohesiveness, and frequency of toilet usage. The volume of solid waste and other debris that is disposed of in the system also needs to be taken into account. In order to obtain a good estimate of FS production, the following data is required:

- number of users;
- location;
- types and number of various onsite systems;
- FS accumulation rates; and
- population of socio-economic levels.

The collection of data can pose some challenges depending on the available information, as frequently, onsite systems are built informally, so there is no official record of how many, or what type, of systems exist on a city-level scale. An accurate estimate of this would require intensive data collection at the level of household questionnaires. In some cases detailed demographic information is available, while in others it does not exist. A further complication is the rapid population growth in urban areas of low income countries. Estimating the volume of FS to be delivered to treatment plants also needs to take into account that vacuum trucks do not always empty the contents of the entire sanitation containment system (Koanda, 2006). This method for estimating total FS production will result in an overestimation of the potential volumes to be delivered to a FSTP. Although the ultimate goal is for all FS to be delivered to a treatment plant, it is not realistic to assume that all of the FS produced will initially be collected and transported for discharge at a FSTP.

2.1.3.2 Sludge collection method

The sludge collection method starts with FS collection and transport companies (both legal and informal), and uses the current demand for services to make an estimate of the volume of FS. The quantity of FS that is currently being collected from onsite systems in an area will vary depending on the FSM infrastructure, based on factors such as acceptance and promotion of FSM, demand for emptying and collection services, and availability of legal discharge or treatment sites. Estimates can be based on the number of collections made each day, the volume of FS per collection, the average emptying frequency at the household level, and the estimated proportion of the population that employ the services of collection and transport companies (Koanda, 2006).

The accuracy of any method to estimate the volume of FS generated will depend on the quality of the available data, and the reasonableness of assumptions that are made. Estimating generation of FS based on this method is complicated by many factors such as presence of a legal discharge location or treatment plant, affordability of discharge fees and scope of enforcement to control illegal dumping. After fulfillment the factors, it is possible that the majority of the FS collected will be transported and delivered to a treatment site. If a legal discharge location exists, a flow meter can be installed in order to provide an indication of the volume of FS that is being discharged. However, there is currently a lack of legal discharge locations, and, collection and transport companies are hesitant to cooperate in an official study that effectively documents their illegal activities. It is difficult to quantify the volume of FS being dumped illegally directly into the environment, either by collection and transport companies, or by households that hire manual laborers to remove FS. In addition, if volumes are being estimated for a treatment plant in an area where no legitimate discharge option currently exists, once it is built, it is expected to rapidly increase the market for these services, and hence the volume that will be delivered will also increase. This could result in an underestimation of the required capacity for the FSTP.

2.1.4 Characterization of fecal sludge

Parameters that should be considered for the characterization of FS include solids concentration, chemical oxygen demand (COD), biochemical oxygen demand (BOD), nutrients, pathogens, and metals. The organic matter, total solids, ammonium, and helminth egg concentrations in FS are typically higher by a factor of ten or a hundred compared to wastewater sludge (Montangero and Strauss, 2002). These parameters are the same as those considered for domestic wastewater analysis, however, it needs to be emphasized that the characteristics of domestic wastewater and FS are very different. Table 2.2 presents examples from the literature illustrating the high variability of FS characteristics and provides a comparison with sludge from a wastewater treatment plant.

Table 2. 2 Reported characteristics of fecal sludge from onsite sanitation facilities and wastewater sludge

Parameter	**FS source**		WWTP sludge	Reference
	Public toilet	Septic tank		
pH	1.5-12.6 6.55-9.34			USEPA (1994) Kengne et al. (2011)
Total Solids, TS (mg/L)	52,500 30,000 ≥3.5%	12,000- 35,000 22,000 34,106 <3%	– – <1%	Koné and Strauss (2004) NWSC (2008) USEPA (1994) Heinss et al. (1998)
Total Volatile Solids, TVS (as % of TS)	68 65	50-73 45	- -	Koné and Strauss (2004) NWSC (2008)
COD (mg/L)	49,000 30,000 20,000- 50,000	1,200-7,800 10,000 <10,000	- 7-608 500-2,500	Koné and Strauss (2004) NWSC (2008) Heinss et al. (1998)
BOD (mg/L)	7,600 -	840-2,600 -	- 20-229	Koné and Strauss (2004) NWSC (2008)
Total Nitrogen, TN (mg/L)	-	190-300	- 32-250	Koné and Strauss (2004) NWSC (2008)

Parameter	FS source		WWTP sludge	Reference
	Public toilet	Septic tank		
Total Kjeldahl Nitrogen, TKN (mg/L)	3,400	1,000	-	Katukiza et al. (2012)
NH_4-N (mg/L)	3,300 2,000 2,000-5,000	150-1,200 400 <1,000	- 2-168 30-70	Koné and Strauss (2004) NWSC (2008) Heinss et al. (1998)
Nitrates, NO_3^- (mg N/L)	-	0.2-21	-	Koottatep et al. (2005)
Total Phosphorus, TP (mg P/L)	450	150	9-63	NWSC (2008)
Fecal coliforms (cfu/100 mL)	$1x10^5$	$1x10^5$	$6.3x10^4$ - $6.6x10^5$	NWSC (2008)
Helminth eggs (Numbers/L)	2,500 20,000-60,000	4,000-5,700 4,000 600-6,000 16,000	- 300-2,000	Heinss et al. (1994) Heinss et al. (1998) Ingallinella et al. (2002) Yen-Phi et al. (2010)

(Source: Strande, et al., 2014)

pH: The pH of FS from septic tanks is normally in the range of 6.5 to 8.0 (Ingalinella et al., 2002; Cofie et al., 2006; Al-Sa'ed and Hithnawi, 2006), but can vary greatly from 1.5 to 12.6 (USEPA, 1994). A pH outside the range of 6 to 9 indicates an upset in the biological process that will inhibit anaerobic digestion and methane production. This could result from a change in the hydraulic loadings, the presence of toxic substances, a large increase in organic loading, or that the systems are receiving industrial or commercial wastewater.

Total solids: TS concentration of FS comes from a variety of organic (volatile) and inorganic (fixed) matter, and is comprised of floating material, settleable matter, colloidal material, and matter in solution. Grit, sand and municipal waste. Total solid values are important as they are used to design and dimension FS treatment technologies such as planted and unplanted drying beds. Solids that settle out of suspension after a certain period of time, for example, the solids that accumulate in the bottom of an Imhoff cone after 30 to 60 minutes, are termed settleable solids. This value is reported as the sludge volume index (SVI), and is used for designing settling tanks.

Biochemical Oxygen Demand (BOD_5): BOD is a measure of the oxygen used by microorganisms to degrade organic matter. Wastewater is considered to be weak, medium, strong and very strong respectively at BOD_5 of 200, 350, 500, and >750 mg/L (Mara, 2004). FS typically has a much higher BOD_5 than that of ‘strong’ wastewater. The oxygen demand of FS is an important parameter to monitor, as the discharge of FS into the environment can deplete or decrease the oxygen content of water bodies resulting in the possible death of aquatic fauna.

Chemical Oxygen Demand (COD): COD represents the oxygen equivalent of the organic matter that can be oxidised chemically with dichromate, a powerful chemical oxidant. The ratio of BOD to COD can also be used as an indicator of the relative biodegradability of the organic matter in different waste streams.

Nutrients: Excreta contains nutrients that originate from food consumption. Of the total nitrogen, phosphorus and potassium that is consumed, 10-20% of nitrogen, 20-50% of phosphorus, and 10-20% potassium is excreted in the faeces, and 80-90% of nitrogen, 50-65% of phosphorus, and 50-80% of potassium in the urine (Berger, 1960; Lentner et al., 1981; Guyton, 1992; Schouw et al., 2002; Jönsson et al., 2005; Vinnerås et al., 2006). Ammonia (NH_3) is produced by deamination of organic nitrogen, and hydrolysis of urea ($CO(NH_2)_2$) in urine by urease. The majority of ammonia in raw FS comes from the urine (Mitchell, 1989; Jönsson et al., 2005).

Phosphorus: The concentration of phosphorus is also an important parameter to consider, as the total phosphorus concentration in FS is quite high (e.g. 2-50 times the concentration in domestic wastewater). Phosphorus in FS will be present as phosphate, the acid or base form of orthophosphoric acid (H_3PO_4 / PO_4-P), or as organically bound phosphate (e.g. nucleic acids, phospholipids and phosphorylated proteins). The fate of phosphorus in the various treatment processes will be based on factors such as sorption, precipitation, complexation, sedimentation, mineralisation, pH, plant uptake in planted drying beds, and redox potential.

Nitrogen: Nitrogen is an important parameter to consider in FS treatment, as the total nitrogen concentrations in FS is typically quite high (e.g. 10-100 times the concentration in domestic wastewater). The nitrogen content in feces is about 20% as ammonia, 17% as organic nitrogen in the cells of living bacteria, and the remainder as organic nitrogen (e.g. proteins, nucleic acid) (Lentner et al., 1981). Depending on factors such as pH, length of storage, the presence of oxygen, and the type of FS, nitrogen will be present in a combination of the following forms; ammonium (NH_4-N)/ammonia (NH_3-N), nitrate (NO_3-N)/nitrite (NO_2-N), and organic forms of nitrogen (e.g. amino acids and amines).

Pathogens in fecal sludge: Exposure to untreated FS should always be considered as a pathogenic health risk. Adequate reductions in pathogens need to be determined based on the intended enduse or disposal option for treated sludge and liquid effluents.

2.1.5 Operational factors that impact the variability of fecal sludge

The wide variability of observed FS characteristics is due not only to the range of different onsite technologies used, but also the way in which the system is used, the storage duration (filling rates and collection frequencies), inflow and infiltration, and the local climate. All of these factors should be taken into account when determining FS characteristics.

2.1.5.1 Local climate

Climate has a direct influence on FS characteristics, mainly due to temperature and moisture. Frequently the highest demand on collection and transport services occurs during the rainy season, as heavy rainfalls result in overflowing and flooding of onsite systems. Rates of biological degradation are also temperature dependent, and rates increase with warmer temperatures.

2.1.5.2 User habits

The use and maintenance of on-site sanitation technologies impact the FS characteristics at the household scale. For example, office toilets receive more urine, household toilets more feces. (Bassan *et al.*, 2015). The TS concentration is dependent on factors such as dry versus flush toilet, volume of flush water used, cleansing method and inclusion or exclusion of grey water from bathing or cooking. . The filling rate will increase as more waste streams enter the toilet (e.g. solid waste from kitchen, rubbish), and with the number of people using the toilet. Due to inclusion of kitchen wastewater without properly maintained oil and grease traps the fat, oil and grease concentration will increase and odors will also increase with additional organic waste streams (Strande, *et al.*, 2014). People also use additives to attempt to reduce filling rates such as supplemental microorganisms, salt, sugar, ash, fertilizer, and kerosene. Some additives can be quite harmful, and in general have not been found to be effective (Foxon *et al.*, 2012).

2.1.5.3 Storage duration

The length of time that FS is stored in onsite containment systems before being collected and transported will greatly affect the characteristics due to the digestion of organic matter that occurs during storage. For example, in informal settlements in general, a large proportion of the population relies on public latrines that are highly frequented, and so require frequent emptying. In Kampala, 30 individuals (or 7 households) are on average sharing one single latrine (Günther *et al.*, 2011). In Kumasi, Ghana, 40% of the population relies on unsewered public toilets, which are emptied every few weeks. Hence, FS collected from public latrines tends to not be stabilized, and have high concentrations of BOD and NH_4^+-N. FS that has been stored in a septic tank for a period of years will have undergone more stabilisation than FS from public toilets.

2.1.5.4 Emptying methods

FS at the bottom of containment systems that is too thick to pump will only be collected if it is manually emptied with shovels, or if water is added to decrease the viscosity and enable pumping. The addition of water to extract settled FS and the extraction mode (manual or mechanical) impact the characteristics of the FS that reaches the treatment plant or discharge site. FS emptied from septic tanks will be more dilute if more supernatant than sludge is collected, or if the pump is not strong enough to remove all of the accumulated sludge. For example, in Dakar, Senegal, 83% of collection and transport vehicles are equipped with pumps and not strong vacuums, and are therefore unable to remove solids settled at the bottom of septic tanks (Diongue, 2006; Sonko, 2008).

2.1.5.5 Inflow and infiltration

The concentration and volume of FS is also greatly influenced by inflow and infiltration of leachate into the environment from the system and / or ground water into the system. The permeability of containment systems is influenced by whether they are unlined, partially lined, completely lined, connected to drain fields or soak pits, and the quality of construction. If systems are permeable, the amount of inflow and infiltration will be influenced by the type of soil and the groundwater level. The exchange of ground water with FS can result in groundwater contamination.

2.2 Target of fecal sludge management

2.2.1 Fecal sludge management (FSM)

Fecal Sludge Management (FSM) refers to a systems approach that includes technologies and mechanisms for containment, emptying, collection, transportation, treatment, disposal and/or reuse of sludge produced in onsite sanitation systems such as septic tanks and pit/pour-flush latrines. Conventional sewerage is not included in a FSM system (Rahman *et al.*, 2015). FS may be treated in separate treatment works or co-treated with sludge produced in wastewater treatment plants. (Strauss et al., 2002).

2.2.2 Elements of FSM system

User: Raise awareness of the pros and cons of the entire service chain and ensure participation in all stages of planning, design, implementation, operation and maintenance of FSM services. Users are a critical stakeholder in the system.

Containment: Proper design for effective containment of fecal matter.

Emptying: Sufficient access for mechanical desludging, particularly in slums and low income areas.

Collection: Align collection vehicle size with available access to OSS facilities and ensure its capability for full operation.

Transport: Include transfer stations for cost-effective transport of fecal sludge up to treatment plants.

Treatment: Ensure availability of land for establishment of fecal sludge treatment plants. Disposal/Reuse: Implement quality assurance of treatment and of treated FS for end use.

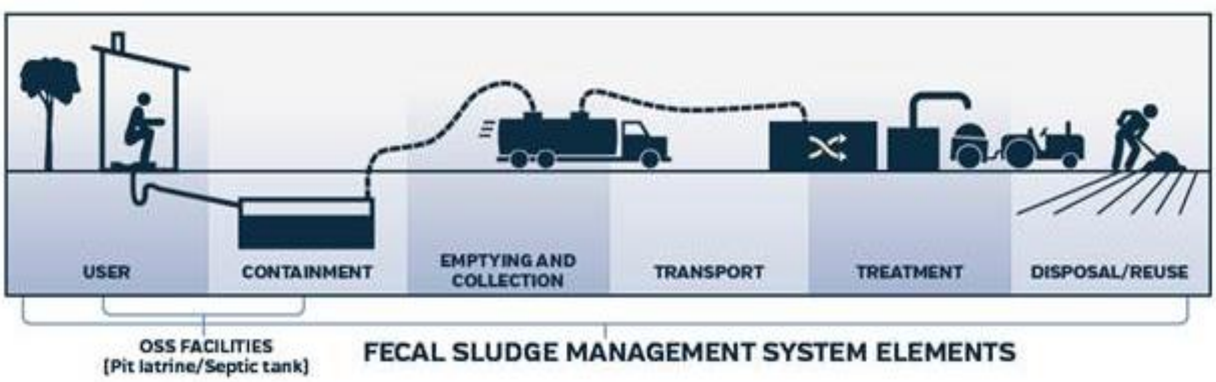


Figure 2. 1 The elements of the entire FSM service chain are equally important and must be properly addressed. (Source: Rahman *et al.*, 2015).

2.2.2 Serious challenges owing to absence of an effective system

People living in high-density urban slums and low-income communities depend entirely on OSS facilities shared by multiple families. As a result, the pits (or septic tanks) are filled up quickly with fecal matter and without desludging services, the toilets become unusable. Thus, in absence of effective 'emptying', a part of the FSM system, sanitation in these communities is becoming unsustainable and people are being compelled to go back to open defecation. It is worth noting that while open defecation has been brought down to 1% on a national level (according to 2015 JMP report), in many slums open defecation is practiced by as much as 20% of the slum population (Oxfam and ITNBUET, 2014).

Figure 2. 2 Fecal sludge being discharged into open environment. (Source: Rahman *et al.*, 2015)

OSS facilities have become major sources of groundwater and surface water pollution, with significant environmental, public health, and economic impacts. Most OSS facilities including septic tanks are built without following any engineering design principle and therefore perform poorly, as was evident from a case study conducted by K-Hub, ITN-BUET (2015). In the absence of effective fecal sludge management (FSM) services, a huge quantity of FS generated in septic tanks and pits/pour-flush latrines are being discharged in low-lying areas, storm water drains, in lakes, canals and rivers leading to serious environmental degradation, particularly in urban areas, endangering public health.

Figure 2. 3 Household latrine directly connected to open drain. (Source: Rahman *et al.*, 2015)

The alarming situation is similar in all major urban areas comprising of 11 City Corporations (CCs) and 325 Paurashavas (Municipalities) as well as across socioeconomic strata within towns and cities.

A root cause for lack of FSM services in these cities and towns is that there is no clear assignment of responsibilities with regard to fecal sludge management among the utility service providers (e.g., water supply and sewerage authorities, WASAs), City Corporations and Paurashavas/ Municipalities, and City Development Authorities in major cities e.g., Dhaka, Khulna, Chittagong, Rajshahi, Cox's Bazar (SNV and DevCon, 2014). There is also lack of awareness among these institutions and organizations regarding FSM. As a result, there is a lack of concerted effort by all concerned to address this serious issue.

2.2.4 Current FSM practice in Bangladesh

FSM has recently been initiated as an urban sanitation option in some areas of Bangladesh. Generally, fecal sludge management is unsystematic, unplanned, poorly regulated and mostly provided by individuals or informal private service providers. Although the WSS sector has an impressive array of legal instruments, policies, strategies and plans in place (the National Policy for Safe Water Supply and Sanitation became effective in 1998), fecal sludge management has long been neglected and it is not yet institutionalized.

In recent years there has been increasing interest in FSM in Bangladesh. The recently approved National Water Supply and Sanitation Strategy, 2014, provides specific strategic directions to address fecal sludge related issues and design, and to implement a comprehensive fecal sludge management programme. There are also a number of ongoing initiatives to carry out fecal sludge management programmes at a small scale or on a pilot basis at local levels. In this regard, already 16 Paurashavas (Municipal) towns have initiated FSM services, on a limited scale, with treatment plants built with assistance from the Department of Public Health Engineering (DPHE) and NGOs, and employing 'vacutug' for emptying, collection and transportation of fecal sludge to treatment plants. In all urban areas, unhygienic manual emptying systems predominate over the mechanical emptying system using 'vacutug' because of its limited availability and lack of public awareness. For example, the Department of Public Health Engineering (DPHE), with Asian Development Bank (ADB) assistance, is executing a project for water and sanitation services in secondary towns. The municipalities will be provided with tractor-towed tanks with suction pumps for emptying and transporting fecal sludge from septic tanks and pit latrines. Sludge treatment plants will be constructed on the outskirts of towns, into which the sludge will be disposed.

In Dhaka city, two NGOs – Dustha Shystha Kendra (DSK) and Population Services and Training Centre (PSTC) – with financial and technical support from WaterAid have been providing mechanical fecal sludge emptying services. Different fees are charged for different economic groups; low-income groups in slums get a subsidized rate but the subsequent disposal of fecal sludge into sewers/low lands without treatment needs addressing.

In Khulna city, under an ADB-funded project, the Khulna City Corporation uses two tank lorries towed by tractors and equipped with suction pumps for mechanical emptying purposes. While the corporation charges a fee from households for providing services, the collected sludge is usually deposited into open water.

In Faridpur town, the municipality provides a mechanical emptying service using a Vacutug purchased through funds provided by the municipality and the INGO Practical Action. However, there is a need to assess the performance of the initiatives and standardization of the FSM processes.

Besides the above initiatives, Bangladesh is participating in an ongoing World Bank (Water and Sanitation Program)-funded study on fecal sludge management issues. The Local Government Engineering Department (LGED) has taken up an urban sanitation strategy preparation task with ADB financing. The National Forum for Water Supply and Sanitation has recently assigned ITN-BUET with the task of coordinating the ongoing initiatives. SNV Netherlands Development Organization, with funding from the Bill & Melinda Gates Foundation, took the initiative to reform FSM practices in southern Bangladesh in partnership with Khulna University of Engineering & Technology, Khulna University, Khulna Water Supply and Sewerage Authority and WaterAid. This baseline survey was conducted with the intention of creating a foundation stone for this FSM modernization scheme, which will offer city-wide, pro-poor, safe and sustainable fecal sludge management services.

Besides the above initiatives, Bangladesh is participating in an ongoing World Bank (Water and Sanitation Program)-funded study on fecal sludge management issues. The Local Government Engineering Department (LGED) has taken up an urban sanitation strategy preparation task with ADB financing. The National Forum for Water Supply and Sanitation has recently assigned ITN-BUET with the task of coordinating the ongoing initiatives.

2.2.5 FSM goal

As FSM is acknowledged as a real need and legitimate solution, it will naturally result in significantly greater amounts of attention and resources being focused on FSM. The overall goal of the program is to establish financially viable and sustainable fecal sludge management solutions for cities and towns in Bangladesh. In turn, this will improve the health condition and well-being of the urban population, especially for low-income groups working in sludge management as well as slum residents who will benefit from the new services. It aims to make hygienic fecal sludge emptying services accessible and affordable to the urban poor through interventions that will make the sanitation sector more sustainable, competitive and dynamic. The proper application of FSM will be hindrance for direct dumping of fecal sludge to environment.

2.3 Existing sanitation system in Bangladesh and its achievement

2.3.1 Country sanitation situation

Bangladesh has made significant progress in sanitation during the last decade mainly because of the Community Led Total Sanitation Approach (CLTS), a coordinated effort led by the government and supported by NGOs and other development partners. The 2014 WHO-Unicef Joint Monitoring Program for Water Supply and Sanitation (JMP) report shows that 57% of the population has access to improved sanitation facilities. Open defecation practice has decreased to only 3% in 2012 compared to 19% in 2000. The report also reveals that in addition to the 57% (55% in urban areas) of people using improved sanitation, 28% (30% in urban areas) use shared latrines and 12% use unimproved latrines. This means that about 97% of the population has access to some form of latrine, irrespective of its quality. In Bangladesh, waterborne sewerage systems cover only 20% of the city of Dhaka's population (about 2% of the country's population). The vast majority (about 94% of the country's population) are served by on-site sanitation (OSS) systems such as septic tanks, improved pit latrines and unimproved pit latrines.

2.3.2 Khulna city context

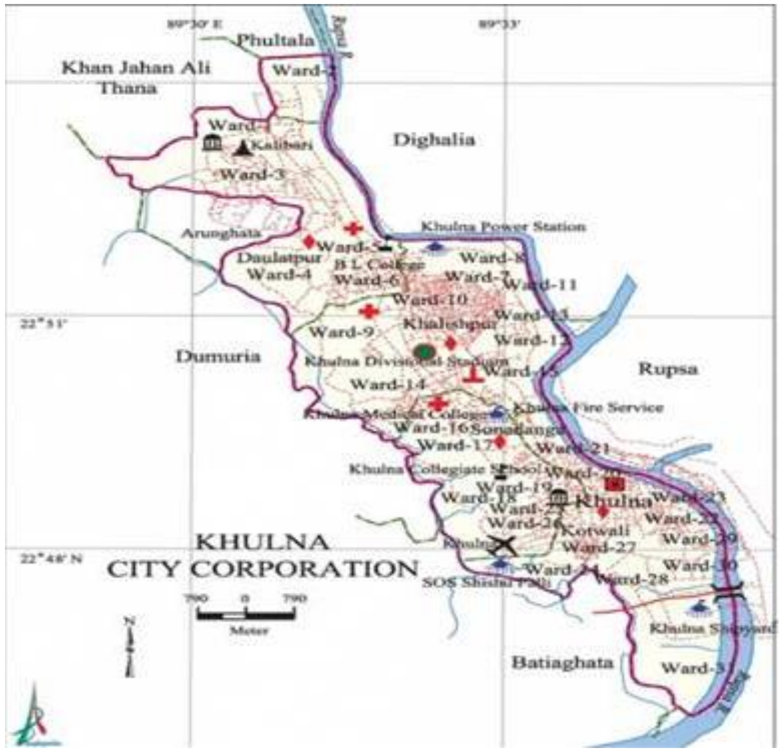


Figure 2. 4 Map of Khulna City Corporation. (Source: Bangladesh Population Census 2001, Bangladesh Bureau of Statistics)

Khulna is one of the most climate vulnerable cities in the world (Haque *et al*., 2014) having a population around 1.5 Million and the population density is 67, 994 per km^2 (KCC website). It is located in between 24°45' and 24°54' north latitudes and in between 89°28' and 89°35' east longitudes. It is bounded by Dighalia upazila and Khan Jahan Ali thana on the north, Batiaghata upazila on the south, Rupsa and Dighalia upazilas on the east and Dumuria upazila on the west (KCC, Banglapedia). Khulna is relatively flat, with no mountainous features, and is located on the late Holocene-recent alluvium of the Ganges deltaic plain (Adhikari *et al.*, 2006), characterized by Ganges tidal floodplains, rivers, tidal marshes and swamps (Khan and Kumar, 2010). As a deltaic plain, Khulna is very susceptible to climate change (ADB, 2011) and prone to cyclones. Khulna City Corporation holds 31 number of wards. Most of the cities in Bangladesh, including the third largest Khulna (Islam, 2012), have no designated dumping sites or treatment facilities for fecal sludge despite acute sanitation challenges owing to high population density, rapid and unplanned growth. In Khulna, there is a basic trenching ground and household sanitation is predominantly on-site technologies, 61.7% septic tanks and 38.3% pits, which require regular emptying (Opel, 2011, FSM Survey 2014). But formal emptying is rare as most are directly connected to surface water drains or water bodies. The rest are mainly emptied manually by sweepers who often do not have capacity to transport emptied sludge to a safe or designated place for disposal (Courilleau and Cartmell, 2010).

2.3.3 Shit flow diagram of Khulna city

A shit flow diagram (SFD) is a tool to readily understand and communicate visualizing how excreta physically flows through a city or town. It shows how excreta is or is not contained as it moves from defecation to disposal or end-use, and the fate of all excreta generated (Susana, 2017). The Shit Flow Diagram (SFD) of Khulna city (Figure 2.5) was created through field-based research by Sandec (Sanitation, Water and Solid Waste for Development) of Eawag (the Swiss Federal Institute of Aquatic Science and Technology).

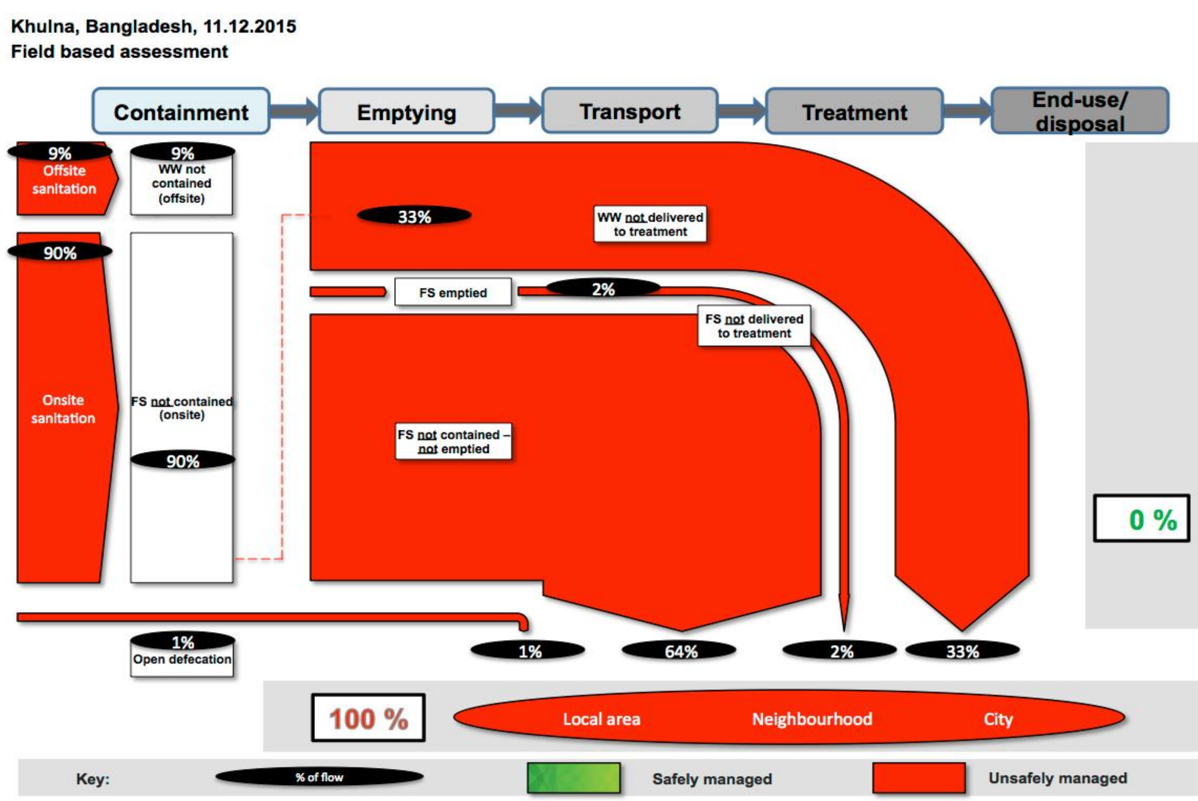


Figure 2. 5 Shit flow diagram (SFD) of Khulna city. (Source: Eawag/Sandec)

The SFD had been reported 9% of the total population being served by offsite sanitation as this 9% consists of systems without any containment structure. Excreta was either discharged to open drains (7%), water bodies (1%) or households did not know where the user interface discharges to (1%). Additionally, open defecation was practised by 1% of the population. The 9% offsite sanitation, mentioned above, together with 24% of septic tank effluent contributed to 33% of wastewater not delivered to treatment. Excreta, entering septic tanks, were defined to contribute 50% to liquid effluent and 50% to fecal sludge in the tank that could be emptied. Only 5% of the total population utilize emptying services, which resulted in 2% of fecal sludge being emptied. In Khulna, literature and interviews suggested that fecal sludge was being transported to and discharged at a trenching ground, which was located at the sanitary landfill for solid waste. However, field observations and records at the discharge location have shown contradictory results and although some sludge is delivered, it is not discharged to the trenches as designed. Therefore, it was assumed that 100% of the collected fecal sludge is not delivered for treatment. Of the total population, 64% use systems that did not contain fecal sludge and furthermore did not receive emptying services. Due to the significant risk of groundwater pollution, this percentage fully contributes to unsafely managed excreta. SNV (2014) identified the enduse of fecal sludge by some households on a very small scale. This included energy recovery through the production of biogas and recovery of nutrients through the use in agriculture.

2.4 Technologies applied to FS treatment

Many FS treatment technologies are based on those developed for wastewater and wastewater sludge treatment, but it is important to remember that these technologies cannot be directly transferred. FS characteristics differ greatly from wastewater, and have a direct impact on the efficiency of treatment mechanisms (Spellman, 1997; Kopp and Dichtl, 2001). Important properties of the sludge to consider include stabilisation, organic load, particle size and density, dissolved oxygen, temperature, pH, water content and viscosity. The current understanding of physical, biological and chemical mechanisms in FS management (FSM) is limited and has been acquired via empirical observations over the years.

2.4.1 Treatment Mechanism

2.4.1.1 Physical separation

One of the most important treatment mechanisms in FSM is dewatering. FS is mainly comprised of water, the proportion of which is dependent on the type of onsite technology. This is an important differentiation in understanding treatment mechanisms because the free water is fairly easily removed, while removal of the bound water is much more difficult (Kopp and Dichtl, 2001). Dewatering is based on physical processes such as evaporation, evapotranspiration, filtration, gravity, surface charge attraction, centrifugal force and pressure.

Gravity separation: Gravity is probably the most commonly employed method of liquid – solid separation in FSM. It can achieve the separation of suspended particles and unbound water. Particles that are heavier than water settle out under quiescent conditions at rates based on size of particles, suspended solids concentration, and flocculation.

Filtration: Filtration is also a commonly applied mechanism for liquid – solids separation in FSM. Several filtration media (e.g. membrane, granular) and types (e.g. slow, rapid, gravity driven or pressurised) are applied to water, wastewater and treated sludge (biosolids) processing. However, in FSM the most common types are unplanted and planted drying beds. The parameters that have the greatest impact on slow filtration efficiency are the characteristics of the influent, the type of filtration media, and the filter loading rate (Metcalf and Eddy, 2003)

Evaporation and evapotranspiration: Evapotranspiration is the combination of two mechanisms- evaporation and evapotranspiration. Evaporation is strongly influenced by climate, and the available heat and moisture content of air are especially important. The surface from where the evaporation is occurring can also influence the evaporation rate (e.g. free standing water versus water in sludge) (Musy and Higy, 2004).

Centrifugation: Centrifugation is employed for FS for the partial removal of bound water. Sludge is placed inside the centrifuge while it rotates at a high speed, and the centrifugal forces accelerate the sedimentation process. Solids settle out at the centrifuge walls, where they are pressed and concentrated. The liquid and solid fractions are then collected separately. Three important characteristics that were identified to be important with sludge from wastewater treatment plants are the settleability, the scrollability and the floc strength (Kopp and Dichtl, 2001).

Heat drying: Heat drying is used to evaporate and dewater wastewater sludge (biosolids) beyond what can be achieved with other more passive, or conventional methods. The amount of heat required depends on the specific heat capacity of the FS, which is the amount of energy required to raise the temperature of a unit mass by 1°C. No literature values were found for the heat capacity of FS, but the heat capacity of solids in wastewater sludge is reported to be 1.95 kJ/kg/°C (Kim and Parker, 2008).

Screening: Screening is another important physical mechanism in FSM. Bar screens at the influent of a FSTP are imperative to remove municipal waste and large solid objects from the FS, thereby preventing clogging and pump failures, and enhancing the value of treatment endproducts. The flow should also not exceed 1 m/s in order to avoid coarse wastes being pulled through the bars due to the strength of the flow (Mara, 1976).

2.4.1.2 Biological Mechanisms

Biological treatment harnesses the metabolism and growth rate of microorganisms in naturally occurring processes, and employs them in controlled situations to optimise the desired outcomes. This is important in order to reduce the oxygen demand, produce stable and predictable characteristics, reduce odors, and allow for easy storage and manipulation (Vesilind, 2001).

Aerobic treatment: Typical aerobic treatment processes in wastewater treatment include activated sludge, sequencing batch reactors, trickling filters and facultative or maturation ponds. Aerobic processes occur in any solid or liquid treatment process where oxygen is present, including FS drying beds and composting.

Composting: Composting is the controlled process by which biological decomposition of organic matter occurs by the same organisms that naturally degrade organic matter in the soil. Important mechanisms that govern this process are the oxidation of organic compounds, the release and immobilisation of nutrients, and the microbial synthesis of new compounds.

Anaerobic treatment: Anaerobic degradation occurs anywhere in FSM systems where oxygen has been depleted, for example anaerobic and facultative waste stabilisation ponds, septic tanks, and settling tanks. Anaerobic fermentation can also be employed for the treatment of sludge. Anaerobic digesters can provide a beneficial method of stabilising FS, as it also results in the production of biogas that can be used for energy generation. Biogas is a mixture of mainly methane (55-75%) and carbon dioxide (30-45%) (Arthur et al., 2011).

Nitrogen cycling: As FS tends to be very high in ammonia nitrogen, biological nitrogen cycling is an important aspect of FSM. Inorganic forms of nitrogen are available for microorganisms to use during growth. Once it is utilized, nitrogen is immobilized and no longer bioavailable as it is bound up into organic molecules such as microbial cellular components and structures. Nitrogen is then mineralized and released back into bioavailable forms as organisms die off and the organic matter is degraded. The majority of nitrogen in FS is present as ammonia that is released during this hydrolysis process.

Nitrification: Ammonia nitrogen that is released during mineralization, can be oxidized to nitrate through biological nitrification, which is an aerobic, autotrophic process. This is a sensitive biological process and it is thus important to consider total nitrogen concentration, biochemical oxygen demand (BOD) concentration, alkalinity, pH, temperature, and potential for toxic compounds when designing systems that rely on nitrification (Metcalf and Eddy, 2003).

Denitrification: Denitrification Biological nitrogen removal happens in anoxic environments with the reduction of nitrate to nitrogen gas thereby releasing nitrogen to the air. The process occurs with both heterotrophic and autotrophic bacteria, many of which are facultative aerobes. The process happens through a series of intermediate gaseous nitrogen oxide products. It is estimated that 4 g of BOD is needed per g of nitrate reduced (Metcalf and Eddy, 2003).

Phosphorus cycling: Phosphorus in FS and excreta is mostly present as phosphates. During biological treatment processes, about 10-30% of phosphorus is taken up by microorganisms. This can be increased through biological dephosphatation, or through chemical precipitation with $FeCl_3$ or $Al_2(SO_4)_3$ or $FeSO_4$ which are used for wastewater treatment. The greatest loss of phosphorus during FS treatment is due to removal by plants in planted drying beds.

2.4.1.3 Chemical Mechanisms

Chemicals can be mixed with FS to improve the performance of other physical mechanisms (e.g. addition of a cationic polymer to increase the flocculation and the settling efficiency), or to inactivate pathogens and stabilise FS. The addition of chemicals can represent a significant increase in the overall cost of treatment, and the benefits therefore need to be carefully weighed.

Alkaline stabilization: Alkaline additives, such as lime, can be used for the stabilization of FS, either pre- or post-dewatering. If quick lime (CaO) is used, it will also result in an exothermic reaction that can increase the temperature up to 60°C (Andreasen, 2001), thereby increasing pathogen reduction, and inactivating Helminth eggs.

Coagulation and flocculation: Coagulation and flocculation are achieved by adding polymers that form a bridge between particles, or by adding potential determining ions (strong acid or base) that reduce the total surface charge. Polymers can be natural or synthetic based chemicals. They work by either forming a bridge between the anionic and non-ionic ends of the polymer to particles, or by forming a bridge with high molecular weight polymers that are adsorbed to particles.

Conditioning: Chemical conditioning is based on the same physical properties as coagulation and flocculation, and can be carried out prior to physical forms of dewatering. Common additives include ferric chloride, lime, alum, and organic polymers. Iron salts and lime can increase the total solids of dried sludge (increasing bulk), whereas polymers do not increase the total solids. To select the appropriate chemical to use, important aspects to consider are sludge age, pH, source, solids concentration, and alkalinity.

Disinfection of liquid effluents: Liquid effluents from settling tanks or drying beds typically require further treatment prior to disinfection. Disinfection should be considered as a 'polishing' step to achieve a final reduction in pathogens and is not a primary form of FS treatment. Chlorination is the most widely used method of disinfection, and can be applied in either a solid or liquid form. Important design parameters include contact time, chlorine concentration, pathogen load, temperature, and other constituents in effluent (e.g. remaining organic load).

2.4.2 Major technologies for solid-liquid separation and FS treatment

In most cases, FS requires separation of solids and liquids, which will undergo further treatment in a second step. Depending on FS characteristics, output criteria and available area, a number of technologies can be used for this purpose. Solid-liquid separation may be achieved through sedimentation and thickening in ponds or tanks or through filtration and drying in sludge drying beds. The resulting solid and liquid fractions both require further treatment. Though the technologies used for solid-liquid separation, secondary treatment and co-treatment with wastewater are often the same, their design and mode of operation vary. A few technology options for the solid-liquid separation and further treatment are illustrated in Figure 2.6.

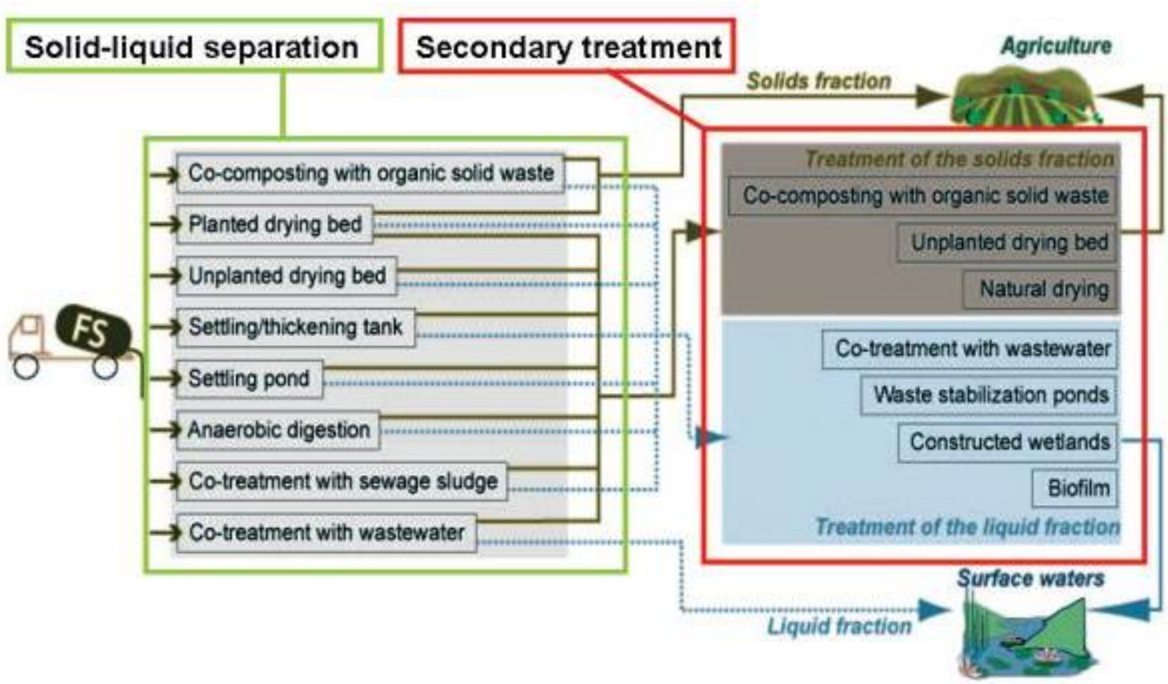


Figure 2. 6 Overview of potential, modest-cost options for fecal sludge treatment. (Source: Strauss *et al*., 2002)

2.4.2.1 Sedimentation ponds and settling tanks

Sedimentation ponds are designed similar to anaerobic ponds in waste stabilization ponds with a sufficient volume for sludge accumulation over a long period (Klingel *et al.* 2002). Sedimentation ponds can be operated in batch and continuous mode and sludge is removed only once every 8 to 12 month (Strauss & Montangenro 2002). Therefore they require generally more space than simple settling ponds. The organic load of sedimentation ponds vary from 250 to 350g BOD/m per day and the volume of accumulated sludge per incoming solids may vary between 0.8 to 2 L/kg/TS (Klingel *et al.* 2002).

Settling tanks need not only sufficient volume for sludge accumulation, but also sufficient depth of the liquid column (>1.5 m) in order to allow a fast and good settling (Klingel *et al.*, 2002). The loading /resting cycle in settling tanks is much shorter than in sedimentation ponds and sludge is removed about every 2 to 4 months (Strauss & Montangenro 2002). The tanks should be equipped with baffles to maintain hydraulic conditions favorable to good settling and to retain floating scum (Klingel *et al.* 2002).

However, the consistency and concentration of fecal sludge is highly variable depending on storage duration, tank emptying technology and pattern, performance of treatment of collection unit, added matters, temperature, intrusion of ground or surface water etc. (Strauss & Montangenro 2002) and treatment systems should be designed on a case to case basis (EAWAG/SANDEC 2008).

Whether a sedimentation pond or a settling tank is used depends on the consistency of the sludge (e.g. fresh vs. old sludge), the space available and the means of sludge removal. When only little space is available, fresh toilet sludge may be diluted with more stabilized sludge in order to be treatable in settling tanks (Klingel *et al.* 2002). It is also important to consider that the quantities of solids, which are produced and have to be removed in settling ponds, are much smaller than the mass of solid to be removed and handled from sedimentation ponds (EAWAG/SANDEC 2008). But frequent sludge removal can also become expensive for operators.

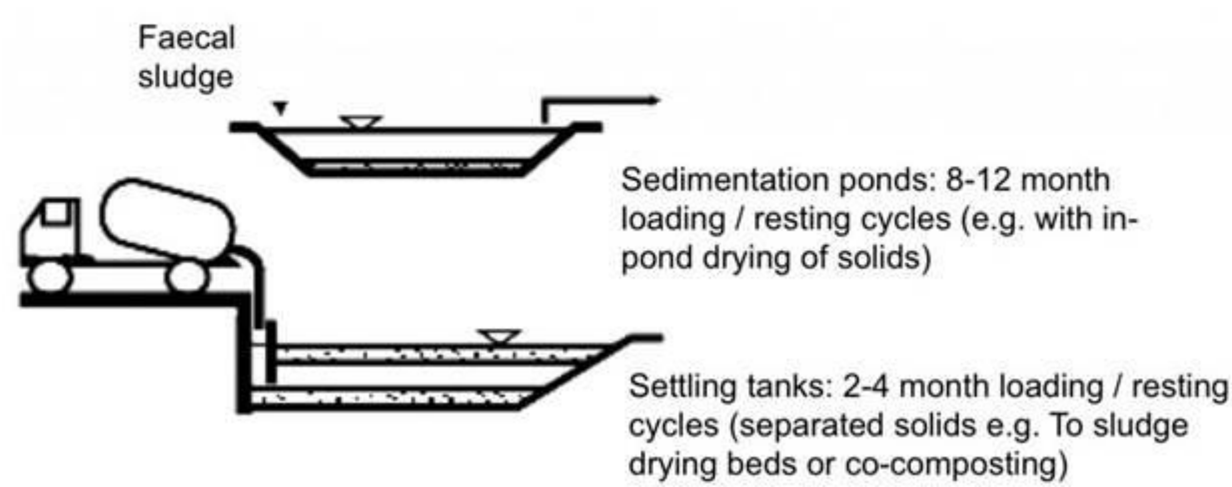


Figure 2. 7 Non-mechanised settling-thickening tanks and anaerobic/sedimentation ponds for solid-liquid separation (schematic). (Source: Strauss & Montangenro, 2002)

2.4.2.2 Unplanted sludge drying beds

An unplanted sludge drying bed is a simple, permeable bed filled with several drainage layers that, when loaded with sludge, collects percolated leachate and allow the sludge to dry by percolation and evaporation. The percolate still contains pathogens and needs to be collected for treatment or controlled reuse. Drying beds are relatively easy to construct and simple to maintain, although large surface areas and man or mechanical power is required for regular desludging.

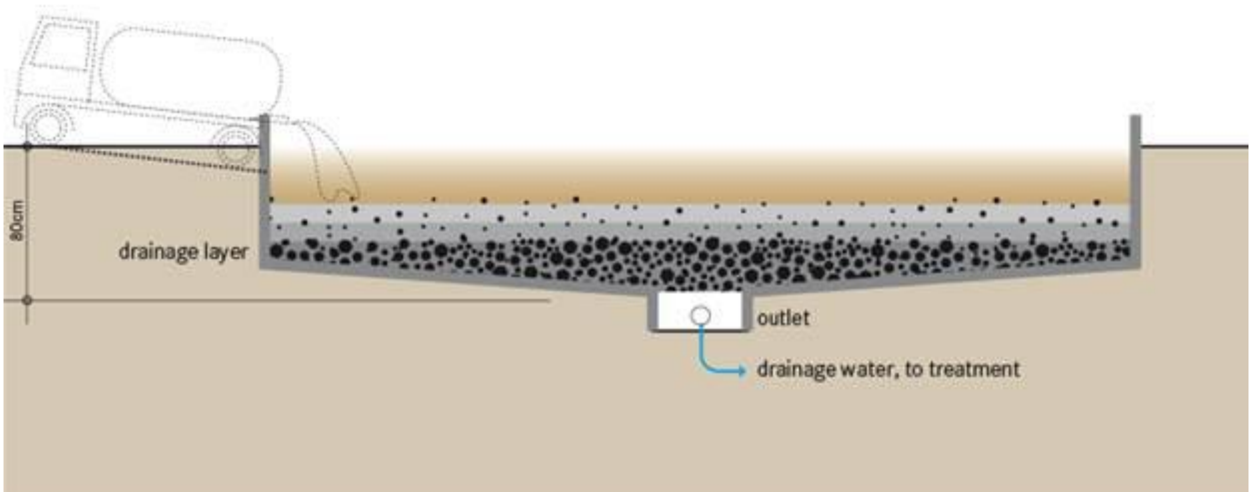


Figure 2. 8 Schematic of an unplanted sludge drying bed. (Source: Tilley *et al.*, 2014)

The bottom of drying bed is lined with perforated pipes to drain the leachate away that percolates through the bed, on top of the pipes are layers of gravel and sand that support the sludge and allow the liquid to infiltrate and collect in the pipe. The bottom layer should be coarse gravel and the top fine sand (0.1 to 0.5 mm effective grain size). The top sand layer should be 250 to 300 mm thick because some sand will be lost each time the sludge is removed (Strauss and Montangenro 2004; Tilley *et al.*, 2008). Indication about the diameter of the medium and the height of the different gravel and sand layers vary depending on the source (Sasse and BORDA, 1998; Strauss and Montangenro, 2004). The sludge is applied in a batch mode about once per week intervals in layers of no more than 20 to 30 cm. On an annual basis, about 100 to 200 kg TS/m^2 can be applied on a drying bed. Drying takes 10 to 20 days. Land requirements are 0.05 m2 per capita for a 10 days cycle (Strauss & Montangero, 2002). Before fresh sludge is applied, dried sludge needs to be desludged and brought to a composting site, what makes it a rather laborious treatment option. To improve drying and percolation, sludge application can alternate between two or more beds. About 50 to 80 % of the initial volume is removed by percolation (Strauss & Montangero, 2002), resulting in total solid (TS) content of 20 to 70, % (Strauss & Montangero 2004) depending on the local weather conditions and climate. The inlet should be equipped with a splash plate to prevent erosion of the sand layer and to allow for even distribution of the sludge.

2.4.2.3 Planted sludge drying beds

A planted drying bed is similar to an unplanted drying bed, but has the added benefit of transpiration and enhanced sludge treatment due to the plants. Planted Drying beds are one of the simplest and oldest techniques for sludge dewatering (SANIMAS 2005). This technology has the benefit of dewatering and stabilizing the sludge.

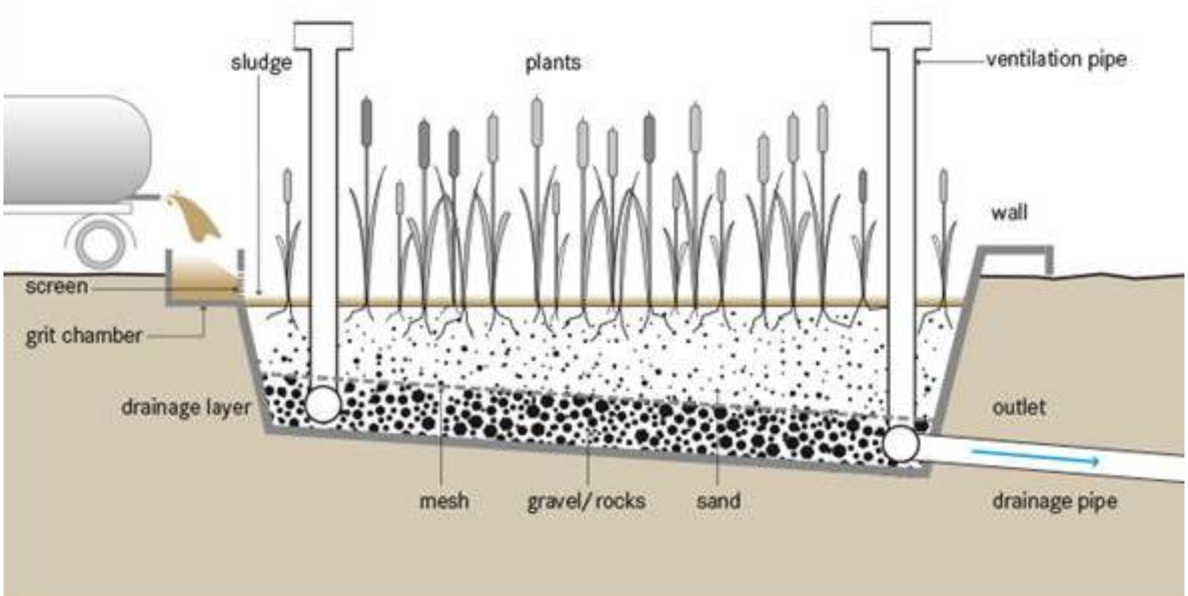


Figure 2. 9 Schematic of a planted sludge drying bed. (Source: Tilley *et al.*, 2014)

When plants are present, evaporation is enhanced by transpiration (evapotranspiration) and sludge can be applied more frequently. Also, the roots of the plants create pathways through the thickening sludge that allow water to easily escape. A general design for layering the bed is: (1) 250 mm of coarse gravel (grain diameter of 20 mm); (2) 250 mm of fine gravel (grain diameter of 5 mm); and (3) 100 to 150 mm of sand (EAWAG/SANDEC, 2008). Free space (1 m) should be left above the top of the sand layer to account for about 3 to 5 years of accumulation. If there is enough space for sludge accumulation, desludging is only required every 5-10 years. *Sludge* should be applied in layers between 75 to 100 mm thick and reapplied every 3 to 7 days, depending on the sludge characteristics, the environment and operating constraints. Unlike unplanted beds, planted beds do not need desludging before each new application as the root system of the plants maintains the permeability. Sludge application rates of 100 to 250 kg/m^2/year have been reported in warm tropical climates. In colder climates, such as northern Europe, rates up to 80 kg/m^2/year are typical. Once the sludge is removed it is well mineralised and has a soil-like structure with a TS content of 40 to 70 % (Strauss & Montangero, 2002). Dried sludge from planted drying beds (if there was no fresh application of sludge during the past 1 to 2 years) is generally free from pathogens and can be used directly in reuse in agriculture (Strauss *et al*., 1997).

2.4.2.4 (Non-aerated) waste stabilization ponds (WSPs)

Waste stabilization ponds are large man-made basins in which greywater, blackwater or fecal sludge can be treated to an effluent of relatively high quality and apt for the reuse in agriculture (e.g. irrigation) or aquaculture. WSP system suitable to treat low to medium-strength fecal sludges. It comprises pretreatment units (tanks or ponds) for solid-liquid separation followed by a series of one or more anaerobic ponds and one facultative pond. This allows the production of a liquid effluent apt for discharge into surface waters. Effluent use in agriculture is not possible due to its high salinity. However, biosolids generated during pretreatment and in the anaerobic ponds constitute a valuable resource easily treated to satisfy safe hygienic standards (Strauss *et al*., 2002).

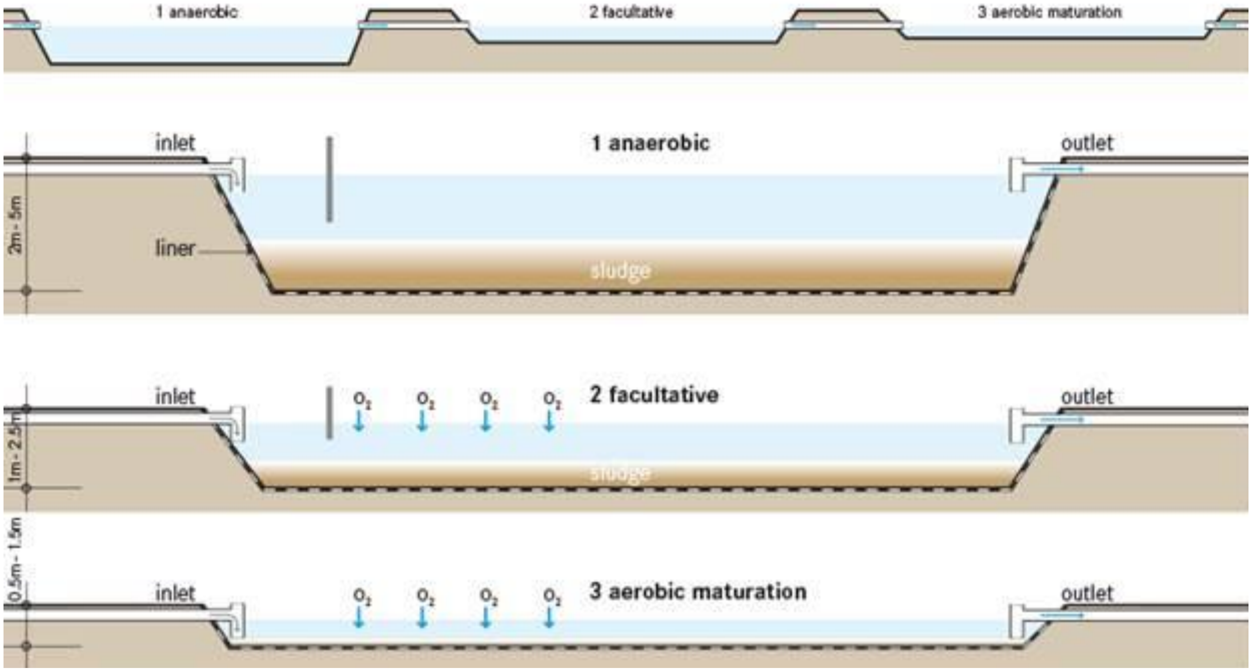


Figure 2. 10 Typical scheme of a waste stabilisation system: An anaerobic, facultative and maturation pond in series. (Source: Tilley *et al*., 2014)

Anaerobic ponds are built to a depth of 2 to 5 m and have a relatively short detention time of 1 to 7 days. The main function of anaerobic ponds is BOD removal, which can be reduced 40 to 85 % (WSP, 2007). BOD removal in anaerobic ponds is governed by the same mechanisms that occur in all other anaerobic reactors (Mara *et al.,* 1992) and anaerobic ponds do not or only rarely contain algae. Facultative Treatment Ponds are the simplest of all WSPs and consist of an aerobic zone close to the surface and a deeper, anaerobic zone. They are designed for BOD removal and can treat water in the BOD range of 100 to 400 kg/ha/day corresponding to 10 to 40 g/m^2/day at temperatures above 20°C (Mara and Pearson, 1998). FPs can result in the removal of 80 to 95% of the BOD_5 (WSP 2007), which means an overall removal of 95% over the two ponds (AP and FP). Total nitrogen removal in WSP systems can reach 80% or more, and ammonia removal can be as high as 95%. It should be constructed to a depth of 1 to 2.5 m and have a detention time between 5 to 30 days. Whereas anaerobic and facultative ponds are designed for BOD removal, maturation or polishing ponds are essentially designed for pathogen removal and retaining suspended stabilised solids (Mara *et al*., 1992; Sasse, 1998; Tilley *et al.* 2008). The size and number of maturation ponds depends on the required bacteriological quality of the final effluent. Aerobic ponds are usually between 0.5 to 1.5 m deep with a detention time of 15 to 20 days. Almost all wastewaters (including heavily loaded industrial wastewater) can be treated, but as higher the organic load, as higher the required surface. In the case of high salt content, the use of the water for irrigation is not recommended.

2.4.2.5 Composting with organic solid waste ("co-composting")

Co-composting is practiced worldwide, generally in small, informal and uncontrolled schemes or on a yard scale. The process occurs most likely at ambient temperatures with concomitant inefficient inactivation of pathogens. In contrast, thermophilic composting, i.e. composting at 50–60 °C, is an effective process, which destroys pathogens, stabilises organic material and creates a valuable soil conditioner-cum-fertiliser (Strauss *et al.*, 2002). Co-composting of FS and municipal solid waste is a most appropriate process, since the two materials complement each other. Human waste is relatively high in N content and moisture, whereas municipal solid waste has a relatively high organic carbon (OC) content with good bulking qualities (Strauss *et al.*, 2003). The technologies chosen for aerobic composting (or co-composting) will depend on the location of the facility, available capital, including amount and type of waste delivered to the site. Strauss et al. (2003) distinguish two main types of co-composting systems:

Open systems:

Windrow, heap or pile composting

The material is piled up in heaps or elongated heaps (so-called windrows). The size of the heaps ensures sufficient heat generation. Aeration is guaranteed by the addition of bulky materials, regular turning and passive or active ventilation.

Bin composting

Compared to windrow systems, bin systems are contained by a constructed structure on three or all four sides of the pile. The advantage of this containment is a more efficient use of space.

Trench and pit composting

Trench and pit systems are characterised by heaps partly or fully contained under the soil surface. Structuring the heap with bulky material or turning is usually the best aeration choice, though turning can be cumbersome if the heap is in a deep pit.

Closed "in-vessel" systems:

In-vessel or "reactors" systems can be static or movable, closed structures, where aeration and moisture are controlled by mechanical means and often require external energy. Such systems are usually cost-intensive and also more expensive to operate and maintain.

Fecal sludges can be co-composted with any biodegradable organic material if the process control composting rules are adhered to. Mixing ratios reported in the literature vary widely, depending on the type of organic bulking material co-composted with fecal matter, consistency of the FS itself, dewatering degree prior to composting, and attention paid to co-composting practice and operation. Reported mixing ratios of dewatered FS (TS = 20–30 %) and other, more bulky organic material tend to range from 1:2 to 1:4. For fresh, non-dewatered FS, ratios used and reported tend to range from 1:5 to 1:10 (Strauss *et al.* 2003)

2.4.2.6 Anaerobic digestion with biogas use

This option may theoretically be perfectly suited to treat higher-strength FS not yet subjected to substantial degradation. Such sludge may comprise the contents of unsewered public toilets whose vault contents are emptied at relatively high frequencies of a few weeks. Two types of digesters, viz. fixed and floating dome units are available in practice (Strauss *et al*., 2002).

Where urine is mixed with faeces, the C:N ratio of the FS is too low to generate maximum gas yields, however, the option may prove technically and economically feasible under specific local conditions. The only municipal biogas systems known to the authors and operated exclusively with FS, are those fed by public pour-flush toilets run by Sulabh, an Indian NGO. Some 100 such plants are currently in operation. The National Environmental Engineering Research Institute (NEERI, India) conducted applied research on FS-fed biogas plants in the sixties and seventies. In many developing countries, biogas plants processing FS mixed with cattle dung are generally operated as small, decentralized schemes serving one or several households or institutions (Strauss *et al*., 2002).

2.5 Legal aspects of FSM

2.5.1 Overview of existing rules and regulations

Clause 41 of the Local Government (City Corporation) Act 2009, hereinafter referred to as City Corporation Act 2009, mentions the responsibilities and functions of a City Corporation and refers to Schedule 3 for the details of its functions.

Schedule 3 of the City Corporation Act 2009, in its Sub-clause 1.4 under Clause 1, clearly mentions that "The City Corporation shall make adequate arrangements for the collection and removal of refuse from all public streets, public latrines, urinals, drains, and all buildings and land within the jurisdiction of the city corporation".

Sub-clause 1.8 of Schedule 3 of the Act states that "the City Corporation shall provide and maintain, in sufficient number and in proper condition, public latrines and urinals separately for both male and female users, and shall make arrangements for proper maintenance of these facilities and keep them clean".

Sub-clause 1.9 of Schedule 3 states that "the individual owners of households having latrines and urinals shall keep them in proper condition and to the satisfaction of the city corporation".

Sub-clause 1.10 of Schedule 3 of the Act further states that "the City Corporation shall serve notice to the owners of households having no latrine or urinal, or having inadequate arrangements, or having latrines and urinals at improper places, to (a) make necessary arrangements for latrines and urinals, (b) change/ improve latrines and urinals, (c) remove latrines and urinals where necessary, and (d) connect appropriately cleanable latrines and urinals to sub-surface sewer network where available".

While the term "fecal sludge" is not specifically mentioned in the City Corporation Act 2009 (primarily because this term was not widely used at that time), it is clear that the primary responsibility of management of "fecal sludge" (referred to in the Act as "refuse" accumulated in "public toilets, urinals, drains and all buildings and land") lies with the City Corporation. It is also clear that the City Corporation shall perform these responsibilities in accordance with the provisions of the City Corporation Act 2009. However, for proper management of fecal sludge, if the City Corporation deems it necessary, it could formulate necessary "rules", "regulations" and "by-laws" according to the provisions (Clauses 120, 121 and 122 of this Act) described in Schedule 6, Schedule 7, and Schedule 8, respectively.

For example, according to Schedule 7 of the City Corporation Act 2009, "regulations" could be formulated, among others, "for the purpose of health system monitoring, inspection of lands and households; cleaning and disposal of waste by house owner; installation of private toilets and urinals, maintenance and inspection; responsibility of the public regarding health system, and providing license to the sweeper".

The Water Supply and Sewerage Authority Act 1996, hereinafter referred to as WASA Act 1996, in its sub-clause (2) of clause 17 clearly describes the major responsibilities vested on the Authority: (a) construction, development and maintenance of water supply system for abstraction/collection, treatment, pumping, storage and distribution of potable drinking water;(b) construction, development and maintenance of sewerage system for collection, pumping, treatment and disposal of sanitary sewage and industrial liquid waste; (c) closing or abandoning of the drains that are, in the opinion of the Authority, not necessary or are dysfunctional;(d) construction and maintenance of storm water drainage system.

The WASA Act 1996 does not specifically mention about responsibility of the Authority with regard to on-site sanitation system or any activity related to emptying of pits and septic tanks, collection, transportation, treatment and disposal and/ or reuse of fecal sludge from on-site facilities.

2.5.2 Institutional roles and responsibilities

2.5.2.1 Overall responsibility of fecal sludge management (FSM)

1. In accordance to the provisions of the City Corporation Act 2009, the "City Corporation" shall be responsible for fecal sludge management (FSM) in areas within its jurisdiction, including planning for and implementation of FSM services (including financial/business model for service delivery). The City Corporation may collaborate with the Water Supply and Sewerage Authority (WASA) where appropriate, the Department of Public Health Engineering (DPHE), the Local Government Engineering Department (LGED), the private sector, the I/NGOs in planning and implementation of FSM infrastructure and services in accordance with the provisions of the Act. The institutional set up for FSM in City Corporation is outlined in Figure 2.11.

2. The City Corporation shall take steps to include within its "master plan" (prepared or being prepared in accordance with the provision of Schedule 3 of the City Corporation Act 2009) the provisions of the infrastructure (i.e., treatment facility) for implementation of FSM services.

3. The City Corporation shall from a Standing Committee on "Fecal Sludge Management" in accordance to Sub-clause (2) of Clause 50 of the City Corporation Act 2009. This Standing Committee shall oversee the activities related to planning and implementation of FSM services. Depending on need and availability, the Committee would co-opt a sanitation/ FSM expert in the Committee (in accordance with Sub-clause (9) of Clause 50 of the City Corporation Act 2009)

4. The City Corporation shall initiate inclusive FSM planning and implementation modality among the government agencies, I/NGOs, community groups and the private sector.

2.5.2.2 Proper design and construction of sanitation facilities

New construction

1. While approving design of buildings, the relevant designated authority (i.e., City Corporation or City Development Authorities, such as CDA, RDA, KDA) shall check the design of the sanitation facilities (e.g., septic tank), as well as its location/layout (to make sure that it is accessible for mechanical desludging). The provisions of Bangladesh National Building Code shall be followed for checking design of septic tank system (i.e., septic tank and soakage pit).

2. The provisions of Bangladesh National Building Code shall be followed for checking design of septic tank system (i.e., septic tank and soakage pit). For pit latrines, where conditions (e.g., availability of adequate land) permit, the City Corporation shall promote use of twin off-set pit pour-flush toilets since this technology (if properly designed, constructed and maintained) provides a long-term solution to the fecal sludge management problem.

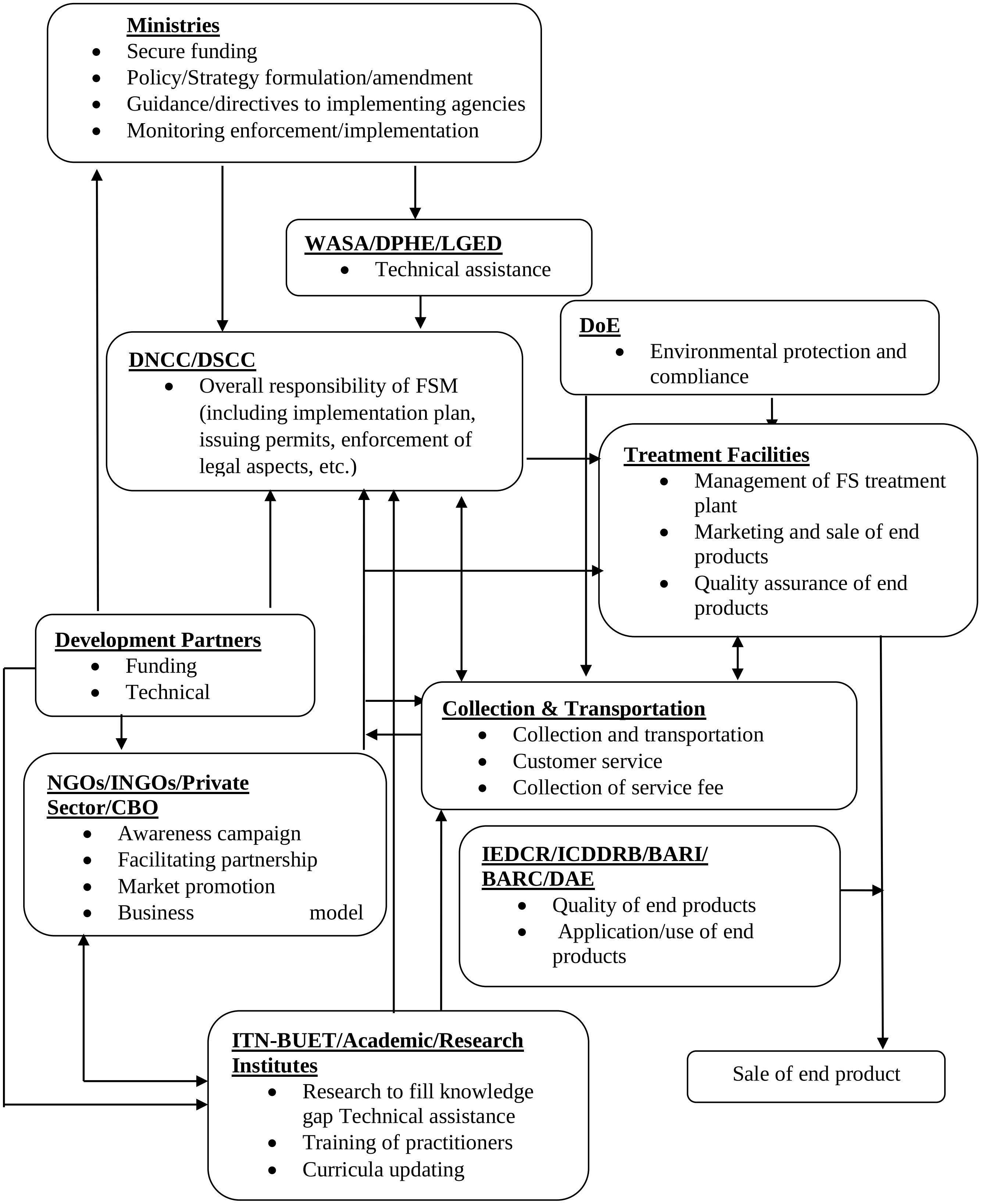


Figure 2. 11 Institutional set up for fecal sludge management (FSM) in City Corporations.

(Source: Institutional and regulatory framework for FSM, City Corporation, 2017)

3. The City Corporation/LGD (Local Government Division) shall formulate necessary rules/regulations/by-laws for ensuring the activities (1) above.

4. The City Corporation may engage private sector/non-government sector in carrying out activity (1) above (i.e., checking design, layout of sanitation facilities).

Existing/completed buildings

5. The City Corporation shall check that the sanitation facilities have been sited and constructed according to the approved design during construction/reconstruction of buildings. In case of non-compliance, the City Corporation shall instruct the owner to reconstruct the sanitation facilities following the approved design.

6. The City Corporation shall serve notice to owners of premises where there is no sanitation facility, or inadequate sanitation facility, or sanitation facility in inappropriate locations to arrange proper sanitation facilities or remove inappropriate sanitation facilities.

7. The City Corporation may engage private sector/non-government sector in carrying out inspection of existing/ completed buildings for assessment of sanitation facilities.

2.5.2.3 Disposal of sewage/wastewater/garbage

1. The City Corporation shall carry out inspection and make sure that domestic sewage/ wastewater, and discharge from house-drain are not connected to storm sewer/drain or irrigation canal, and that "refuse" (which include fecal sludge) is not thrown/disposed or stored on street or open place (not designated for disposal of "refuse"); these activities are treated as punishable offence according to the provisions the City Corporation Act 2009.

2. In accordance to the provisions of the City Corporation Act 2009, the City Corporation shall ask owners of buildings/premises that are in such violation to discharge domestic sewage/ wastewater into a septic tank system (consisting of adequately designed septic tank and soakage pit); the effluent from adequately designed septic tank system (i.e., overflow, if any) may be discharged into storm drains/sewers. Until treatment facility for fecal sludge are built, fecal sludge (e.g., those desludged from onsite sanitation facilities) shall be disposed in a land/area designated by the City Corporation by digging pits/trenches in a ground, and covering the pits/trenches with soil after it is filled with sludge.

3. The City Corporation may engage the private sector/non-government sector (e.g., outsourcing) in carrying out inspection/survey for identifying illegal practices of sewage/ wastewater/ “refuse” disposal, as service procurement.

4. The LGD/ City Corporation shall work with the Ministry of Railways and the Ministry of Shipping to device appropriate plans/programs to make sure that fecal matters/sludge from trains and water vessels are not discharged directly into the environment.

2.5.2.4 Fecal sludge collection and transport

1. The City Corporation shall be responsible for proper execution of the entire FSM service chain, including collection (emptying) and transportation. The City Corporation shall carry out and/or oversee the collection (emptying) and transportation, making sure that these operations are carried out in a hygienic manner without adversely affecting health and safety of emptiers, the public and the environment.

2. The pit emptying service shall include “transportation of the collected fecal sludge to the designated site for treatment and disposal”. The City Corporation shall make sure that the collected fecal sludge is transported to the designated site(s) for treatment and disposal, and that the collected fecal sludge is never disposed in open space or water bodies or storm drains or sewers (which is a punishable offence according to the City Corporation Act 2009).

3. The City Corporation may engage the private sector/non-government sector (e.g., outsourcing) for collection and transportation of fecal sludge from onsite sanitation facilities, as service procurement.

4. The City Corporation shall introduce and promote mechanical pit emptying (desludging) services for ensuring health and safety of emptiers and protection of the public health and environment. The City Corporation shall make sure that the manual emptier (traditional pit emptier/cleaner) communities are integrated into the modern FSM services through proper training and support, without adversely affecting their income.

5. The process of pit emptying involves significant hazard, and the City Corporation shall follow/enforce appropriate health and safety guidelines for emptying services. Until such a

health and safety guideline is prepared and approved (by the LGD), the City Corporation shall follow available similar guidelines being practiced/promoted elsewhere.

6. In accordance with Clause 82 and Schedule 4 of the City Corporation Act 2009, the City Corporation may fix fees/charges for collection and transportation of fecal sludge from sanitation facilities. If fecal sludge treatment facilities are operational in the City Corporation area and the collected fecal sludge is transported to such facilities for treatment, the City Corporation may consider the entire service chain (i.e., from collection to treatment) while fixing such fees/charges.

7. In order to ensure proper and timely emptying of onsite sanitation facilities, the City Corporation shall gradually develop a database of all sanitation facilities within areas of its jurisdiction, along with probable emptying frequency of these facilities. Once the entire FSM service chain (i.e., from collection to treatment/disposal) is in place, this database would be used for efficient and timely emptying of all on-site sanitation facilities. The City Corporation shall also develop a database of households/ institutions availing the FSM (e.g., emptying) services.

2.5.2.5 Fecal sludge treatment, disposal and end-use

1. The City Corporation shall be responsible for proper execution of the entire FSM service chain, including fecal sludge treatment, disposal and end-use. The City Corporation shall carry out and/or oversee these operations, making sure that these are carried out in compliance with existing rules and regulations (e.g., with regard to disposal of liquid effluent, and quality of end products such as compost), and without adversely affecting public health and the environment.

2. Until treatment facility for fecal sludge are built, fecal sludge (e.g., those desludged from onsite sanitation facilities) shall be disposed in a land/area designated by the City Corporation by digging pits/trenches in the ground, and covering the pits/trenches with soil after it is filled with sludge.

3. The City Corporation may collaborate with WASA where appropriate, the Department of Public Health Engineering (DPHE) and the Local Government Engineering Department (LGED) in development and O&M of fecal sludge treatment facilities.

4. The City Corporation may engage the private sector/non-government sector (e.g., outsourcing) for treatment and disposal of fecal sludge, and use/marketing of endproducts. The City Corporation/LGD may formulate regulations as per Clause 121 of the City Corporation Act 2009 for engaging private sector/NGOs (Non-Government Organization)/INGOs (International and National NGO)/CBOs (Community Based Organization) for activities under the section which is mentioned in institutional and regulatory framework for FSM (IRF for FSM -City corporations, 2017).

5. The City Corporation may fix fees/charges for treatment of fecal sludge separately, or together with the collection and transportation fees/charges as outlined in Article (6) of Section 2.5.2.4 of institutional and regulatory framework for FSM.

6. The City Corporation shall seek assistance of the Department of Environment (DoE), and the Institute of Epidemiology, Disease and Research (IEDCR) (or any competent/accredited national/international institution) in fulfilling compliance with the existing rules and regulations with regard to installation and operation of fecal sludge treatment facilities.

7. The City Corporation shall seek assistance of the Department of Agriculture Extension (DAE) under the Ministry of Agriculture with regard to simplifying the procedure for securing license for using/marketing of compost/organic fertilizer produced (if any) at fecal sludge treatment facilities.

8. The City Corporation shall work with the Ministry of Agriculture to ensure safe use of treatment end products (compost/organic fertilizer) in agriculture, landscaping and other purposes.

2.5.3 “Environmental Police” for field compliance

1. The Ministry of Environment and Forest (MoEF) through the Department of Environment (DoE) shall ensure that all relevant environmental laws, regulations and principles are strictly followed by all concerned throughout the FSM service chain.

2. The MoLGRDC (Ministry of Local Government Rural Development and Co-operatives) and MoEF, in consultation with all stakeholders shall initiate development of standards/ guidelines for enduse or disposal of treated sludge.

3. The MoLGRDC in consultation with MoEF, MoHA (Ministry of Home Affairs), Ministry of Law, Justice and Parliamentary Affairs, and other concerned stakeholders shall take initiative to make a legal provision to develop well-trained, skilled contingents of environmental force styled as "Environmental Police" for ensuring field compliance of laws, regulations, safety standards and policy guidelines with provisions of instant penalties to be decided by the ministries concerned.

2.5.4 Capacity building, training and research

1. The institutions participating in capacity building would provide support to fill the knowledge gaps, technical assistance, training, quality assurance of processes and products (e.g., compost) in the FSM service chain.

2. The Ministry of LGRD&C would take steps for setting up Unit/Division for FSM in the City Corporation organogram, for effective delivery of FSM services.

3. The relevant Ministries and line organizations, research and training institutions, development partners, and I/NGOs would provide support to develop/enhance skills of personnel of City Corporations and other stakeholders, and to fill the knowledge gaps with regard to FSM.

4. National level research and training organizations (e.g., ITN-BUET, technical and agricultural universities/institutes/centers) would collaborate with relevant international research/ training organizations/institutions/universities, I/NGOs and the private sector in capacity building, training and research on FSM. The Ministries of the GoB (Government of Bangladesh) and the development partners shall support such initiatives.

5. The LGD of the MoLGRDC shall coordinate, and develop guidelines for capacity building, research and training initiatives on FSM, and facilitate sharing and dissemination of knowledge/ information on FSM among City Corporations.

2.5.5 Awareness building

1. The institutions participating in awareness building will support awareness campaign, promote private sector participation, and demonstration of FSM business. The relevant Ministries and line organizations would support awareness building campaigns on FSM.

2. Local, national and international NGOs/CBOs, with support from the Government Ministries, research organizations and development partners shall play the key role in raising public awareness on FSM and facilitating partnership among key stakeholders including the private sector.

3. The civil society organizations would also work with I/NGOs and research organizations (for support on technical issues) in sensitizing the public on FSM through use of print, electronic and social & mass media.

2.5.6 Technical assistance and funding support

1. The GoB will increase funding support and provide other assistance (e.g., securing land for construction of treatment facility) for development of FSM infrastructure in the City Corporations.

2. Development partners, multilateral or bilateral, may provide technical assistance and funding support to the City Corporations for establishing FSM services through the MoLGRD&C.

3. The MoLGRDC through its line organizations (DPHE, LGED, WASA) would provide technical and other relevant support directly or on project-basis in planning and implementation of FSM service infrastructure (e.g., fecal sludge treatment plant).

4. The LGD shall take initiative to develop standards/guidelines for emptying, transportation, and treatment of fecal sludge; operation and maintenance (O&M) of fecal sludge treatment plant; disposal of effluent from fecal sludge treatment facilities, quality control/ standardization of treated products/by-products; and protocol for securing license for using/marketing of compost/ organic fertilizer produced (if any) at fecal sludge treatment facilities.

CHAPTER 3

METHODOLOGY

CHAPTER 3
METHODOLOGY

3.1 Research strategy

This chapter presents the research method that has been employed in this study to accomplish the research objectives as reported in section 1.2. The chronological activities of this study are delineated as below:

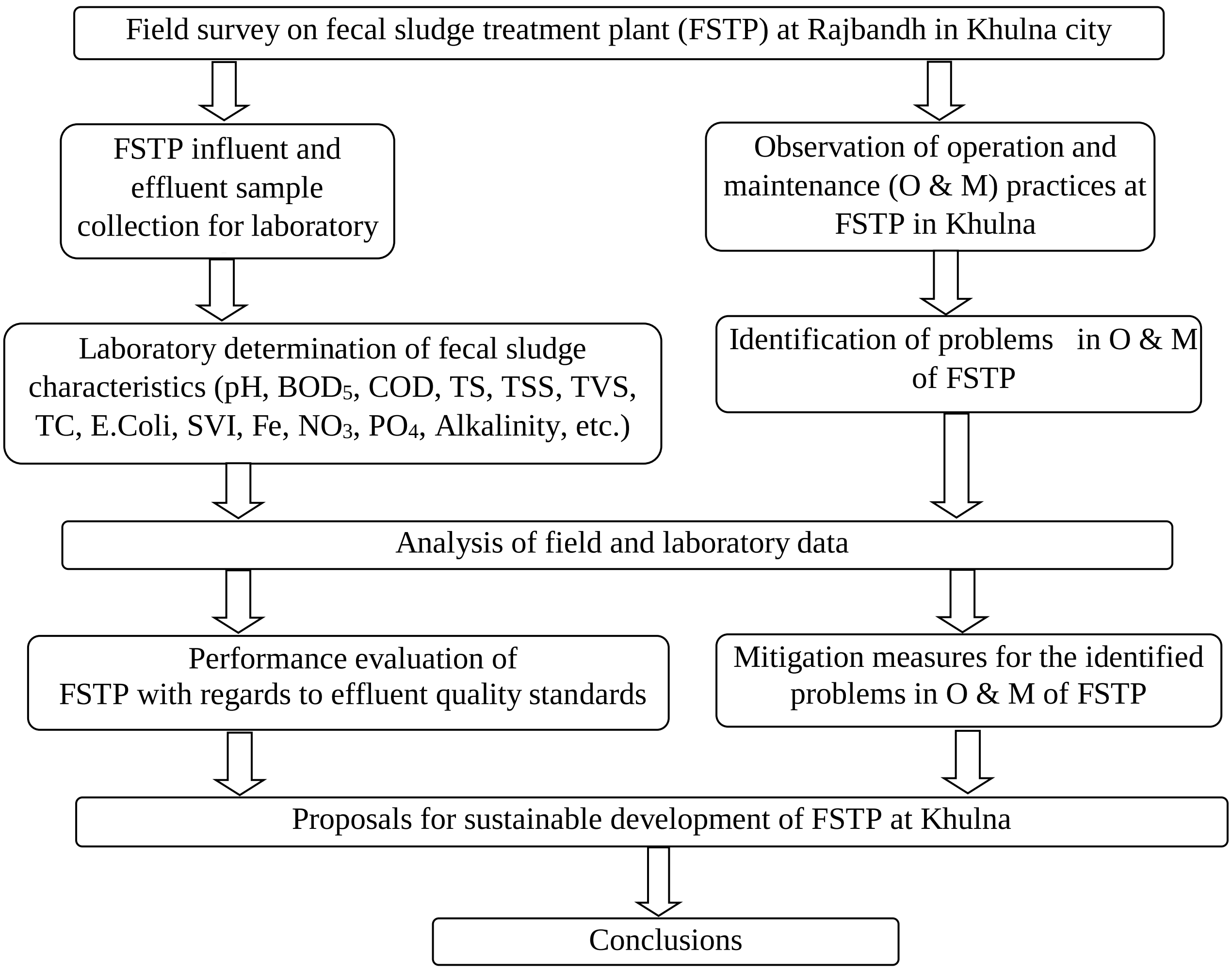


Figure 3. 1 Flowchart showing the sequential steps in the research work.

A detailed field inspection was made since its construction phase to identify its operational capability and detect its treatment performance. Firstly, field survey was observed through the beginning of Khulna FSTP as it was passive land fill site earlier. The influent and effluent have been collected during its functional period. Simultaneously the operation and maintenance (O & M) practices was investigated. There were samples of effluent- after primary treatment. The samples of effluent have been collected from CW (1-6) after primary and final treatment taken to laboratory for analysis its characteristics. A comparative analysis was brought out by compiling all the test results along with inspecting the permissible limits of final effluent. The detected flaws of FSTP were mitigated through taking applicable technical measures. Finally, a proposal for sustainable development of Khulna FSTP was recommended considering its performance and operation and maintenance practices.

3.1.1 Field survey on Khulna FSTP

Khulna FSTP was not built as a regular civil infrastructure as it was previously a passive landfill site. There were some potential risks so compacted soil embankment is expected to hold the CW ponding settlement, combustible gas migration and generation. An intensive field study has been carried out from the beginning of its construction. For performance evaluation influent and effluent samples have been collected from Khulna FSTP. Field monitoring was a continuous process to observe operation and maintenance. Data and information were gathered through questionnaire survey, field investigation and personal contact with plant caretaker. The questionnaire was designed to collect information based on the operation at several steps and inspection of every part of FSTP so as to maintenance could be made easier through gathering those knowledge.

3.1.2 Collection of samples and preparation for laboratory analysis

For evaluation of effluent percolate from vertical flow CW (1-6) and final treated effluent was selected and denoted as **Sample1** and **Sample 2** (Figure 3.2).

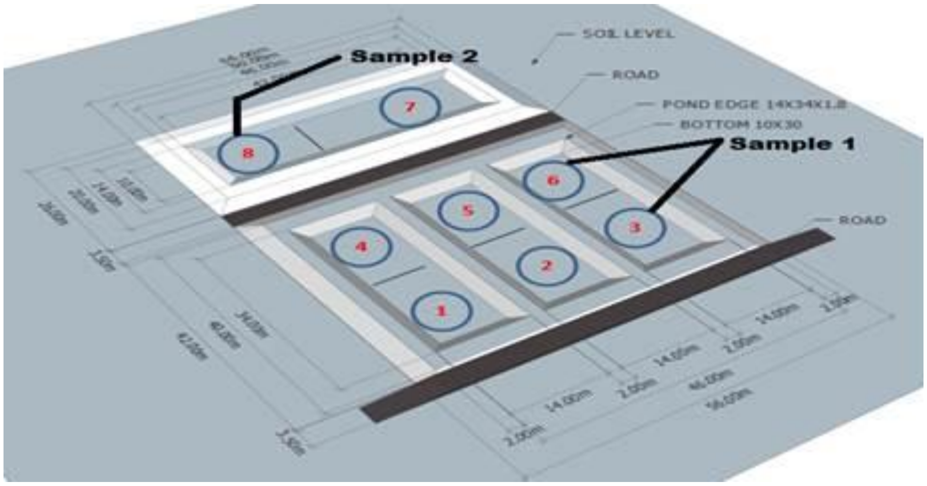


Figure 3. 2 Collection of sample 1 from VF wetlands (1 to 6) and sample 2 from final receiving tank.

Clean plastic water bottles were used to collect percolate effluent from receiving tank after primary treatment and final treatment (Figure 3.3). The sample containers have been immediately closed to prevent volatilization or contamination. The bottles were labelled at that time according to its collection point. Then took samples to the laboratory within couple of hours from the time of collection. Three sets of samples were collected in dry and wet seasons separately.

Figure 3. 3 Collection of samples from Khulna FSTP.

3.1.3 Methods of analysis

There are a number of tests parameters for FS standards mentioned in the Table 3.1. In this study, selected water quality parameters have been tested at the Environmental Engineering Laboratory in KUET. All the laboratory tests have been conducted as per standard methods (APHA, 2012). The tested water quality parameters included various types of physical, chemical and bacteriological characteristics. The tested water quality parameters along with respective standard methodologies information have been shown in Table 3.1.

Table 3. 1 Laboratory Analysis of Water Quality Parameters for Fecal Sludge Characteristics

Type of test	Water quality parameter	* Standard Methods (SM) for Water Quality Analysis
Physical test	Temperature	SM 2550 B
	Sludge Volume Index (SVI)	SM 2710 D
	Total Solids (TS)	SM 2540 B
	Total Suspended Solids (TSS)	SM 2540 D
	Total Volatile Solids (TVS)	SM 2540 E
Chemical test	pH	SM 4500-H^+ B
	Biochemical Oxygen Demand (BOD_5)	SM 5210 B
	Chemical Oxygen Demand (COD)	SM 5220 C
	Iron (Fe)	SM 3500-Fe B
	Nitrate (NO_3)	SM 4500-NO_3^- E
	Phosphate (PO_4)	SM 4500-P E
	Electrical Conductivity (EC)	SM 2510 B
	Total Alkalinity (as $CaCO_3$)	SM 2320 B
Bacteriological test	Total Coliform (TC)	SM 9222 B
	Escherichia Coli (E. Coli)	SM 9222 D
*Standard Methods for the Examination of Water and Wastewater (APHA-AWWA-WEF)		

3.1.4 Laboratory analytical methods

The value of pH, temperature and electrical conductivity (EC) were measured by portable multiparameter (sension156, HACH Co., USA). The concentration of nutrients including Fe, NO_3 and PO_4 were determined by spectrophotometer (DR 2700, HACH Co., USA). The diluted samples were kept refrigerated in incubator (FTC 90E, VELP SCIENTIFICA) at 20°C for five days to observe the depletion of dissolved oxygen by HQ 40D portable multimeter (HACH Co., USA) so as to measuring BOD_5. Analysis of Chemical Oxygen Demand (COD) for collected water samples were carried out by closed reflux method and COD reactor block (DRB200, HACH Co., USA). Analyses of solids concentration of raw and treated sludge for various parameters such as: total solids (TS), total suspended solids (TSS), total volatile solids (TVS) were conducted in accordance with the 22^{nd} edition of Standard Methods for the Examination of Water and Wastewater. Microbial parameters includes Total Coliform (TC) and Escherichia Coli (E. Coli) were determined by membrane filter technique. For incubation at 35ºC±0.5°C for 22 to 24 hours the dishes were kept in incubator (MINI/30/DD, Genlab Limited, UK).

3.2 Details of Khulna FSTP

3.2.1 Plot of establishment of FSTP

Most of the cities in Bangladesh have no designated dumping sites or treatment facilities for fecal sludge despite acute sanitation challenges owing to high population density, rapid and unplanned growth (Islam, 2012). Khulna is one of the most climate vulnerable cities in the world having a population around 1.5 million has no sewer network (Haque, 2014, KCC 2015). In Khulna there is no sewerage network. Therefore, most of the toilets are onsite facilities, like pit latrines or septic tanks. Toilets with septic tanks are much higher. 68.4 percent toilets have septic tanks and the remaining 31.6 per cent toilets are with pit. Particularly in Khulna, only 2% households empty their pits or septic tanks mechanically and only a U trench was used to dispose collected sludge (Figure 3.4)

Figure 3. 4 Existing Fecal Sludge Trenching Ground at Khulna.

3.2.2 Location

The quantity of fecal sludge generation in Khulna city was estimated to be approximately 710,000 m^3/year and 721,000 m^3/year from field survey and theoretical assessment, respectively (O&M manual FSTP Khulna, 2015). The fecal sludge treatment plant (FSTP) for Khulna is located at 22^{o}47’39” latitude and 89^{o}29’32” longitude, outside the city corporation boundary.

Figure 3. 5 Location of Proposed FSTP onto Existing Landfill Site.

Existing FSTP area is located within the municipal landfill site boundary. This area had been used for the development of pilot scale sanitary landfills since 2008 – 2009. Thus, the old solid wastes that had been buried are still laying beneath this area. The configurations of the existing FSTP are outlined as below:

a) This area was used as the pilot-landfill site

b) The total available area is about 65x75 m as shown in layout plan

c) Currently, there is a little change of soil covering level due to the settlement

d) Nearby U-trench is temporarily used for fecal sludge disposal, filtration into ground is expected. The final cover by top soil is planned after this trench is full.

From the field observation the limitations of this plant are:

a) Land or area for construction of the FSTP is on the old sanitary landfills

b) Land settlement is the major concern for the development of this area

c) Any disturbance of landfills may cause the failure of landfill stability, gas leakage, etc.

3.3 Design configuration of Khulna FSTP

Options for Khulna FSTP are based on available area and its condition. Existing area for the construction of FSTP is the old pilot-scale landfill site. This landfill site was constructed in March 2008 and operated from Jul 2008 to Sep 2009. It contained approximately 15,000 tons of municipal solid wastes within 70 m x 55 m land area. The depth of this landfill was about 3 m (Alamgir, 2015). In order to use the old landfill site, the concerns are listed below (Martin, 2002)

a) The potentials for old landfills to generate dangerous levels of methane gas over many years must never be ignored or overlooked in any landfill use project. Even when engineering controls are added to a project to manage the gas, problems can still develop. Care must be taken to have redundant systems in place to ensure the protection of human health.

b) Design and construction of structures over old landfills must include a thorough understanding of the foundation requirements for the structures. A two-foot soil layer over waste will not normally be an adequate foundation for an overlying structure. In some cases, support pilings may also not be adequate.

c) Regulators need to develop clear regulations to help guide the use of old landfills.

d) Properly designed, constructed and operated landfill use projects can provide environmental protection of the wastes, be protective of human health and allow for alternate beneficial uses of the landfill. Recreational uses seem to be the best options for old landfills. Construction of structures over old landfills should be avoided.

3.4 Treatment options for Khulna FSTP

Fecal sludge treatment is a process of removing contaminants from septage adopting physical, chemical and biological processes. There are many types of treatment systems such as anaerobic digestion, cover lagoon, sand drying bed, sludge drying bed, constructed wetlands, stabilization pond, activated sludge process, etc. Options of the treatment are based on the quality of final products, solid and liquids. Alternative natural treatment systems, which are simple in the construction and operation, yet inexpensive and environmentally friendly, seem to be appropriate for developing countries like Bangladesh. Based on basic information, quantity and effluent standards selected treatment option for fecal sludge in Khulna City Corporation in feasibility study is Constructed Wetland (CW) for FS + CW for percolate system. Constructed Wetlands (CWs) are a natural, low-cost, eco-technological biological wastewater treatment technology designed to mimic processes found in natural wetland ecosystems, which is now standing as the potential alternative or supplementary systems for the treatment of wastewater.

3.4.1 Planted constructed wetland

The design of Khulna FSTP is based on available area. The CW for FS is designed for 6 units of VF (vertical flow) type. Each unit is individual operation. Percolate from CW treating FS is further treated by CW for percolate no.7 and no.8. In which no. 7 is designed for subsurface horizontal flow (SF) and the no. 8 is designed for VF type. However, the feeding to no.7 and no.8 is based on overflow from no. 1 – no.6. The design configuration of CW unit for FS is the on-ground pond type as to avoid the disturbance of landfills beneath this area. While the percolate CW is designed as excavation pond at the existing pond. After that, the effluent from percolate CW will be discharged into the canal.

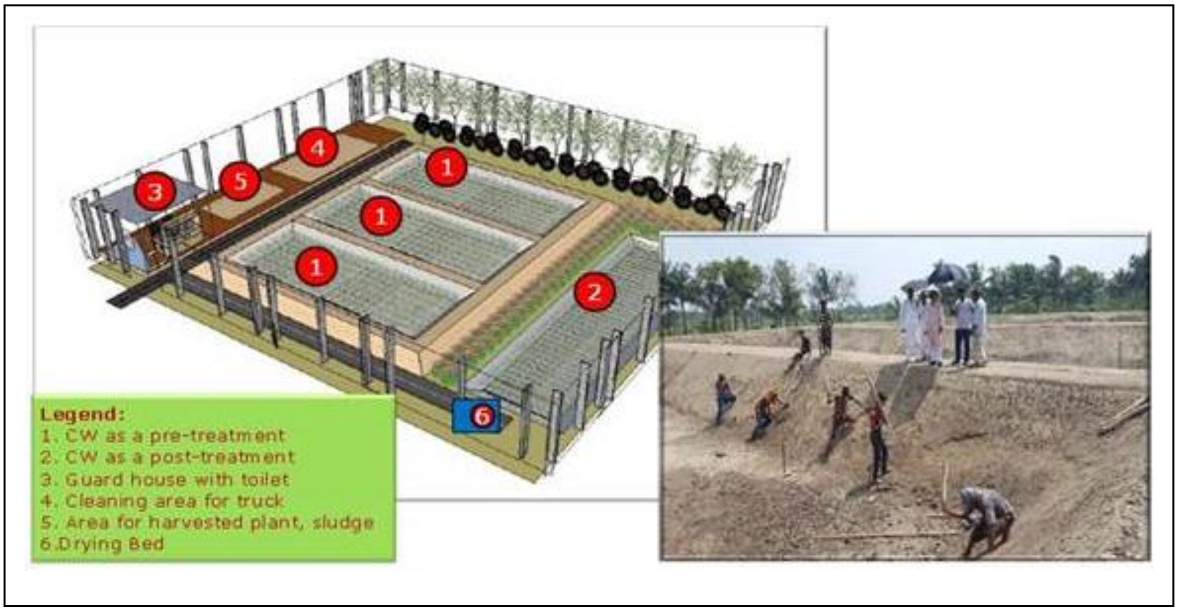


Figure 3. 6 Fecal sludge treatment plant construction over passive landfill site in Khulna.

3.4.1.1 Vertical flow (VF)

A vertical flow constructed wetland (vertical flow CW) is a planted filter bed for secondary or tertiary treatment of wastewater (e.g. greywater or blackwater) that is drained at the bottom (Figure 3.7). Pre-treated wastewater from onsite sanitation system is poured or dosed onto the surface using a mechanical dosing system. The water flows vertically down through the filter matrix to the bottom of the basin where it is collected in a drainage pipe. The water is treated by a combination of biological and physical processes. The filtered water of a well-functioning constructed wetland can be used for irrigation, aquaculture, groundwater recharge or is discharged in surface water. They are relatively inexpensive to build where land is affordable and can be maintained by the local community. The vertical flow constructed wetland can be designed as a shallow excavation or as an above ground construction. Clogging is a common problem. Therefore, the influent should be well settled in a primary treatment stage before flowing into the wetland. A ventilation pipe connected to the drainage system can contribute to aerobic conditions in the filter.

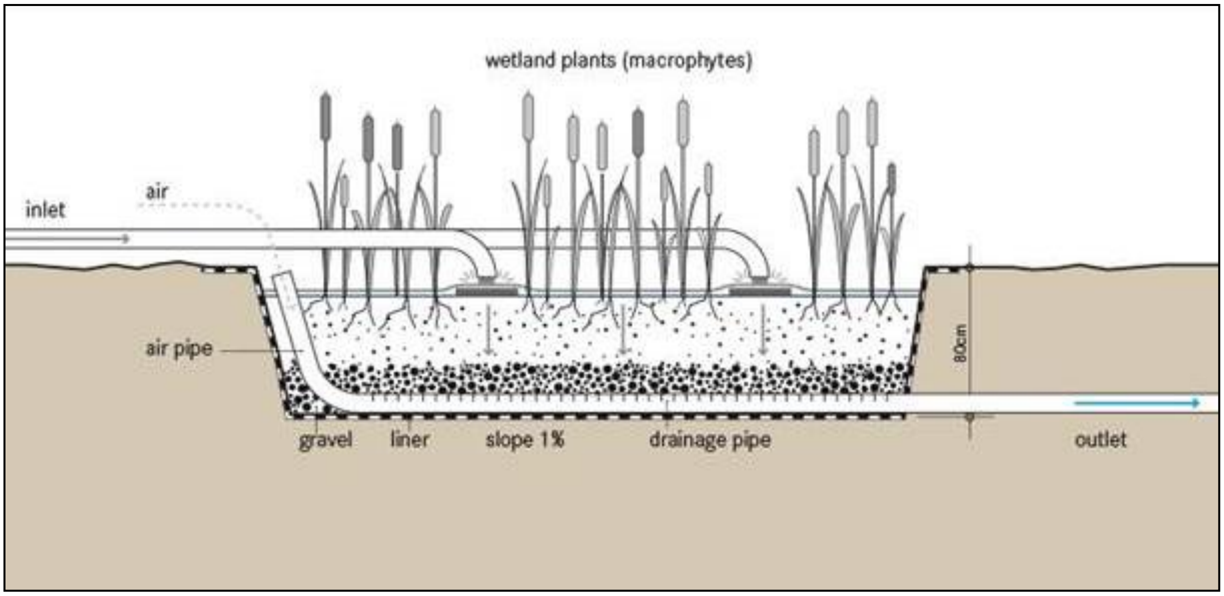


Figure 3. 7 Schematic cross- section of a vertical flow constructed wetland. (Source: Tilley *et al*., 2014)

3.4.1.2 Subsurface horizontal flow (SF)

A horizontal subsurface flow constructed wetland (horizontal subsurface flow CW) is a large gravel and sand-filled basin that is planted with wetland vegetation (Figure 3.8). It is used for secondary or tertiary treatment of wastewater (e.g. greywater or blackwater). Solids are removed in a primary treatment (e.g. in a septic tank or pit latrine). As wastewater flows horizontally through the basin, the filter material filters out particles and microorganisms degrade the organics. The effluent of a well-functioning constructed wetland can be used for irrigation and aquaculture or safely been discharged to receiving water bodies. Horizontal flow CW are relatively inexpensive to build where land is affordable and can be maintained by the local community as no high-tech spare parts, electrical energy or chemicals are required. As wastewater flows horizontally through the channel, the filter material filters out particles and microorganisms degrade organics. The water level in a horizontal subsurface flow constructed wetland is maintained at 5 to 15 cm below the surface to ensure subsurface flow (Tilley *et al*., 2008).

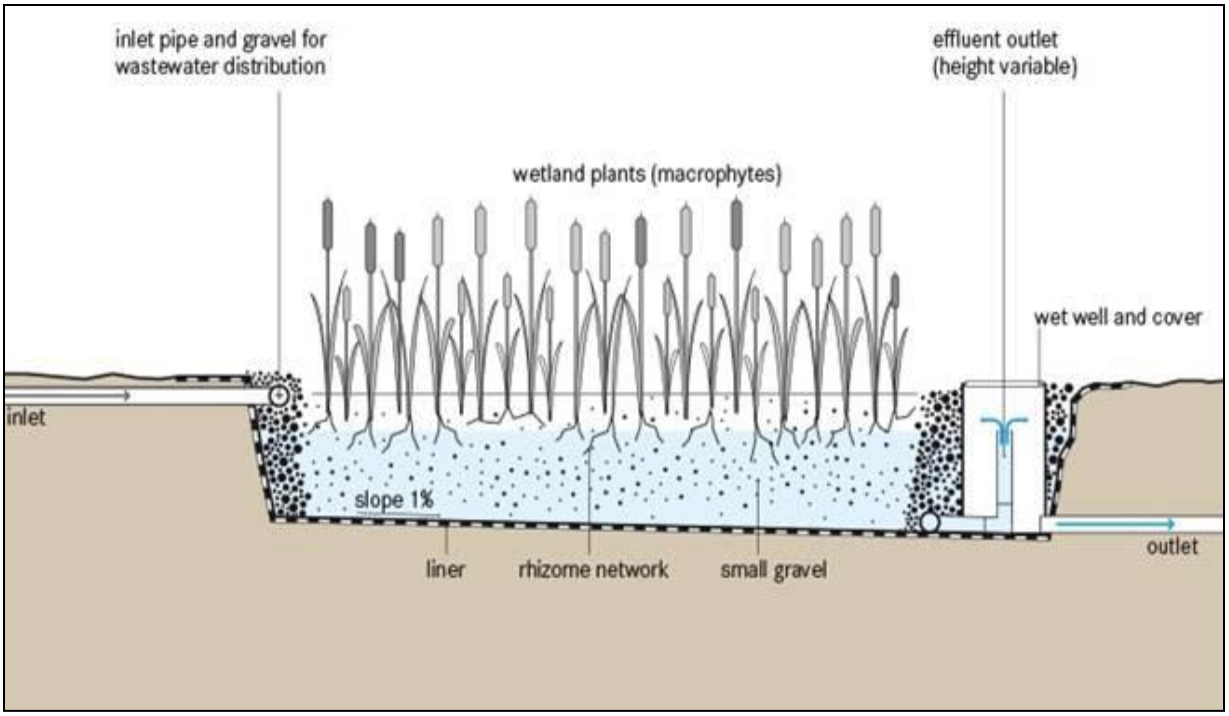


Figure 3. 8 Schematic cross-section of a subsurface horizontal flow constructed wetland. (Source: Tilley et al., 2014)

Pre-treated wastewater flows slowly through the porous medium under the surface of the bed in a horizontal path until it reaches the outlet zone. The bed should be lined with an impermeable liner (clay or geotextile) to prevent leaching. It should be wide and shallow so that the flow path of the water in contact with vegetation roots is maximized.

3.4.1.3 Feeding options

There are five options for feeding and operation. This design configuration can support the treatment rate from 30 to 180 m^3/d. In the first option, FS is fed on each CW with rate of 30 m^3/day and the HRT more than 6 days (Table 3.2). In day-7, FS will be loaded again in CW no.1. Therefore, feeding options are based on the amount of FS. Details of feeding are shown in Table 3.2 to Table 3.6.

Table 3. 2 Feeding option 1 for 30 m^3/d (or 15 trucks of 2 m^3)

Option	Loading design to	Day1	Day2	Day3	Day4	Day5	Day6	Day7	Remark
Option1	CW1								Each of 30 m^3/bed/day Overflow pattern
	CW2								
	CW3								
	CW4								
	CW5								
	CW6								
	CW7								
	CW8								

Table 3. 3 Feeding option 2 for 60 m^3/d (or 30 trucks of 2 m^3)

Option	Loading design to	Day1	Day2	Day3	Day4	Day5	Day6	Day7	Remark
Option2	CW1								Each of 30 m^3/bed/day Overflow pattern
	CW2								
	CW3								
	CW4								
	CW5								
	CW6								
	CW7								
	CW8								

Table 3. 4 Feeding option 3 for 90 m^3/d (or 45 trucks of 2 m^3)

Option	Loading design to	Day1	Day2	Day3	Day4	Day5	Day6	Day7	Remark
Option 3	CW1								Each of 30 m^3/bed/day Overflow pattern
	CW2								
	CW3								
	CW4								
	CW5								
	CW6								
	CW7								
	CW8								

Table 3. 5 Feeding option 4 for 120 m^3/d (or 60 trucks of 2 m^3)

Option	Loading design to	Day1	Day2	Day3	Day4	Day5	Day6	Day7	Remark
Option 4	CW1								Each of 30 m^3/bed/day Overflow pattern
	CW2								
	CW3								
	CW4								
	CW5								
	CW6								
	CW7								
	CW8								

Table 3. 6 Feeding option 5 for 180 m^3/d (or 90 trucks of 2 m^3)

Option	Loading design to	Day1	Day2	Day3	Day4	Day5	Day6	Day7	Remark
Option 5	CW1								Each of 45 m^3/bed/day Over flow pattern
	CW2								
	CW3								
	CW4								
	CW5								
	CW6								
	CW7								
	CW8								

3.4.1.4 Vegetation management

Establishing vegetation within a constructed wetland involves the planting of suitable vegetative materials at the appropriate time (Miller, 2007). Wetland plant communities are self-maintaining and will grow, die, and regrow each year. Water emergent plants are selected to use for constructed wetlands. The species used in the wetland receiving fecal sludge is the species that can stand for the high pollution load as high total dissolved solids (TDS). Moreover, the species should be available in Bangladesh. Species selection for different types of constructed wetlands has been previously established. Heliconia, Cyperus and Canna (Kolaboti) are selected in this design for the treatment of fecal sludge in VF constructed wetlands system. Nevertheless, for treating the percolates in constructed wetlands, uses of Canna has been considered.

For SF type constructed wetlands, the water level should just cover the top of the rooting material. Emergent plants need access to air, and if the new plants are inundated for extended periods they will drown. As the plants grown taller the water level may be raised (WERF, 2006). For VF type constructed wetlands, the water level should be just above the gravel bed, but not above the mulch. The goal is to provide a continuous source of water to the plant root zone during establishment (WERF, 2006). Routine maintenance of wetland vegetation is not required for systems operating within their design parameters. Wetland plant communities are self-maintaining and will grow, die and regrow every year. Plants should naturally spread to areas not intended for vegetation, the plants should be harvested (US EPA, 2000).

Harvesting will affect hydraulic performance, so the harvested cell should be taken out of service before and after harvesting. Harvested vegetation can be burned, chopped and composted, chopped and used as mulch or digested (Crites and Tchobanoglous, 1998). Special attention should be paid to land application of any harvested rhizomes, as unwanted propagation of plant material may occur on resultant fields.

In temperate climates, the prime planting period begins after dormancy has begun in the fall and ends after the first third of the summer growing season has passed. Early spring growing-season plantings have been the most successful (Allen *et al.*, 1990). Planting seedlings or clumps is the simplest method. The soil should be maintained in a moist condition after planting. The water level can be increased slowly as new shoots develop and grow. The water level must never be higher than the tips of the green shoots or the plants will die. In Khulna FSTP, the planting density was within at least 0.3 m (1 ft) centers or as much as 1 m (3 ft). The higher the density, the more rapid will be the development of a mature and completely functional wetland system. Canna seedlings were planted on the January moth of running year. If planted on 1 m (3 ft) centers, a wetland system will take at least two full growing seasons to approach equilibrium and optimal plant-related performance objectives. Example of canna-planted in constructed wetlands at Khulna FSTP is shown in Figure 3.9.

Figure 3. 9 Vegetation establishment on CW of Khulna FSTP.

3.5 Unplanted sludge drying beds

In Khulna FSTP, a pilot scale unplanted drying beds are constructed simultaneously with constructed wetland system with a view to collecting dry sludge for enduse purpose. It is planned to build to get dry sludge by this plant and further it could be beneficial to operate FSTP for long run sustainability.

The drying process in a drying bed is based on drainage of liquid through the sand and gravel to the bottom of the bed, and evaporation of water from the surface of the sludge to the air. Sludge is discharged onto the surface of beds for dewatering and shallow filters filled with sand and gravel beneath the surface with an under-drain at the bottom to collect leachate. After reaching the desired dryness, the sludge is removed from the bed manually or mechanically. Further processing for stabilization and pathogen reduction may be required depending on the intended enduse option. When considering the installation of a drying bed, the ease of operation and low cost needs to be considered against the relatively large footprint and odor potential.

3.5.1 Design parameters of unplanted sludge drying bed

There are several influencing factors that vary from location to location, condition of climate factors and the type of sludge need to be taken into consideration. Different aspects are discussed in the following sections.

3.5.1.1 Climate factors

Climate factors affecting the operation of unplanted drying beds include the following:

- Humidity: High humidity reduces the contribution of evaporation to the drying process;
- Temperature: Higher temperatures, also in combination with relatively low humidity and high wind, will enhance the total amount of water removed via evaporation;
- Rainfall: In locations where rainfall is frequent and occurs for long periods of time intense, a drying bed may not be feasible. Pronounced rainy seasons can be accommodated for by not using the beds in that period, or by covering them with a roof. Rainfall will may rewet the sludge, the intensity of which depends on the phase of drying.

3.5.1.2 Type of fecal sludge

The origin of the sludge is important when using drying beds. Septic tank sludge has less bound water and is hence more readily dewatered than fresh FS. In other words, it is considered to contain a lower specific sludge resistance for dewatering. It therefore can be applied in a thicker sludge layer or at a higher total solids loading rate or at a higher sludge loading rate. Sludge from public toilets is typically not digested: particles have not settled. Because it has a higher specific sludge resistance for dewatering less water will be removed, a longer sludge drying time may be required, or it may not be appropriate for drying beds.

3.5.1.3 Sludge loading rate

The sludge loading rate (SLR) is expressed in kg TS/ m^2/year. It represents the mass of solids dried on one m^2 of bed in one year. It is possible to indicate a range of sludge loading rates which typically vary between 100 and 200 kg TS/m^2/year in tropical climates, with 100 for poorer conditions and 200 for optimal conditions, while approximately 50 kg SS/m^2/year is commonly used in temperate climates in Europe (Duchêne, 1990). Poor conditions entail high humidity, low temperature, long periods of rainfall, and/or a large proportion of fresh FS. Optimal conditions comprise a low humidity, high temperature, a low amount of precipitation, and stabilized sludge.

3.5.1.4 Thickness of the sludge layer

It may seem a better option to apply a thicker sludge layer as more sludge can be applied to one bed; however, this will result in an increased drying time, and a reduction in the number of times the bed can be used per year. For any particular sludge dried under the same weather conditions, Pescod (1971) found that an increase in the sludge layer of only 10 cm prolonged the necessary drying time by 50 to 100%. It is also important that the sidewalls of the drying beds are high enough to accommodate different loadings. For example, if a layer of 20 cm is applied with a water content of 90%, the initial height before the water is drained-off will be much greater than 20 cm.

3.5.1.5 Number of beds

The number of beds required depends on the amount of sludge arriving at the plant per unit of time, the sludge layer thickness and the allowable sludge loading rate. For instance, for two weeks of drying duration and FS arriving 5 days per week, a minimum of 10 beds is required. The number of beds can then be increased or decreased considering the optimal sludge layer thickness. It is also important to adapt the number of beds based on the actual operating conditions, for example frequency of sludge removal, or frequency of rain. An increased number of beds increases the safety factor for adequate treatment with variable FS, or poor operation, but also increases capital costs.

3.5.2 Construction of Unplanted Sludge Drying Bed

A drying bed treatment facility consists of the beds with an inlet and an outlet, a leachate collection and drainage system, a designated area outside of the beds for storage and continued drying of the sludge, and potentially settling-thickening tanks.

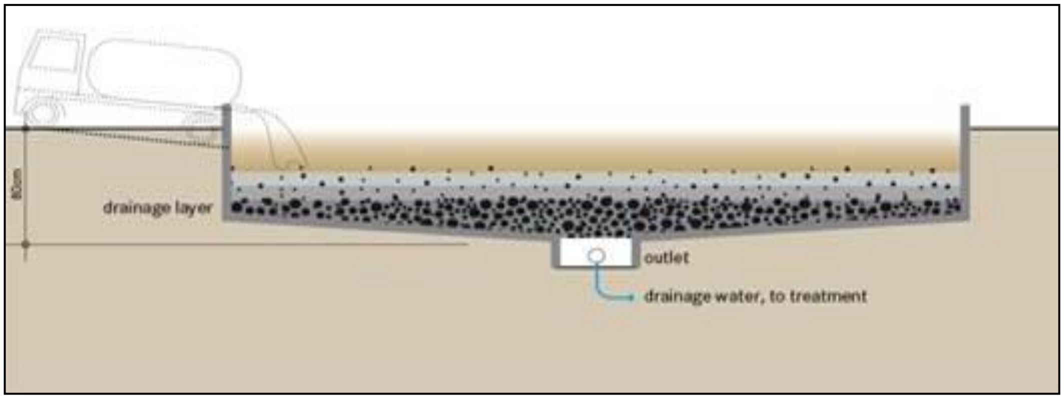


Figure 3. 10 Schematic overview of an unplanted sludge drying bed. (Source: Tilley *et al.*, 2014)

The drying process is based on two principles. The first principle is percolation of the leachate through sand and gravel. The second process, evaporation, removes the bound water fraction and this process typically takes place over a period of days to weeks (Heinss et al., 1998) reported removal of 50 to 80% by volume due to drainage, and 20 to 50% due to evaporation in drying beds with FS.

3.5.2.1 Site Preparation

In principle the construction of unplanted drying beds is similar to gravel/sand filters. The bed frame is usually made from concrete or a plastic liner with the bottom surfaces slightly sloped in order to facilitate percolation and drainage. The drainage pipes are covered by 3-5 graded layers of gravel and sand. The bottom layer should be coarse gravel and the top fine sand (0.1 to 0.5 mm effective grain size). The top sand layer should be 250 to 300 mm thick because some sand will be lost each time the sludge is removed (Strauss & Montangero 2004; Tilley et al. 2008). Indication about the diameter of the medium and the height of the different gravel and sand layers vary depending on the source (Sasse & Borda 1998; Strauss & Montangero 2004). Generally, the coarse gravel layer (grain diameter: 15 to 50 mm) is within 20 to 30 cm of height. A gravel layer (diameter of 7 to 15 mm) of 10 to 15 cm follows this layer. There should be a final sand layer of 25 to 30 cm.

Figure 3. 11 Construction phase of unplanted sludge drying bed at Khulna FSTP.

At Khulna FSTP, the bottom of the drying bed is lined with perforated pipes to drain the leachate away that percolates through the bed. While the solid fraction remains on the filter surface and is dried by natural evaporation the liquid percolates.

There are six number of bed which is made of brick and then walls and bottom are covered with liner incorporating HDPE sheet and geotextile (Figure 3.11). Each bed has a surface area of 9.5 m^2.These beds are vertical flow type and every bed has a perforated pipe to carry the leachate. The leachate carrying through all distribution pipes finally goes down to CW no. 7 pond for percolation. The feeding option is based on quantity of sludge to be discharged. Details of feeding are shown in Table 3.7

Table 3. 7 Feeding option for 2 m^3/d/bed

Days per week	1	2	3	4	5	6		1	2	3	4	5	6
DB 1							**1 week rest**						
DB 2													
DB 3													
DB 4													
DB 5													
DB 6													

3.5.2.2 Gravel and sand

Layers of gravel and sand are applied on top of the drainage system. When constructing drying beds, it is essential to use washed sand and gravel in order to prevent clogging of the bed from fine particles. This is important both for the initial construction, and for further supplemental additions of sand. The gravel layers function as a support and there are typically two or three layers with two different diameters of gravel (Figure 3.12).

A sand layer is placed on top of the gravel. The sand layer enhances drainage and prevents clogging, as it keeps the sludge from lodging in the pore spaces of the gravel. The diameter of the sand is crucial as sand with a larger diameter (1.0-1.5 mm) can result in the relatively fast accumulation of organic matter, thereby increasing the risk of clogging, This risk is reduced if sand with a smaller diameter (0.10.5 mm) is used (Kuffour et al., 2009). The distribution of diameter size in the layers is based on avoiding clogging from small particles washing into the drain.

In unplanted sludge drying bed at Khulna FSTP the bottom layer contains coarse aggregate bricks at a height of 40 cm with size approximately 2-3 inch and the intermediate layer of height around 30 cm contains stone chips of around 1 inch size. Then, 10 cm coarse sand layer was laid. Finally, a layer of whole brick was put on the bed material in a herringbone pattern. The whole brick layer provides less chance of losing sand also helps to prevent clogging.

Figure 3. 12 Distribution of filter bed materials in unplanted sludge drying bed.

3.5.2.3 Sludge removal

The drying time of a specific sludge type depends on a number of factors, one of which is the sludge dewatering resistance. The higher the sludge dewatering resistance, the lower the drainage rate which leads to a prolonged drainage time. Sludge is removed mechanically or manually, with shovels and wheel barrows being the most common manual method. In order to remove the sludge, a ramp must be provided to allow wheel barrows or other equipment to access the bed. If a drier sludge is required, this can be achieved by evaporation after it is removed from the drying bed. The dried sludge is frequently stored in heaps for periods of up to one year, during which time pathogen reduction can occur. It is however, recommended that a more controlled treatment is employed in order to produce reliable and consistent end products. Rewetting of the sludge is considered problematic if rainfall occurs before the free water of the sludge is completely drained. In this case, the moisture content of the sludge increases again and the drying period is prolonged. When the sludge is already dry enough to expose the sand layer through the cracks in the sludge, rain water can pass straight through the sludge and drains through the drying bed.

CHAPTER 4

EVALUATION OF TECHNICAL PERFORMANCE OF FSTP

CHAPTER 4
EVALUATION OF TECHNICAL PERFORMANCE OF FSTP

4.1 Introduction

Performance evaluation of such treatment plant is highly depended on its treatment efficiency. Suitable design, properly operated and maintained of any treatment plant enhance the treatment efficiency of it. For CW treatment plant filter media selection plays a vital role in treatment efficiency. Khulna FSTP at Rajbandh is a kind of Combined CWs, sequentially arranged by VF (vertical flow) and SF (subsurface horizontal flow) wetland. To evaluate the treatment efficiency of Khulna FSTP, percolate from primary treatment and final effluents have been collected and analyzed in the laboratory. In this context, this chapter provides the test results obtained from laboratory analysis.

4.2 Characterization of influent and effluent of FS

Parameters that should be considered for the characterization of influent and effluent of FS include solids concentration, physical and chemical parameters and pathogens. In the study previous test results of raw sludge collected from different septic tanks and pit latrines are used to assess the variability between raw sludge and effluent which were tested in KUET laboratory.

4.2.1 Physical characteristics

Physical characteristics include temperature, sludge volume index (SVI), total solids (TS), total suspended solids (TSS) and total volatile solids (TVS). Test results of certain parameters are strictly followed by Inland disposal Limit (ECR'97, Bangladesh).

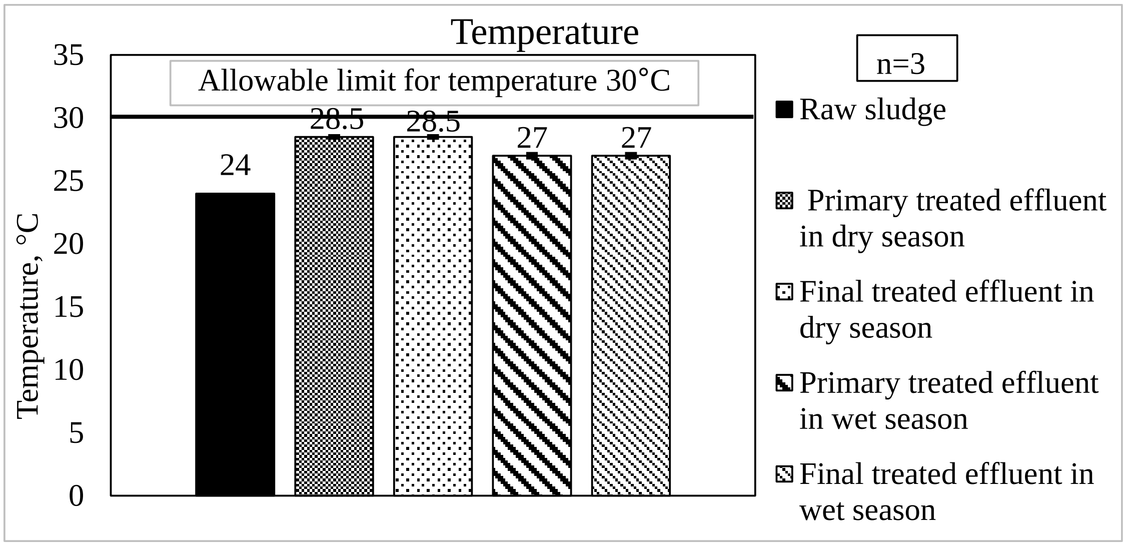


Figure 4. 1 Variation of temperature at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation

For temperature, the highest limit according to allowable Inland disposal (ECR'97, Bangladesh) is 30°C. The final effluent was always found to be within the limit. Effluent temperature was getting lowered from dry season to wet season (Figure 4.1).

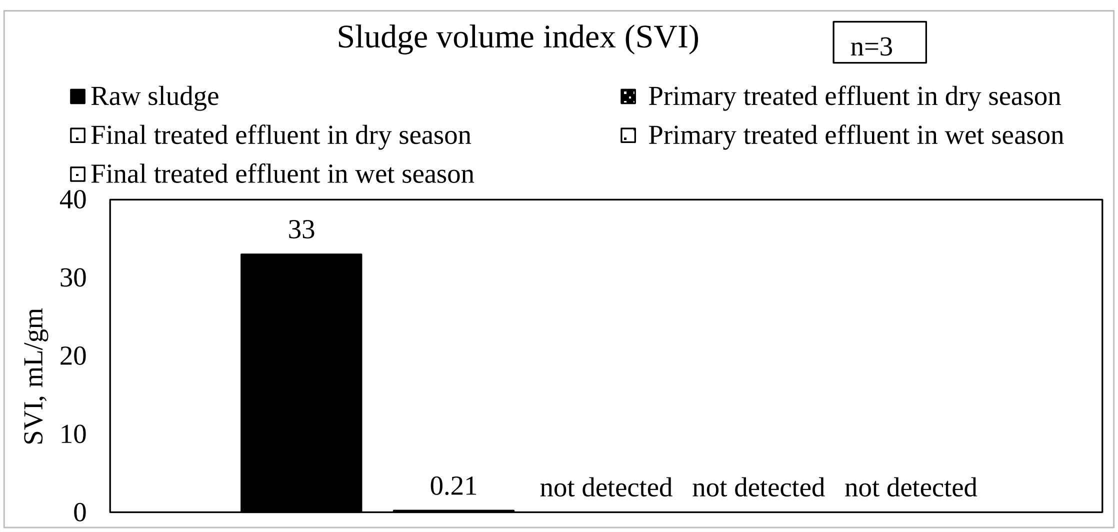


Figure 4. 2 Variation of sludge volume index (SVI) at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

SVI was primarily found to be 0.21 mL/gm in dry season and later on it was less than detection limit in rainy seasons (Figure 4.2).

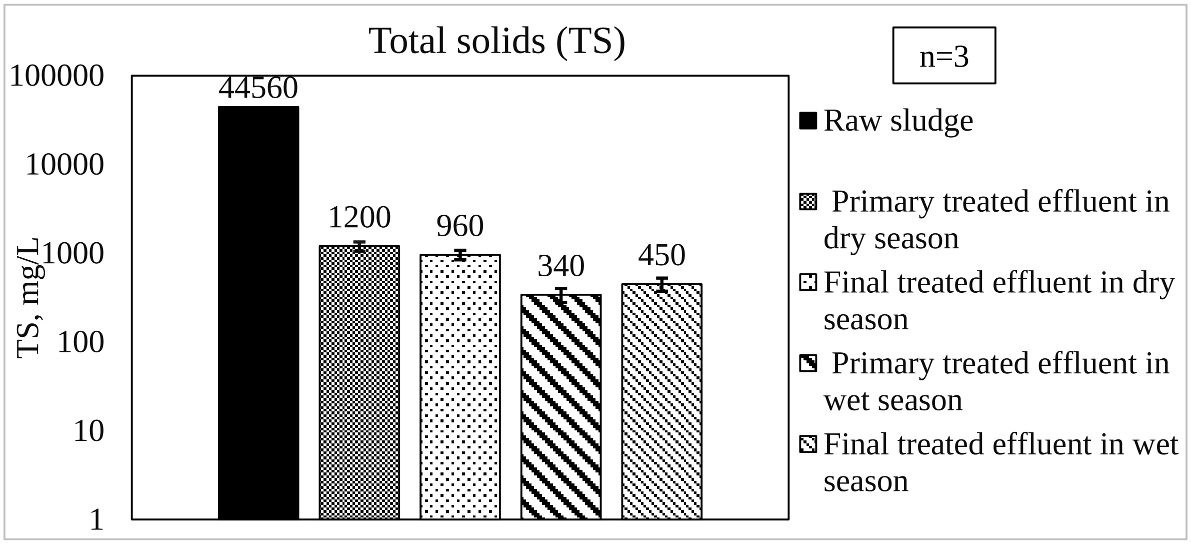


Figure 4. 3 Variation of total solids (TS) at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

Raw sludge, percolate from primary treatment and final effluent were collected and tested in the laboratory for total solids (TS) determination. Total solids concentration was found to be approximately 97% reduced after primary treatment. After final percolate treatment it was found to be 960 mg/L and 450 mg/L, respectively in dry and wet seasons (Figure 4.3). In wet season total solids in final effluent was found to be little higher than primary treated effluent having 340 mg/L. Possibly, it was due to the storm runoff from neighboring areas to percolate pond.

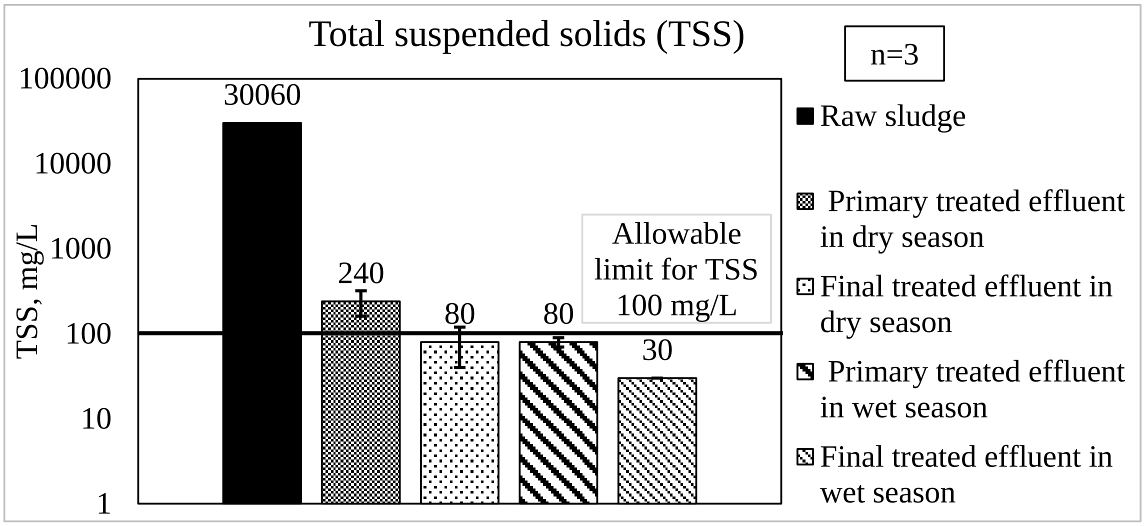


Figure 4. 4 Variation of total suspended solids (TSS) at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

TSS were found to be approximately 99% reduced after primary treatment. In dry and wet season, after final percolate treatment it was found to be 80 mg/L and 30 mg/L, respectively which is within the allowable limit of 100 mg/L (ECR’97, Bangladesh) (Figure 4.4).

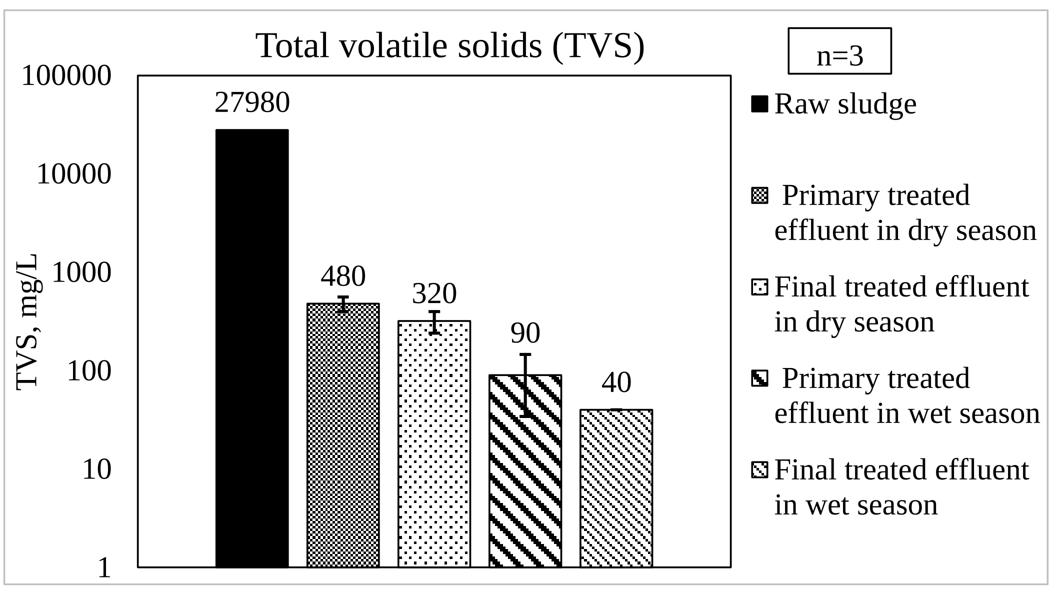


Figure 4. 5 Variation of total volatile solids (TVS) at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

The concentration of total volatile solids has been reduced around 98% after primary treatment. After final percolate treatment it was found to be 320 mg/L and 40 mg/L, respectively in dry and wet seasons (Figure 4.5).

4.2.2 Chemical characteristics

Different chemical water quality parameters comprising pH, Biochemical Oxygen Demand **(**BOD_5), Chemical Oxygen Demand (COD), iron Fe, nitrate NO_3, phosphate PO_4 and Total Alkalinity (as $CaCO_3$) of influent, primary percolate and final effluents have been determined by laboratory analysis in both dry and wet seasons and graphically represented below.

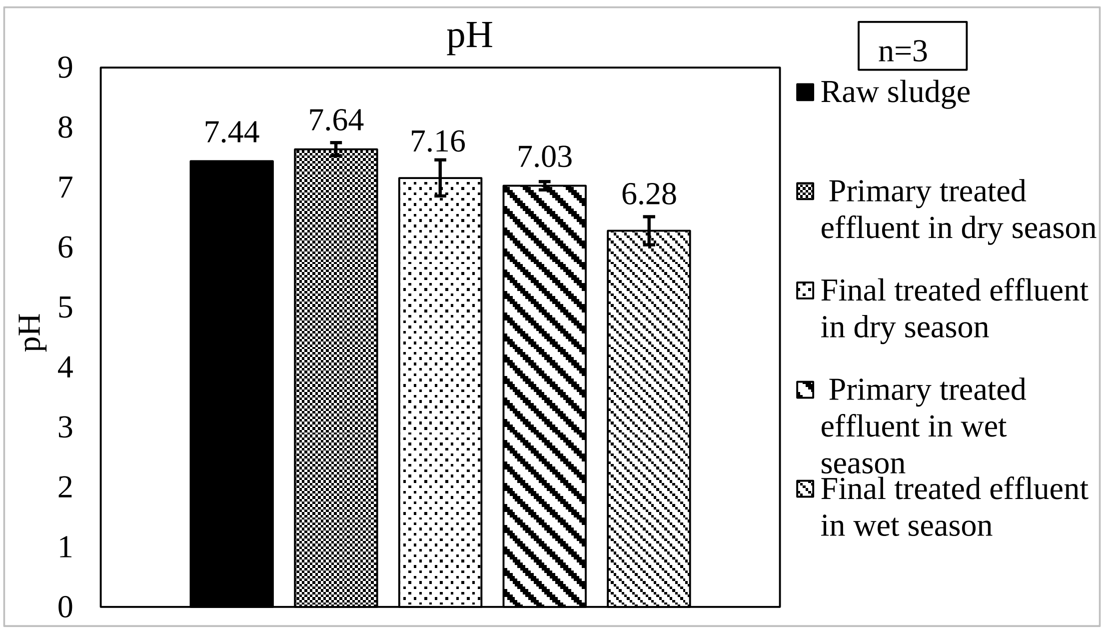


Figure 4. 6 Variation of pH at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

In this study pH was found to be 7.16 after percolate treatment in dry season. In wet season, pH was observed 6.28 as rain water possesses some acidic constituents (Figure 4.6).

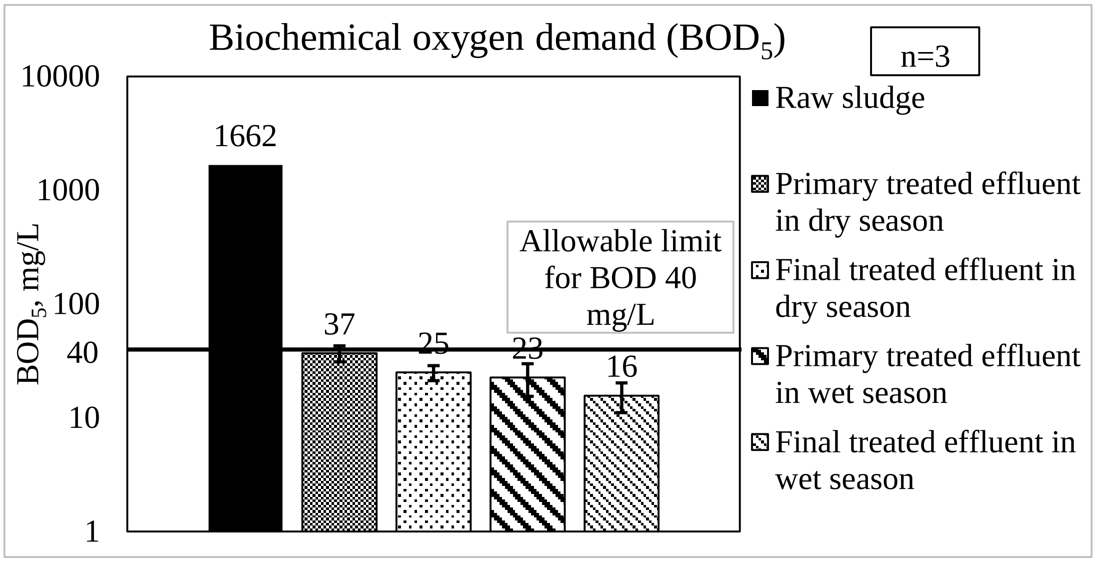


Figure 4. 7 Variation of BOD_5 at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

For BOD_5, the highest limit according to allowable Inland disposal (ECR'97, Bangladesh) is 40 mg/L. After final percolate treatment it was found to be 25 mg/L and 16 mg/L, respectively in dry and wet seasons (Figure 4.7) which were within the allowable limit.

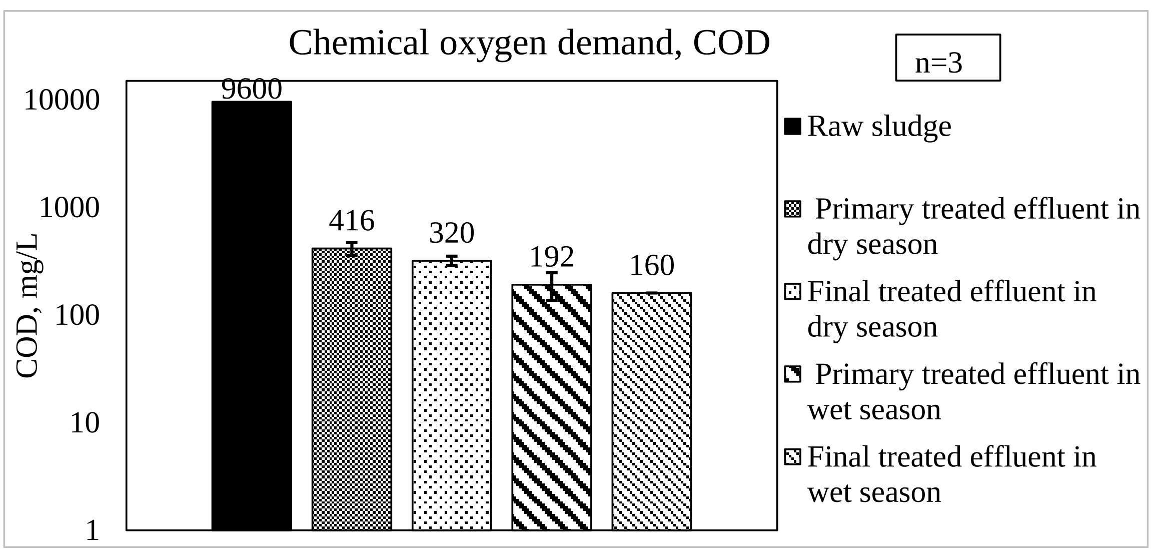


Figure 4. 8 Variation of COD at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

COD were found to be approximately 96% reduced after primary treatment. It was found to be 320 mg/L and 160 mg/L after final percolate treatment in dry and wet season, respectively (Figure 4.8).

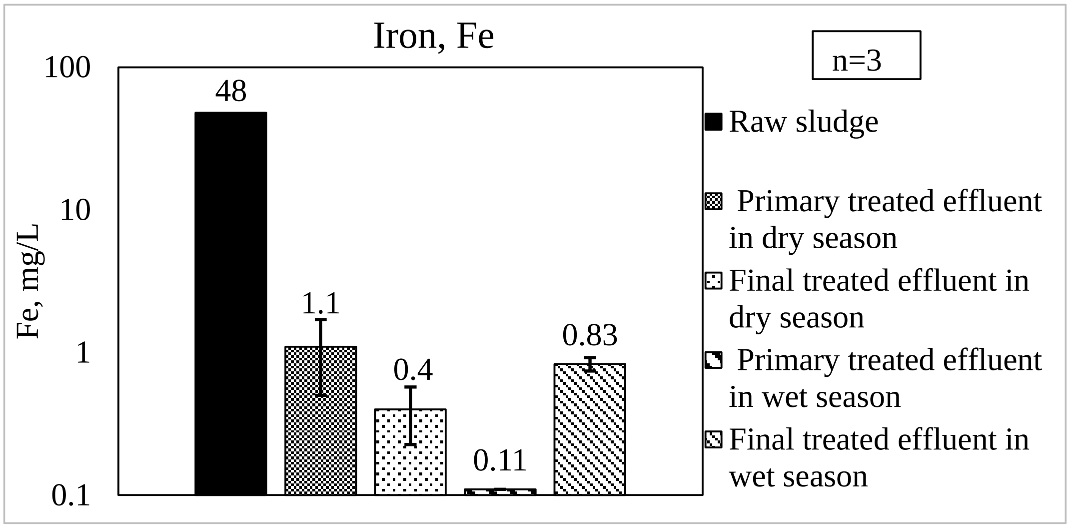


Figure 4. 9 Variation of Iron at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

Iron (Fe) was found to be approximately 98% reduced after primary treatment. After final percolate treatment it was found to be 0.4 mg/L and 0.83 mg/L, respectively in dry and wet seasons (Figure 4.9). In wet season Fe in final effluent was found to be little higher than primary treated effluent.

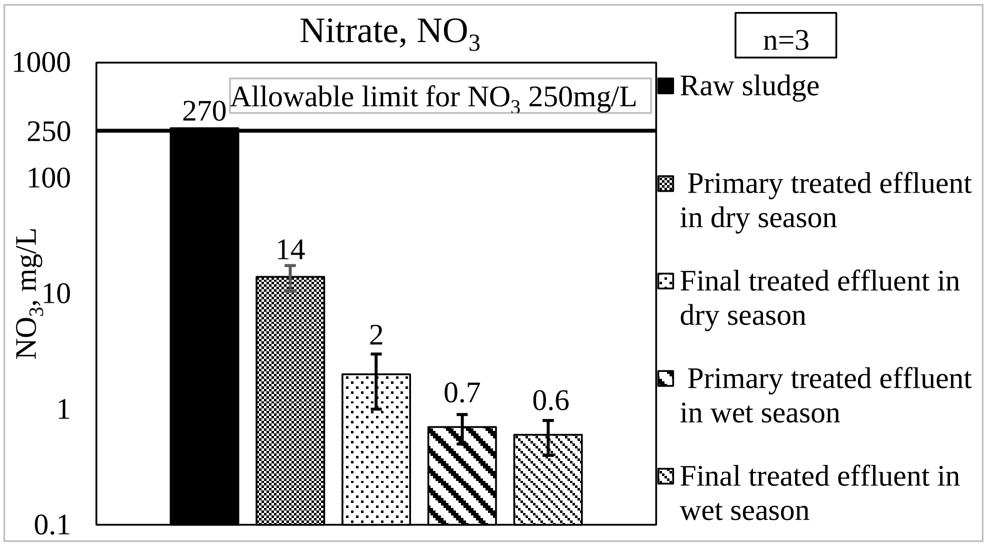


Figure 4. 10 Variation of Nitrate at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples and error bars show the range of standard deviation.

For nitrate (NO_3), it was found to be approximately 95% reduced after primary treatment. The highest limit according to allowable Inland disposal (ECR'97, Bangladesh) for nitrate is 250 mg/L. However, in final effluent, NO_3 concentration was found to be 2 mg/L and 0.6 mg/L, respectively in dry and wet seasons (Figure 4.10).

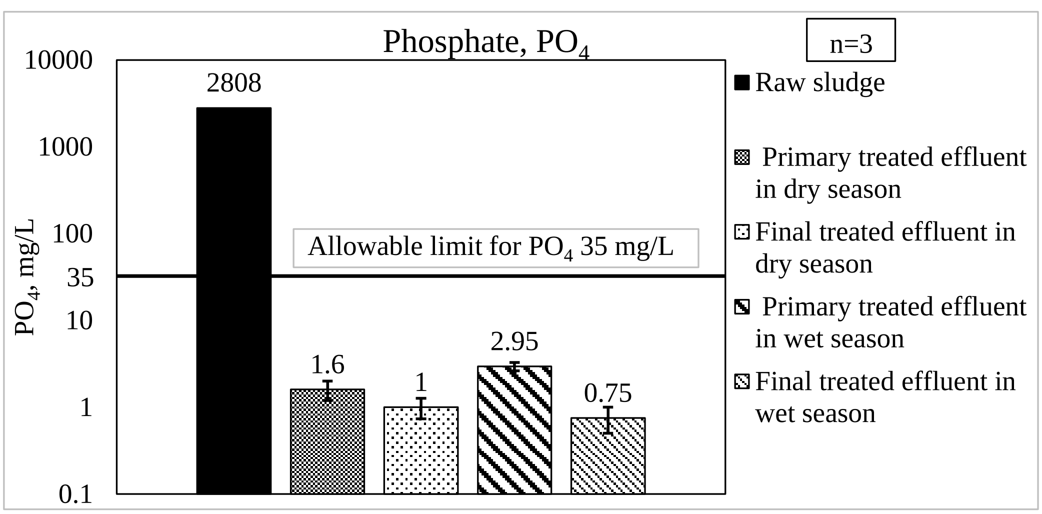


Figure 4. 11 Variation of Phosphate at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

According to allowable Inland disposal (ECR'97, Bangladesh) the highest limit for phosphate is 35 mg/L. In dry and wet seasons, phosphate concentrations were found to be within the disposal limits having 1 mg/L and 0.75 mg/L, respectively (Figure 4.11).

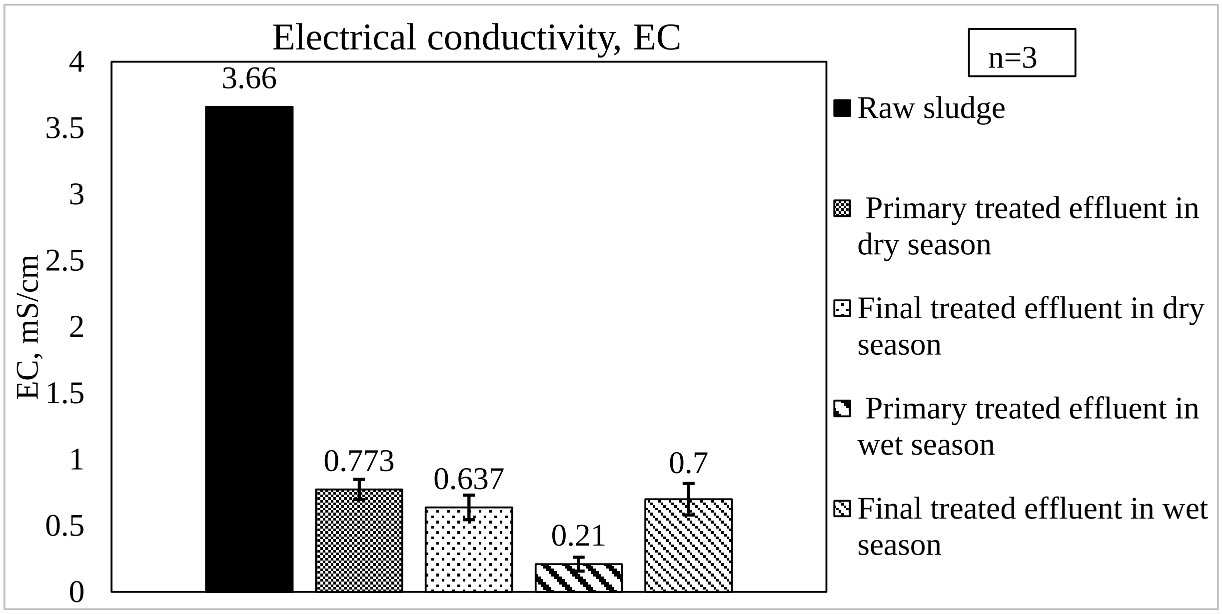


Figure 4. 12 Variation of EC at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

Electrical conductivity (EC) was found to be 0.637 mS/cm and 0.7 mS/cm after final percolate treatment in dry and wet season, respectively (Figure 4.12). In wet season EC of was observed to be higher than primary treated effluent possibly due to the storm runoff from neighboring areas to percolate pond.

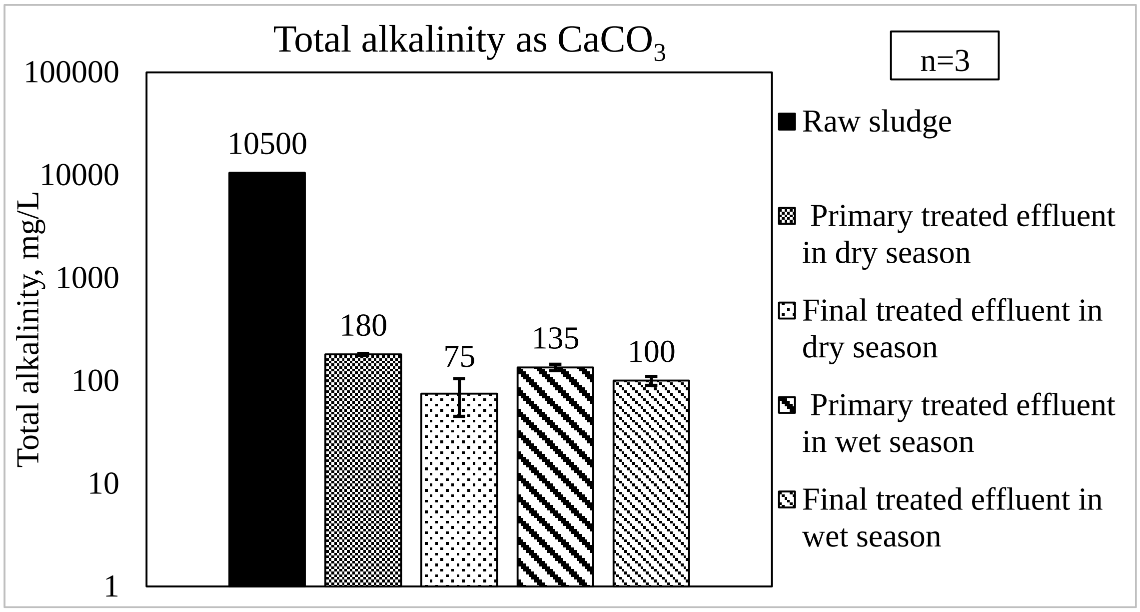


Figure 4. 13 Variation of total alkalinity (as $CaCO_3$) at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

Total alkalinity (as $CaCO_3$) was found to be approximately 98% reduced after primary treatment. After final percolate treatment it was found to be 75 mg/L and 100 mg/L in dry and wet season, respectively (Figure 4.13).

4.2.4 Microbial characteristics

Raw sludge from septic tank and pit latrine contains higher amount of pathogens which has a great health risk if it is disposed untreated. The vertical flow and horizontal flow systems in wetland is vigorously capable of reduction in number of coliforms. The test results at wet and dry seasons reveal the number of coliforms per 100 ml of percolate and effluent.

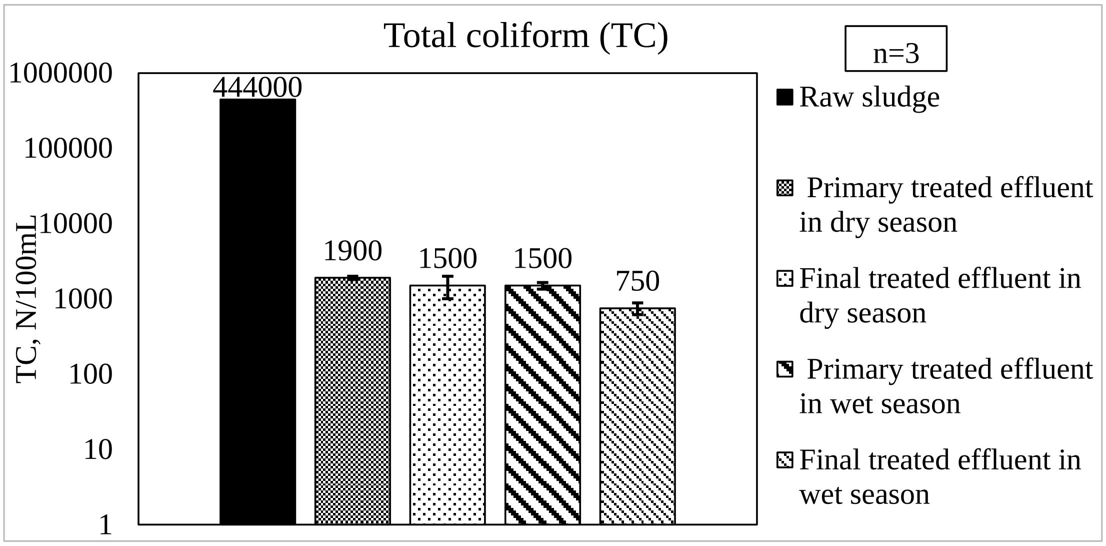


Figure 4. 14 Variation of total coliform (TC) at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

TC was found to be removed approximately 99% after primary treatment. In final effluent, TC was found to be 1500 N/100mL and 750 N/100 mL, respectively in dry and wet seasons.

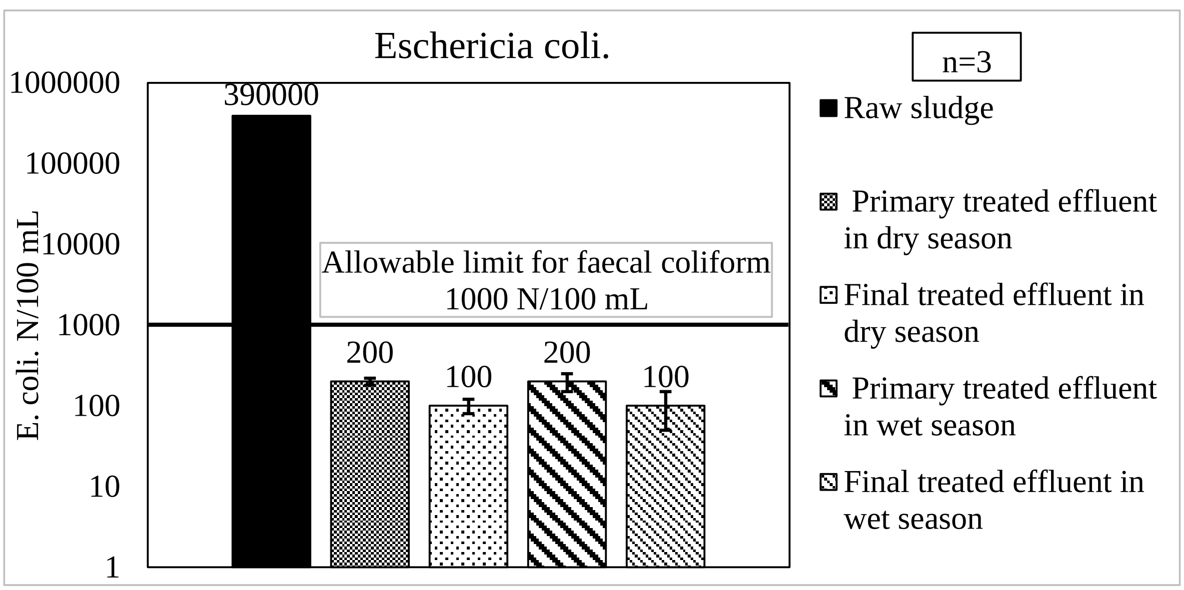


Figure 4. 15 Variation of E.coli. at different stages of treatment in Khulna FSTP. Graphical values represent the average of triplicate samples, and error bars show the range of standard deviation.

According to allowable Inland disposal (ECR’97, Bangladesh) the highest limit for E.coli. is 1000 N/100mL. In final treated effluent, E.coli. was found to be 100 N/100mL in both dry and wet seasons.

4.3 Conclusions

Constructed wetland system in Khulna FSTP is very potential for the treatment of raw sludge. In that FSTP, horizontal subsurface flow (SF) wetland is followed by vertical flow (VF) wetland system which can make sure of satisfactory removal of solids, chemical pollutants and microbial contaminants. To assess the performance of Khulna FSTP, effluent water samples had been collected and tested in the laboratory for various water quality parameters. The tests were done in two main seasons to observe the variation in effluent quality. However, the results were not significantly different by seasons and always found to be within the acceptable limits.

CHAPTER 5

CONSTRUCTION OF FSTP AND ITS OPERATION AND MAINTENANCE

CHAPTER 5

CONSTRUCTION OF FSTP AND ITS OPERATION AND MAINTENANCE

5.1 Introduction

Operation and maintenance of any process control system are dependent on a monitoring plan that provides information for judging the achievement of treatment, objectives, efficiency and long term sustainability of the system. A constructed wetland has a limited number of operational controls compared to mechanical treatment systems. Operation and maintenance can be classified in terms of start-up, routine and long-term operations. In some instances if poor operational decisions kill all of the emergent plants in an SF constructed wetlands, it may take one or more growing seasons (after replanting) to reestablish a plant canopy (WERF, 2006). In addition, thorough checkups should be done at least twice a year for the effective operation of the wetland (Constructed Wetlands Manual, 2008).Constructed wetlands at Khulna FSTP are identical to natural systems. As a result, operation is mostly passive and requires little operator intervention. The operator must be observant, take appropriate actions when problems develop, and conduct required monitoring and operational monitoring as necessary.

5.2 Mitigation of challenges associated with construction of FSTP

The existing ground level was found to be unusually compressed at load application and then expanded instantly at load withdrawal. This instability in field compaction was observed possibly due to the underneath loose and spongy landfill contents. In such instance, the lower value of degree of compaction (lower than 95%) as achieved practically in this site would be made safe by incorporation of geotextile and HDPE sheet for the construction of FSTP in this site.

5.2.1 Earthen embankments

Compacted soil embankment is expected to hold the CW ponding settlement, combustible gas migration and generation (Figure 5.1). For earth works at bed and embankments, field compaction was done using mechanical roller as well as manual compactor. Local expertise available due to massive fishing industries (fish ponds all over the country). The application of high degree of compaction also required to use for transportation on that embankment, however, the embankment in this case is not for vehicle.

Figure 5. 1 Earthen embankment at Khulna FSTP

5.2.2 Use of Geotextiles and High Density Polyethylene (HDPE) sheet as liner

Liners are usually be subjected to gravel and sand under high liquid weights or pressures and exposed to indentation action. Linings must have relatively high surface hardness to resist these pressures and puncturing. HDPE combines high surface hardness together with other mechanical properties that enable it to move smoothly when exposed to sand and gravel. HDPE under stress may undergo elastic (reversible) or plastic (irreversible) deformation. The limit of the elastic performance is typically reached for HDPE at a deformation of 15-20% of the original length (elongation at yield). Nevertheless, HDPE sheet has been laid over the whole top surface of FSTP bed as well as embankments which could provide additional strength (approximately 20-30%) through reinforcing effect for holding the filter bed materials and accumulated sludge. Furthermore, HDPE sheet would provide additional resistance against the slope failure of embankment as well as differential settlement of FSTP beds. HDPE has also been used for the sub-division of CW ponding system.

Figure 5. 2 Use of Geotextiles and High Density Polyethylene (HDPE) sheet over the basins of FSTP

5.3 Operational activities

Fecal sludge treatment plants (FSTPs) require ongoing and appropriate operation and maintenance (O&M) activities in order to ensure long-term functionality. An operating cycle generally consists of a start-up phase with reduced loading to acclimatize the plants, followed by loading at the design rate with intermittent plant harvesting and desludging. (Strande, *et al.*, 2014). Operational activities are required to ensure the anticipated treatment services as designed of a FSTP. However, operation of a constructed wetlands is mostly passive and therefore requires little operator input (Miller, 2007).

5.3.1 Start up

The start-up period will vary in length depending on the type of design, the characteristics of the influent wastewater, and the season of year. Under ideal conditions, start-up of a wetland should be delayed six weeks after planting to provide sufficient time for the emergent plants to acclimatize and grow above the working water level. When start-up is initiated, the water level must be gradually raised to the design level by adjusting the flow control device at the outlet of each cell. This is done to allow the tops of the emerging plants to remain above water. The influent transported to Khulna FSTP which is primary or septic tank effluent, was diluted with clear water to slowly increase the pollutant loadings to the wetland until the vegetation is acclimatized (Figure 5.3). During the start-up period, the operator inspected the wetland several times per week. Plant health and growth observation, berms and dikes inspection for any structural problems, water levels adjustment, and mosquito emergence were invigilated at a regular timing. The experience developed during this period will be helpful in determining the inspection frequency that will be required during the mature phase of the wetland.

Figure 5. 3 Startup phase at Khulna FSTP

5.3.2 Screening / unload

The initial operation of FSTP has to be confirmed by unobstructed flow of sludge which is free of grit or garbage. Before loading the beds, vacuum trucks should discharge the sludge into a holding-mixing tank that is fitted with a bar screen to retain coarse material and garbage and prevent it from clogging the bed of CWs. A manual bar screening is fitted at each side of every VF constructed wetlands in Khulna FSTP. In which, garbage in the influent are simply separated by a bar screen (Figure 5.4) and garbage are cleaned by collecting those from the tank. For sludge drying beds in Khulna FSTP one type of screen which is locally made by using large plastic container is used to allow only sludge to flow and isolate the garbage caught in the container (Figure 5.4).

Figure 5. 4 Manual screening (SS304) for VF-CWs and locally made plastic container screen for drying beds

When influent is disposed from vacutug to the manual screening the high flow of influent makes thrust on wall and spills out. So it generates littering of surrounding areas and also a problem for vacutug operator. As a result sometimes operators ignored to use screening and used to discharge the influent directly to the bed (Figure 5.5) so it causes the clogs in filter media. This inconvenient situation is due to the size of manual screening. The problem can be minimized by modifying the screening size and pipes. The road should be raised to the embankment level as influent could pass at gravity flow.

Figure 5. 5 Trash noticed at the bed of CWs

5.3.3 Feeding frequency and resting phase

The resting time between loading periods is very important as it prevents biological clogging and allows pores to refill with oxygen (Stefanakis and Tsihrintzis, 2012a). In Khulna FSTP in wet season for each of 30 m^3/day/bed for two beds in total 60 m^3/day is practiced to feed which following alternative one day of feeding and two days of resting. In dry season for each of 45 m^3/day for four beds in total180 m^3/day is practiced to feed which following alternative two days of feeding and one day of resting. This feeding pattern is practiced for VF-CWs and continuously flow through from normal and maximum loads at wet season and dry season respectively to SF-CW. For drying beds, 2 m^3/day/bed of sludge is allowed to dispose. Each bed gets total eleven days to reach desired final dried condition. But in present condition the estimated volume of sludge is not coming to the FSTP that's why all beds cannot be used equally. It possibly hampers the growth and health of plant in those beds and eventually it degrades the treatment efficiency. Minimum volume of sludge disposing should be ensured by taking proper initiatives.

5.3.4 Plant monitoring and plant harvesting

The primary objective in vegetation management is to maintain the desired plant communities where they are intended to be within the wetland. Plants will naturally spread to unvegetated areas with suitable environments (e.g., depth within plant's range) and be displaced from areas that are environmentally stressful. Three types of plant which is suited for wetland vegetation are selected – canna, heliconia and cyperus. In Khulna FSTP canna was chosen to plant for vegetation which has very productive growth. Its full-grown takes around 3-4 months when height becomes 1-1.5 m (Figure 5.6). Medium wilting of canna has been noticed in wetlands Wilting plant will be harvested very soon as needed. After plantation of canna, it is about 8 months to wilt itself. Whereas heliconia plant has slow growth pattern compared to canna. Its full grown period is 6 to 12 months. So, heliconia plants has been monitored young in VF-CWs. Cyperus was adopted for one VF wetland. It is not yet achieved its full growth and it can reach 2 to 3 meter in height at full growth. It has slow growth and propagation is limited. The harvest will be cut canna stem only in the old plant.

Figure 5. 6 Canna at its full growth and wilting after full growth

5.3.5 Bed emptying and sludge removal

Finding the optimum loading rate is important for the operation and maintenance of CWs to ensure that the sludge layer does not accumulate and become too thick and require desludging before it is fully drained. The optimum loading rate is considered as 250 kg total solids (TS) per m^2 per year for VF wetland and 100 200 kg total solids (TS) per m^2 per year for drying beds in Khulna FSTP and resulting sludge accumulation is about 10-20 cm per year (AIT, 2001). Sludge was not removed as it is newly built (Figure 5.7) and afterward it is planned to be desludged manually. Depending on how carefully the bed was desludged, it may be necessary to reconstitute the substrate of the bed, either by adding to or replacing the upper layer (sand or fine gravel), or by replacing the entire bed (Strande, *et al.*, 2014). In order for the sludge to be removed properly from unplanted drying bed, it needs to be dry enough that it can be shoveled. The drying time of a specific sludge type depends on a number of factors, one of which is the sludge dewatering resistance. Rewetting of the sludge is considered problematic if rainfall occurs before the free water of the sludge is completely drained. Unplanted drying bed in Khulna FSTP which has a roof shed over the beds protects from entering rainwater into the dry beds. Fully dried sludge is collected by local people related to agricultural industry to utilize it as compost or soil conditioner.

Figure 5. 7 Dried sludge in planted CW and unplanted sludge drying bed.

5.4 Plant monitoring of different pond components

The maintenance of a FSTP involves a detailed understanding of the treatment processes and performance requirements. This understanding should not only be based on the theoretical information concerning the treatment mechanisms and the design of the technology, but also on a monitoring procedure that requires specific planning, infrastructure (e.g. laboratory), employees, and finance (Strande, *et al.*, 2014).

Maintenance refers to all the activities that ensure long-term operation of equipment and infrastructure (Bräustetter, 2007). Routine monitoring are essential in managing and ensuring of long existing wetland. So, maintenance will be carried out corresponding to needs arising in the operational phase. Different components in constructed wetland system are maintained considering its current condition (Appendix-1)

5.4.1 Embankment

Embankment in constructed wetlands contain water within specific flow paths. Embankment are typically built to provide 0.6 to 1 m (2–3 ft) of freeboard. The amount of freeboard should be enough to contain a given storm rainfall amount. Side slopes should be a maximum of 3:1; however, slopes of 2:1 have been used for internal side slopes, particularly when liners or erosion control blankets are used. Prior to establishing filter media and drainage system HDPE sheet and geotextile were lined throughout the basin and embankment. Noteworthy as the embankments are earthen structure so no machinery access would not be allowed for maintaining purpose. But recent day infestation of burrowing animals such as muskrats has been identified in cutting down HDPE sheet (Figure 5.8). It is difficult to control these animals directly. Now it is in limited case and the sheet is repaired by gluing another piece of HDPE sheet. Adequacy of vegetation is noticed at embankment area (Figure 5.8). Inner and outer slopes of embankment is covered with HDPE sheet so it helps to prevent cracking, bulging and sliding. Erosion of embankment is absent due to covering of HDPE sheet. For the designed constructed wetland system at Khulna, perforated or slotted manifolds running the entire wetland width typically had been used for the collection of percolate towards outlet structure. Shut-off devices have been provided on all inlets to permit maintenance of the wetland. Outlet structures help to control uniform flow through the wetland as well as the operating depth. The emergent vegetation in the wetland will drop many leaves, and storm events can uproot many plants that float to the collection manifolds or outlet structures. Thus, close monitoring and instant actions are required to prevent the debris from clogging the downstream piping or treatment processes or impairing effluent quality.

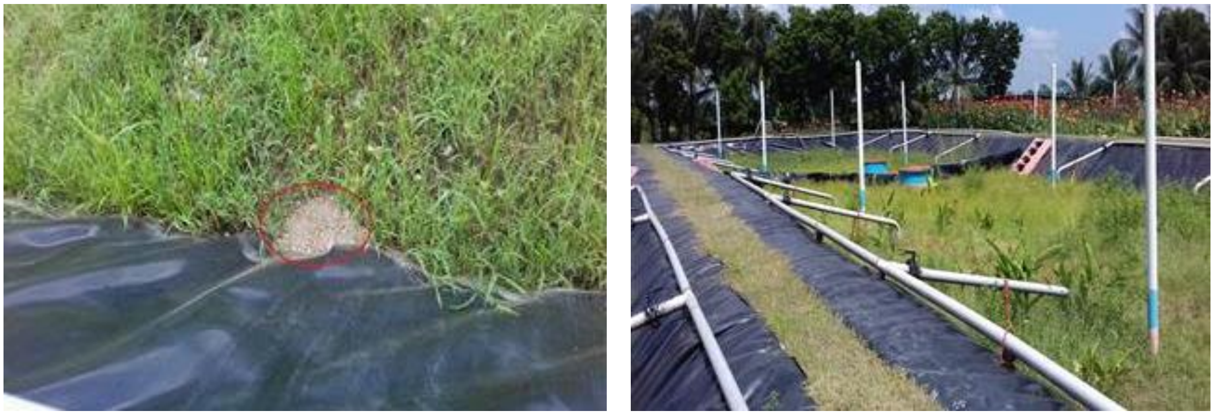


Figure 5. 8 Creating a hole by muskrats at embankment and vegetation across the berm.

5.4.2 Receiving tank

Every CW pond has a receiving tank as an outlet structure made of reinforced concrete (Figure 5.9). In VF and SF systems, the collection system may consist of a network of drainage pipes surrounded by large stones. The drainage pipe will lead to a collection sump which will allow the vertical bed to completely drain. Receiving tank consists of a flexible plastic pipe connected to the discharge pipe which can be held in position by a chain or rope. Maintaining uniform flow across the wetland through inlet and outlet adjustments is extremely important to achieve the expected treatment performance. The inlet and outlet manifolds should be inspected routinely and regularly adjusted and cleaned of debris that may clog the inlets and outlets. At Khulna FSTP perforated subsurface manifold connected to receiving tank to collect the percolate and leave for further treatment. The function of receiving tanks performs well as no excessive sediment accumulation inside the riser is found. The condition of risers and barrels are quite fair and no cracks, joint failure and displacement are noticed. A regular visual checking and maintenance must be continued because any failure of outlet structure ultimately degrade the treatment efficiency. Pond drain valves are kept open so that discharge could not be obstructed.

Figure 5. 9 Receiving tank at Khulna FSTP

5.4.3 Constructed wetland no. 7 (horizontal subsurface flow)

Horizontal subsurface filter beds have a very small external oxygen transfer and a smaller inlet compared to a vertical flow constructed wetland. Therefore they require a larger area. SF-CW in Khulna FSTP is used for percolate treatment from VF-CW. Harvesting and litter removal may be necessary depending on the design of the wetland. Maintenance works should be functioned monthly which includes any debris removal and undesirable vegetative growth like weeds. The CW is constructed as same manner of VF-CW so erosion of edge is not occurred. In wet season this bed fully filled with rain water and then water overflowed directly to CW no. 8. This difficult situation has been under consideration.

Figure 5. 10 Constructed wetland no. 7 (horizontal subsurface flow) at Khulna FSTP in wet season

5.4.4 Constructed wetland no. 8 (vertical flow)

CW 8 is constructed for final treatment of treated percolate coming from CW 7. Vegetation cover is not present and stagnant water always remains in the wetland. Any trash or debris are removed in time because it may hinder the operation. Sediment accumulation should be observed monthly and removed if necessary. A problem had been noticed in wet season that water level raised over the receiving tank due to excessive rain water that could not be passed away because the nearby canal was also full to the brim. Further receiving tank will be made higher so that overflowing will not occur.

Figure 5. 11 Constructed wetland no. 8 (vertical flow) at Khulna FSTP

5.5 Miscellaneous maintenance of FSTP

Since constructed wetlands are "natural" systems, routine operation is mostly passive and requires little operator intervention. The operator must be observant, take appropriate actions when problems develop, and conduct required operational monitoring as necessary. Some maintenance of FSTP are essential to keep its performance qualitatively high.

5.5.1 Odor Control

Odors are rarely a nuisance problem in properly loaded wetlands. Odorous compounds emitted from open water areas are typically associated with anaerobic conditions, which can be created by excessive BOD and ammonia loadings. Generally there is no odor problem in Khulna FSTP mainly due to controlled loading rate and aerobically treatment.

5.5.2 Control of Nuisance Pests and Insects

Potential nuisances and vectors that may occur in constructed wetlands include burrowing animals, dangerous reptiles, and mosquitoes. An infestation of burrowing animals such as muskrats can seriously damage vegetation in a system. Temporarily raising the operating water level may discourage the animals. As Khulna FSTP is naturally introduced so live trapping and release may be successful and appreciated. Fencing has little success. Dangerous reptiles are common in the wetlands. The most common are snakes, particularly the water moccasin. Warning signs, fencing, raised boardwalks, and mowed hiking trails can be used to minimize human contact with the animals. Operators and visitors should be made aware of the dangers and preventive actions through warning signs adopted by Khulna FSTP (Figure 5.12). Management of enough lighting is being arranging which cover total area of FSTP to avoid any undesirable situation at night. Mosquito control is a critical issue in constructed wetlands. Mosquito disturbance is more in evening time and it could be mitigated by keeping clean the surrounding area.

Figure 5. 12 Warning signs at Khulna FSTP

5.5.3 Other protective measures

A number of closed circuit cameras are being installed at Khulna FSTP to keep all operations visible at any time. It would add new dimension to monitoring level. Various protective equipment are available in FSTP (Figure 5.13).

Figure 5. 13 Various protective equipment at Khulna FSTP

5.6 Proposals for sustainable development of Khulna FSTP

It has been defined by the FAO Council in 1988 as “the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment of continued satisfaction of human needs for present and future generations. Such sustainable development conserves (land,) water, plants and (animal) genetic resources, is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable".

The proposals that would be offered in the study are entirely based on the complications which was identified during operation. In this chapter the problems have been clearly defined and solutions also drawn.

1. To get gravity flow the road adjacent to CWs (1-6) has to be levelled to the embankment level to ensure uniform disposal from vacutugs and avoid littering of surrounding areas. Modifying the size of screening and pipe will be further depended on the success or failure of the measure described above.
2. Heliconia and cyperus are growing slowly compare to canna so if needed canna has to be replanted accordance with heliconia and cyperus.
3. The height of receiving tank has to be made higher as extreme rainfall in wet season flooded over the tank.
4. The problem associated with overflowing of water from CW no. 7 to CW no. 8 in wet season will be decided through deep reviewing of experts.
5. The responsibility of operating the FSTP should be taken by government body (City Corporation).
6. Trained and skilled plant operators have to be appointed by responsible authority to ensure its long term monitoring.

5.7 Conclusions

Lessons learned from these failures are that O&M must be considered as an integral component of the full life cycle costs of a facility, and that ongoing training and capacity building is essential for the operators. In addition, the O&M plan must be incorporated into the design process and receive appropriate review and approvals along with the engineering plans. This helps to ensure that O&M is fully integrated into the facility once construction is complete and operation has begun.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This study explored the performance of Khulna FSTP for fecal sludge treatment along with operation and maintenance activities. The research work had two major objectives: (1) To determine the treatment efficiency of Khulna FSTP with regards to its effluent quality. (2) To give proposals for sustainable development of the FSTP based on field monitoring of operation and maintenance (O & M) and mitigation measures for identified difficulties. Conclusions with regard to each objective are stated in section 6.2 and recommendations are listed in section 6.3.

6.2 Conclusions

To facilitate sanitation to a viable state fecal sludge treatment plant is established in Khulna. A number of constructed wetlands are built to carry out full-fledged treatment properly. The constructed wetland system at Khulna City Corporation can be considered a pioneer venture in fecal sludge treatment system in Bangladesh. It is a good example of a wastewater filtration system for fecal sludge management with environmental enhancements. This study aims at evaluating the performance and close monitoring which ultimately fulfills the objectives and leads to propose for sustainable development.

Regarding the first objective, this study reveals that:

1. In FSTP treated effluent, the BOD values were found to be varied from 16 mg/L to 25 mg/L while the allowable disposal limit is 40 mg/L for inland surface water bodies (ECR'97, Bangladesh).

2. In the treated effluent from FSTP, COD values were found to be reduced approximately 96%.

3. Total suspended solids (TSS) concentrations were observed in the range of 30~80 mg/L which is within the allowable limit of 100 mg/L.

4. The temperature of treated effluent was always within the acceptable limit of 30°C.

5. In this study, the effluent pH value was found to be varied from 7.16 to 6.28 in dry and wet seasons, respectively. Lower pH value in wet season was observed possibly due to addition of rain waters in treatment process.

6. The nitrate and phosphate concentrations in treated effluent were always found to be less than 2 mg/L and 1 mg/L, respectively which were far below the acceptable limit of 250 mg/L and 35 mg/L, respectively.

7. Total coliform (TC) removal efficiency in the treated effluent was found to be approximately 99%. Escherichia coli (E.coli) in final effluent never exceeded 100 N/100ml while the acceptable limit was 1000 N/100ml.

Regarding the second objective, this study emphases on field inspection to reach predictable success of operation and maintenance (O&M). In this endeavor, field monitoring had been focused on various critical intervention issues such as: site preparation on passive landfill site, adjustment of water levels, maintenance of flow uniformity, vegetation management, odor control and maintenance of berms. Finally, some constitutive proposals had been recommended for the FSTP which would confirm its long-term sustainability. The observations through field monitoring are elucidated below:

1. The FSTP was built on passive land fill site so infrastructure was developed by replicating the natural wetland mechanism. HDPE sheet and geotextile have been used for lining because of additional resistance against the slope failure of embankment as well as differential settlement of FSTP beds.

2. Although, the treatment capacity of FSTP had been designed for 180 m^3/day. However, at real field situation, the fecal sludge is received in the range of 3~7 m^3/day so far.

3. The inlet screen and pipes were found to be insufficient and hence causes problems to influent disposal. Moreover, the road level should be raised up to embankment level to allow influent disposal at gravity flow into the CW beds.

4. Proper vegetation management was also needed for the wetlands. Canna had higher growth than heliconia and cyperus. So, canna has to be replanted to confirm equal density of vegetation throughout the whole beds.

5. Any kind of breach within the earthen berm of embankments should be repaired as soon as it is noticed.

6. In wet season CW-7 was found to be completely filled with rain water and overflowed to CW-8. Nevertheless, the water level in CW-8 was found to be raised over the receiving tank and could not be disposed because of higher water level in nearby canal.

7. Finally, total monitoring of FSTP has to be led by efficient operators and management should be undertaken by City Corporation. Routine monitoring is essential in managing a wetland system. Over time, these data would help the operator to predict potential problems and select appropriate corrective actions.

6.3 Recommendations

The following recommendations could be implied for further studies:

1. Evaluation of different parameters of dried sludge from sludge drying bed.

2. Evaluation of treatment efficiency of effluent from individual CWs and CW no.7.

3. Long term monitoring to ensure proper vegetation management and skill of O&M.

4. Analysis of chances for its sustainable development compliance with national acts entitled in institutional and regulatory framework for FSM.

REFERENCES

ADB (2011). Adapting To Climate Change: Strengthening the climate resilience of water sector infrastructure in Khulna Bangladesh. The Philippines: Asian Development Bank.

Adhikari, D. K., Roy, M. K., Datta, D. K., Roy, P. J., Roy, D. K., Malik, A. R. & Alam, B. (2006). Urban Geology: A case study of Khulna city corporation, Bangladesh.

Aalbers, H. (1999). "Resource Recovery from Faecal Sludge using Constructed Wetlands".

Alamgir M., Bidlingmaier W., Stepniewski W., Park K-H., Islam S.M. T. (2015). "Safe and Sustainable management of Municipal Solid waste in Bangladesh through the Practical application of WasteSafe". Proposal-WasteSafe II, Final Report, WasteSafe, ISBN: 978-984-33-8694-6.

Allen, H.H., Pierce, G.J. and Wormer, R.V. (1990). "Considerations and techniques for vegetation establishment in constructed wetland". In: D.A. Hammer (ed.) Constructed wetlands for wastewater treatment, municipal, industrial and agricultural. Chelsea, MI: Lewis Publishers, Inc.

Al-Sa'ed, R.M.Y., Hithnawi, T.M. (2006). "Domestic septage characteristics and co-treatment impacts of Albireh wastewater treatment plant efficiency". Dirasat Engineering Sciences 33(2), pp.187-197.

Andreasen, P. (2001). "Chemical stabilization. Sludge into Biosolids: Processing, Disposal, Utilization". Edited by L. Spinosa and P. A. Vesilind, IWA Publishing, United Kingdom.

APHA/AWWA/WEF (2012). "Standard Methods for the examination of water and wastewater". 22nd Edition. American Public Health Association, American Water Works Association, and Water and Environment Federation Publication. Washington D.C., USA. ISBN: 978-087553-0130

Arthur, R., Baidoo, M.F. (2011). "Biogas generation from sewage in four public universities in Ghana: A solution to potential health risk". Biomass and Bioenergy 35(7), pp.3086-3093.

Banglapedia, Khulna City Corporation http://en.banglapedia.org/index.php?title=Khulna_City_Corporation (Accessed on: 19 September, 2016)

Bassan, M., Ferré, A., Nguyen, V.A., Holliger, C., Strande, L. (2015). "Local Factors Influence FS Characteristics: Research in Hanoi, Vietnam". Excreta and Wastewater Management, Sandec, pp.14-15

BBS (2011). Population and Housing census, Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People's Republic of Bangladesh.

Berger, E.Y. (1960). “Intestinal absorption and excretion”. In: Comar C. L. and Bronner F. (eds). Mineral Metabolism, pp.249-286. Academic Press, New York.

Bräustetter, A. (2007). “Operation and maintenance of resource-oriented sanitation systems in peri-urban areas”. Fakultat Umweltsicherung, Fachhochschule Weihenstephan Master.

Chowdhary, S. and Kone, D. (2012). “Business Analysis of Faecal Sludge Management: Emptying and Transportation Services in Africa and Asia”. Seattle, WA: Bill & Melinda Gates Foundation http://www.susana.org/en/resources/library/details/1662(Accessed on 17 December 2016).

Cofie, O.O., Agbottah, S., Strauss, M., Esseku, H., Montangero, A., Awuah, E., Kone, D. (2006). “Solid-liquid separation of faecal sludge using drying beds in Ghana: Implications for nutrient recycling in urban agriculture”. Water Research 40(1), pp.75-82.

Constructed Wetlands Manual (2008). UN-HABITAT Water for Asian Cities Programme Nepal, Kathmandu.

Cooper, P.F., Job, G.D., Green, M.B. and Shutes, R.B.E. (1996). “Reed Beds and Constructed Wetland for Wastewater Treatment”. WRc Swindon, UK.

Courilleau, V. and Cartmell, E. (2010). “A step towards improved decentralized sludge management Khulna (Bangladesh)”. Cranfield University, UK.

Crites and Tchobanoglous, (1998). “Small and Decentralized Wastewater Management Systems”. McGraw – Hill Publishers.

Diongue, S.T. (2006). “Strategies d’optimisation de la filiere de vidange de boues de latrines a Dakar”. Institut International du Genie de l’Eau et de l’Environnement (Burkina Faso)/Ecole Ploytechnique Federale de Lausanne (Suisse). Master: 81.

Dodane, P.H., Mbeguere, M., Ousmane, S., Strande, L. (2012). “Capital and Operating Costs of Full-Scale Faecal Sludge Management and Wastewater Treatment Systems in Dakar”. Senegal. Environmental Science & Technology, 46(7), pp.3705-3711.

Duchêne, P. (1990). “Les systemes de traitement des boues des stations d’epuration des petites collectivites”. Documentation technique FNDAE 09, Ministere de l’Agriculture et de la Foret, France, in French. Available from www.fndae.fr/archive/PDF/fndae09-a.pdf.

EAWAG/SANDEC (Editor) (2008). Faecal Sludge Management. Lecture Notes. (= Sandec Training Tool 1.0, Module 5). Duebendorf: Swiss Federal Institute of Aquatic Science (EAWAG), Department of Water and Sanitation in Developing Countries (SANDEC), Switzerland. (Accessed on: 21 January 2017)

Food and Agriculture Organization, FAO (1988). http://www.fao.org/docrep/W4745E/w4745e0f.htm (Accessed on 17 June 2017).

Feachem, R.G., Bradley, D.J., Garelick, H., Mara, D.D. (1983). "Sanitation and Disease, Health aspects of excreta and wastewater management". World Bank studies in water supply and sanitation. John Wiley and Sons, New York.

Foxon, K., Brouckaert, C., Wood, K. (2012). "How fast do pits fill up? Empirical evidence and mathematical models". FSM2, Durban, South Africa.

FSM Survey (2014). "Draft report on baseline study on fecal sludge management of residential premises". SNV and Khulna University, Bangladesh.

Gao, X.Z., Shen, T., Zheng, Y., Sun, X., Huang, S., Ren, Q., Zhang, X., Tian, Y., Luan, G. (2002). "Practical manure Handbook, (In Chinese)", Chinese Agricultural Publishing House. Beijing, China. In: WHO. 2006. Guidelines for the safe use of wastewater, excreta and greywater. Volume 4. Excreta and greywater use in agriculture. ISBN 92 4 154685 9.

Guyton, A.C. (1992). "Human physiology and mechanisms of disease". W. B. Saunders Co, Philadelphia, USA.

Haque A.N., Dodman D. and Hossain M. M. (2014). "Individual communal and institutional responses to climate change by low-income households in Khulna of Bangladesh". Environment and Urbanization, 26(1), pp. 112-129.

Heinss, U., Larmie, S. A., Strauss, M. (1998). "Solids Separation and Pond Systems for the Treatment of Fecal Sludges in the Tropics, Lessons learnt and recommendations for preliminary design". SANDEC Report No. 5/98. Second Edition, Swiss Federal Institute for Environmental Science and Technology (EAWAG) and Water Research Institute (WRI), Accra/Ghana.

Hutton, G. (2012). "Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage). World Health Organization, Geneva, pp. 4.

Ingallinella A.M., Sanguinetti G., Koottatep, T., Montangero, A., Strauss, M. (2002). "The challenge of fecal sludge management in urban areas – strategies, regulations and treatment options). Water Science and Technology 46(10), pp.285-294.

Institutional and regulatory framework for FSM, City corporations (2017).

Islam, N. (2012) Urbanization and Urban Governance in Bangladesh; Report for 13th Annual Global Development Conference on "Urbanization & Development: Delving Deeper into the Nexus", Budapest.

Jönsson, H., Baky, A., Jeppsoon, U., Hellstrom, D., Karrman, E. (2005). "Composition of urine, faeces, greywater and biowaste for utilization in the URWARE model". Urban water Report of the MISTRA Programme, Report 2005:6, Chalmers University of Technology, Gothenburg, Sweden. Available at: www.urbanwater.org.

Katukiza A.Y., Ronteltap, M., Niwagaba, C., Foppen, J.W, A., Kansiime, F., Lens, P.N.L. (2012). "Sustainable sanitation technology options for urban slums". Biotechnology Advances 30(5), pp.964-978.

KCC (2015). Basic Statistics of Khulna City Corporation, Official Website of KCC; http://www.khulnacity.org/Content/index.php?pid=30&id=32&page=About_KCC (Accessed on: 15 February 2016)

Kengne, I.M., Kengne, S. E., Akoa, A., Bemmo, N., Dodane, P.-H., Koné, D. (2011). "Vertical-flow constructed wetlands as an emerging solution for faecal sludge dewatering in developing countries". Journal of Water, Sanitation and Hygiene for Development 01(1), pp.13-19.

Khan, M. S. A. and Kumar, U. (2010). Water Security in Peri-Urban South Asia, Adapting to Climate Change and Urbanization, Scoping Study Report: Khulna. Institute of Water and Flood Management; Bangladesh University of Engineering and Technology.

Kim Y., Parker W. (2008). "A technical and economic evaluation of the pyrolysis of sewage sludge for the production of bio-oil". Bioresoures Technology 99(5), pp.1409-1416.

Klingel, F., Montangero, A., Kone, M., Strauss, M. (2002). "Fecal Sludge Management in Developing Countries - A Planning Manual". (= First Edition). Duebendorf: Swiss Federal Institute for Environmental Science (EAWAG). (Accessed on: 20 January 2017)

Koanda, H. (2006). "Vers un assainissement urbain durable en Afrique subsaharienne: Approche innovante deplanification de la gestion des boues de vidange". Ecole Polytechnique Federale de Lausanne. These de doctorat: 351.

Koné, D. and Peter, S. (2008). "Faecal Sludge Management (FSM)", Sandec Training Tool 1.0 Module 5, Eawag, Switzerland.

Koné, D., Strauss, M. (2004). "Low-cost Options for Treating Faecal Sludges (FS) in Developing Countries – Challenges and Performance". Paper presented to the 9th International IWA Specialist group conference on wetlands systems for water pollution control; and to the 6th International IWA Specialist Group Conference on Waste Stabilisation Ponds, Avignon, France.

Koottatep, T., Surinkul, N., Polprasert, C., Kamal, A.S.M., Koné, D., Montangero, A., Heinss, U., Strauss, M. (2005). "Treatment of septage in constructed wetlands in tropical climate:

lessons learnt from seven years of operation). Water Science & Technology 51(9), pp.119-126.

Kopp, J., Dichtl, N. (2001). “Characterization. Sludge into Biosolids ‐ Processing, Disposal, Utilization). Edited by L. Spinosa and P. A. Vesilind, IWA Publishing, United Kingdom.

Kuffour, A. R., Awuah, E., Anyemedu, F.O.K., Strauss, M., Kone, D., Cofie, E. (2009). “Effect of using different particle sizes of sand as filter media for dewatering fecal sludge”. Desalination 248, pp. 308-314.

Lentner, C., Lentner, C., Wink, A. (1981). “Units of Measurement, Body Fluids, Composition of the Body, Nutrition”. Geigy Scientific Tables, CIBA-GEIGY Ltd, Basle, Switzerland, ISBN 0-914168-50-9.

Local Government Division (LGD), Ministry of Local Government, Rural Development and Cooperatives, Government of the People’s Republic of Bangladesh (2016). Bangladesh Country Paper, Sixth South Asian Conference on Sanitation (SACOSAN-VI)

Luthi, C. (2011). “Sustainable Sanitation in Cities: A framework for action”. pp-10

Mara, D. D. (1976). “Sewage Treatment in Hot Climates”. Wiley, London, United Kingdom.

Mara, D.D. (2004). “Domestic Wastewater Treatment in Developing Countries”. London: Earthscan Publications.

Mara, D.D., Alabaster, G.P., Pearson, H.W., Mills, S.W. (1992). “Waste Stabilization Ponds: A Design Manual for Eastern Africa”. Leeds: Lagoon Technology International.

Mara, D.D., Pearson, H. (1998). “Design Manual for Waste Stabilization Ponds in Mediterranean Countries”. Leeds: Lagoon Technology International Ltd.

Martin W. L. and Tedder R. B. (2002). “Use of old landfill in Florida”. Proceedings of the 16th GRI Conference, Geosynthetic Institute Philadelphia, PA, USA, December 16-17, 2002, pp. 136

Metcalf and Eddy (2003). “Wastewater Engineering: treatment, disposal, reuse”. Tchobanoglous, G., Burton, F.L. eds. McGraw-Hill Book Company.

Miller, J. (2007). “Constructed Wetlands Technology Assessment and Design Guidance”. Iowa Department of Natural Resources.

Morel A. and Diener S. (2006). “Greywater Management in Low and Middle-Income Countries, Review of different treatment systems for households or neighbourhoods”. Swiss Federal Institute of Aquatic Science and Technology (Eawag). Dubendorf, Switzerland.

Musy, A., Higy, C. (2004). “Hydrologie, une science de la nature”. Presses Polytechniques et Universitaires Romandes, Lausanne, Switzerland.

NWSC (National Water and Sewerage Corporation) (2008). Kampala Sanitation Program (KSP) - Feasibility study for sanitation master in Kampala, Uganda.

Opel, A. (2011). “Landscape Analysis and Business Model Assessment in Fecal Sludge Management: Extraction and Transportation Models in Bangladesh”. Water Aid Bangladesh.

Oxfam and ITN BUET (2014). Wash Challenges in Slum Areas of Dhaka City

Pescod, M. B. (1971). “Sludge handling and disposal in tropical developing countries”. Journal of Water Pollution and Control Federation 43(4), pp. 555-570.

Rahman, M. M. (2009). “Sanitation Sector Status and Gap Analysis: Bangladesh”. Global Sanitation Fund, WSSCC.

Rahman, M. M., Ali, M. A., Choudhury, M. R. (2015). “Fecal Sludge Management (FSM)-A Way Forward to Overcome Urban Sanitation Challenges In Bangladesh”. ITN-BUET K-Hub Policy Brief, Bangladesh National Center, Dhaka.

SANIMAS (Editor) (2005): Informed Choice Catalogue. pdf presentation. BORDA and USAID. (Accessed on: 21January 2017)

Sasse, L., BORDA (Editor) (1998) DEWATS. “Decentralised Wastewater Treatment in Developing Countries”. Bremen: Bremen Overseas Research and Development Association (BORDA). (Accessed on: 20 January 2017)

Schouw, N.L., Danteravanich, S., Mosbaek, H., Tjell, J.C. (2002). “Composition of human excreta – a case study from Southern Thailand”. Science of the Total Environment Journal 286(1-3), p.155-166.

SNV and DevCon (2014). “Review of Legal and Other Governing Factors related to Fecal Sludge Management in Bangladesh”.

Sonko, E.M. (2008). “Traitement des boues de vidange de systemes autonomes d’assainissement a Dakar (Senegal): evaluation de l’efficacite de la separation solide/liquide de lits de sechage non plantes soumis a differentes charges de boues de vidange et a divers apports”. Memoire de DEA: Institut des Sciences de l’Environnement, UCAD. pp. 73

Spellman, F.R. (1997) “Dewatering Biosolids”. Technomic Publishing, Lancaster, United States.

Stefanakis, A. I., Tsihrintzis, V. A. (2012a). "Effect of various design and operation parameters on performance of pilotscale Sludge Drying Reed Beds". Ecological Engineering 38(1), pp.65-78.

Strande, L., Ronteltap, M., Brdjanovic, D. (2014). "Faecal Sludge Management, Systems Approach for Implementation and Operation".

Strauss, M. et al. (2003). "Co-composting of Faecal Sludge and Municipal Organic Waste". IWMI and Sandec. www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_ewm/downloads_ewm/cocomp_review.pdf (Accessed on: 23 January 2017)

Strauss, M., Larmie, S.A., Heinss, U. (1997). "Treatment of sludges from on-site sanitation — Low-cost options". In: Water Science and Technology 6, pp.129-136. (Accessed on: 21January 2017)

Strauss, M., Montangero, A. (2004). "Faecal Sludge Treatment". Duebendorf: Swiss Federal Institute of Aquatic Science (EAWAG), Department of Water and Sanitation in Developing Countries (SANDEC). (Accessed on: 21 January 2017)

Strauss, M.; Montangero, A. (2002). "FS Management – Review of Practices, Problems and Initiatives". London and Duebendorf: DFID Project R8056, Capacity Building for Effective Decentralised Wastewater Management, Swiss Federal Institute of Aquatic Science (EAWAG), Department of Water and Sanitation in Developing Countries (SANDEC). (Accessed on: 15 January 2017)

Susana (2017). http://sfd.susana.org/ (Accessed on: 24 January 2017)

The Environment Conservation Rules (1997). Government of the People's Republic of Bangladesh Ministry of Environment and Forest.

Tilley, E., Luethi, C., Morel, A., Zurbruegg, C., Schertenleib, R. (2008). "Compendium of Sanitation Systems and Technologies". Duebendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (EAWAG) and Water Supply and Sanitation Collaborative Council (WSSCC). (Accessed on: 21 January 2017)

Tilley, E., Ulrich, L., Luethi, C., Reymond, P., Zurbruegg, C. (2014). "Compendium of Sanitation Systems and Technologies". 2nd Revised Edition. Duebendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (Eawag). (Accessed on: 20 January 2017)

UNICEF and World Health Organization (2014). Progress on Drinking Water and Sanitation: 2014 Update

UNICEF (2016). http://data.unicef.org/child-health/diarrhoeal-disease.html#sthash.zSTYHbzJ.dpuf (Accessed on: 09 April 2016)

UNICEF (2016). http://www.unicefrosa-progressreport.org/opendefecation.html (Accessed on: 09 April 2016)

United States Environmental Protection Agency (USEPA) (1994). "Guide to Septage Treatment and Disposal". Document EP/625/R-94/002. Washington D.C. 20460.

United States Environmental Protection Agency (1999). "Free Water Surface Wetlands for Wastewater treatment". A Technology Assessment, EPA 832/S 99/002, various pages

United States Environmental Protection Agency (2000). "Constructed Wetlands Treatment for Municipal Wastewaters" EPA 625/R-99/010, various pages

United States Environmental Protection Agency, EPA (2014). http://water.epa.gov/polwaste/wastewater/treatment/biosolids/genqa.cfm (Accessed on: 19 February 2017)

Vesilind, P.A. (2001). "Introduction to stabilization. Sludge into Biosolids ‐ Processing, Disposal and Utilization". Edited by L. Spinosa and P. A. Vesilind, IWA Publishing, United Kingdom.

Vinnerås, B., Palmquist, H., Balmer, P., Weglin, J., Jensen, A., Andersson, A., Jonsson, H. (2006). "The characteristics of household wastewater and biodegradable waste - a proposal for new Swedish norms". Urban Water 3, pp.3-11.

Water Environment Research Foundation (2006). "Small – Scale Constructed Wetland Treatment Systems Feasibility, Design Criteria and Operation and Maintenance Requirements". Wallace and Knight, IWA Publications, various Pages

World Health Organization WHO (2015). http://www.who.int/water_sanitation_health/monitoring/jmp-2015-key-facts/en/ (Accessed on: 15 February 2016)

Worldometers (2017). http://www.worldometers.info/world-population/bangladesh-population/ (Accessed on: 12 February 2017)

WSP (Editor) (2007): Philippines Sanitation Source Book and Decision Aid. pdf presentation. Washington: Water and Sanitation Program.

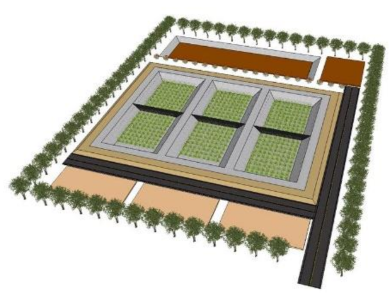
Yen-Phi, V.T., Rechenburg, A., Vinnerås, B., Clemens, J., Kistemann, T. (2010). "Pathogens in septage in Vietnam". Science of the Total Environment 408 (9), pp.2050-2053.

Appendix-1

Design criteria for FSTP

Criteria	VF-CW for FS (AIT, 2001)	DB for FS (Duchene, 1990)	SF-CW for FS (AIT, 2005)
1) Solid loading rate	125 - 250 kgTS/m2-yr 2.4 – 4.8 kgTS/m2-wk	100-200 KgTS/m2-yr	-
2) Hydraulic loading rate	0.3 – 0.4 m3/m2-d (or wk)	0.1 – 0.3 m3/m2-d	-
3) HRT	2-6 days	No impoundment	1-2 days
4) Typical bed	Big gravel 40 cm Small gravel 30 cm Sand 10 cm	Big gravel 50 cm Small gravel 10 cm Sand 10 cm	
5) Recirculation	-	-	50 – 100 % for NO3-N removal
5) Efficiency	> 90 % SS removal > 90 % BOD removal	> 90 % SS removal > 90 % BOD removal	60-80% BOD removal

Design summary for Khulna FSTP

Khulna FSTP		
Flowrate	180 m3/d	
TS	10,000 g/m3	
Area for VF-CW	6x150 m2	
Area for SF-CW	450 m2	
Maximum load HRT SLR HLR	 1.75 days 14 kgTS/m2-wk 1.4 m3/m2-wk	
Normal load HRT SLR HLR	 5.25 days 4.67 kgTS/m2-wk 0.47 m3/m2-wk	
Feeding practices to VF-CW (1-6)	Maximum (dry season)	Each of 45 m3/bed/day > for 4 beds with alternative 2days feeding and 1 day resting (total 180 m3/d)
	Normal (wet season)	Each of 30 m3/bed/day > for 2 beds with alternative 1 day feeding and 2 days resting (total 60 m3/d)
Feeding practice to SF-CW(7)	HRT = 0.87 days (Max. loads) & HRT = 2.6 days (Norm. loads)	Continuously flow through from normal and maximum loads

Operation for Khulna FSTP

	Operation	Action/Notice
1) Screening/ unload		
☑	Racking of garbage	Yes. Racking bars in manual screening at every CW separates garbage from influent.
☑	Collection of garbage	Yes. Garbage entrapped in manual screening are collected.
☑	Cleaning	Yes. Collected garbage are cleaned before use.
2) Storage and mixing		
☒	Mixing condition	No. Mixing is not done at FSTP
☑	Pumping condition	Yes. Influent discharges to the CWs by pumping.
3) Feeding program		
☑	Each of 30 m3/bed/day > for One	(see schedule below)
☐	Each of 30 m3/bed/day > for Two (total 60 m3/d)	(see schedule below)

Option	Loading design to	Day 1	Day 2	Day 3	Day 4	Day5	Day 6	Day 7	Remark
	CW1								Each of 30 m^3/bed/day Overflow pattern
	CW2								
	CW3								
	CW4								
	CW5								
	CW6								
	CW7								
	CW8								

	Operation	Action/Notice
4) Feeding for DB		
		Every day 1 to 3 m^3 for one DB depending on concentration of influent.
5) Plant monitoring		
☒	Wilting	No
☑	Small/young	Yes. Canna are young and has plenty growth. Heliconia are small and emerging slowly.
6) Retaining program		
☑	Overflow	Filtering rate measurement= 0.2 m^3/day/m^2
☑	Drain	Drainage facility is available for every CWs.
7) Samplings		
☒	Influent	Influent characteristics had been determined by various laboratory tests
☑	1# Percolate	CW (1-6). For dry season- March to May and wet season- June to August.

☑	Effluent	CW 8. For dry season- March to May and wet season- June to August.
☒	Sludge	No sludge is collected yet
☒	Plant	No plants are collected yet
8) Plant harvesting		
☒	Cutting/taking the debris out	No.
☒	Replanting	No.
9) Sludge harvesting		
☒	DB	No.
☒	VF- CW	No.

Plant inspection

	INSPECTION ADVICE		Investigating officer: Date: 20. 09.2017 Time: 2 PM Weather: Sunny			
Site Name:	Khulna Fecal Sludge Treatment Plant (FSTP)		File No:			
Client:						
Engineer:						
FSTP WETLAND OPERATION & MAINTENANCE INSPECTION CHECKLIST	☐	Need immediate attention	Clarification Required			
"As built"	Required Y/N	Available Y/N	Adequate Y/N			
"Operation & Maintenance Plan"	Required Y/N	Available Y/N	Adequate Y/N			
"Planting Plan"	Required Y/N	Available Y/N	Adequate Y/N			
Pond Components:						
Items Inspected	Checked		Maintenance Needed		Inspection Frequency	
EMBANKMENT	**Y**	**N**	**Y**	**N**	**A,S**	
1. Is the embankment level OK?	X		X		**A**	
2. Adequate vegetation & ground cover?	X		X		**S**	
3. Appropriate plants / weeds?	X		X		**S**	
4. Adequate freeboard?	X		X		**S**	
5. Embankment erosion evident?		X	X		**S**	
6. Cracking, bulging or sliding of dike						
a. Upstream face		X	X		**S**	
b. Downstream face		X	X		**S**	
c. At or beyond toe upstream		X	X		**S**	
d. At or beyond toe downstream		X	X		**S**	
7. Pond & toe drains clear & functioning?	X		X		**S**	
8. Evidence of animal burrows?	X		X		**S**	
9. Seep/leeks on downstream face?	X		X		**S**	
10. HDPE condition?	X		X		**S**	

11. Provision of access for maintenance?					
a. By hand?	X		X		**A**
b. For machinery?		X	X		
12. Other?					
Receiving tank	**Y**	**N**	**Y**	**N**	**A**
Type: Reinforced concrete ✓ Metal pipe Masonry	X		X		X
13. Low flow orifice obstructed?		X	X		X
14. Is there excessive sediment accumulation inside the riser?		X	X		X
15. Pipe condition	Good✓		Fair		Poor
16. Concrete/Masonry/plastic condition Riser and barrels:	X		X		X
a. Cracks or displacement?		X	X		X
b. Minor crack or leak?		X	X		X
c. Major crack or leak?		X	X		X
d. Joint failures?		X	X		X
e. Water tightness adequate?	X		X		X
17. Pond drain valve:					X
a. Operation/ exercised?	X		X		X
b. Chained and locked?	X		X		X
18. Others?					
WET POND (CW-7)	**Y**	**N**	**Y**	**N**	**M**
19. Undesirable vegetative growth?		X	X		X
20. Removal of floating debris required?		X	X		X
21. Visible pollution?		X	X		X
22. Evidence of edge erosion?		X	X		X
23. Other?					
DRY POND (CW-8)					**M**
24. Adequate vegetation cover?	X		X		X
25. Presence of undesirable vegetation/ woody growth?		X	X		X
26. Standing water or wet spots?	X		X		X
27. Sediment and/or trash accumulation?		X	X		X
28. Low flow channels unobstructed?		X	X		X
29. Other?					
SLUDGE					
30. Is sludge accumulation > 70% (maintenance req'd immed. If yes)		X	X		**M**
31. Provision of access for maintenance:					
a. By hand?	X		X		**M**
b. For machinery?		X		X	
OUTFALL	**Y**	**N**	**Y**	**N**	**A,S**
32. Leak or failures?		X	X		**S**
33. Condition of valve	Good✓		Fair		Poor
34. Evidence of slope erosion?		X	X		**S**

OTHER	Y	N	Y	N	S
35. Encroachments on pond or easement area?		X			X
36. Complaints from residents?		X			X
37. Aesthetics	X		X		
a. Grass mowing required?	X				X
b. Graffiti removal needed?		X			X
c. Other (specify)?					
38. Any public hazards (specify)?		X			X
CONSTRUCTED WETLAND AREAS	**Y**	**N**	**Y**	**N**	**A**
39. Vegetation healthy any growing?	X		X		X
40. Evidence of invasive species?	X		X		X
41. Excessive sedimentation in wetland area?		X	X		X

Inspection Frequency Key A= Annual, M= Monthly, S= After monthly storm

OFFICERS REMARKS

OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N
In accordance with as built plans Y / N
Maintenance required as detailed above? Y / N
Compliance with other consent conditions? Y / N
Comments: ____

Dates by which maintenance must be completed: / /
Dates by which outstanding information as per consent conditions is required by: / /

Officers signature: ____

Consent Holder/ Engineer/ Agent's signature: ______________________________

Plant evaluation

Date	BOD (inf)	BOD (#1 Per.)	BOD (Eff)	COD (inf)	COD (#1 Per.)	COD (Eff)	SS (inf)	SS (#1 Per.)	SS (Eff)	TS (inf)
Average										
Efficiency										