A systematic review on fecal sludge management in humanitarian contexts, including design considerations for Rohingya refugee camps in Bangladesh

A thesis submitted by

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In partial fulfillment of the requirements for the degree of

Master of Science in Civil and Environmental Engineering

Tufts University

February 2021

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Abstract

To improve environmental and health conditions, fecal sludge management (FSM) is a critical component of humanitarian response. To provide evidence-based recommendations for FSM, I conducted a literature review of FSM technologies for emergencies. I identified 166 documents, of which 141 were on different FSM technologies, and 25 studies were on the Rohingya refugee camp's FSM conditions. I: 1) summarized descriptions of different types of technologies for five stages of FSM; 2) presented conditions of FSM facilities in the Rohingya refugee camps; 3) identified several necessary design considerations before implementing FSM technologies; and 4) presented criteria for future studies to assess the appropriate FSM technologies in the context of Rohingya refugee camps. In this thesis, the summary of knowledge on FSM for emergencies, the design considerations, and the criteria for future studies for FSM of the Rohingya refugee camps provide a framework for evidence-based support for improving existing FSM conditions.

Acknowledgements

I would first like to acknowledge the Chair of my committee, Daniele Lantagne, for her support and mentorship over the course of my graduate studies. I cannot thank her enough for her contribution to my personal, academic, and professional growth. I would also like to thank the rest of my committee: Dr. Gabrielle M. String, for providing assistance with feedback of my evaluation of work and for continuing support of my professional development in the field of environmental health throughout my lab work, Ms. Marine Ricau for sharing his knowledge about systematic reviews in the field of Fecal Sludge Management. I would not be able to complete this work without each of my committee members. I have truly enjoyed working with them and I value everything I have learnt in the process of producing this thesis.

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Acronyms

ADB	Asian Development Bank
BORDA	Bremen Overseas Research and Development Association
CXB	Cox's Bazar
DoE	Department of Environment
Ecosan	ECOlogical SANitation
EMRCRP	Emergency Multi-sector Rohingya Crisis Response Project
FFM	Financial Flow Models
FS	Fecal Sludge
FSM	Fecal Sludge Management
ICT	Information Communication Technologies
IFRC	International Federation of Red Cross & Red Crescent Societies
IHE	International Institute for Hydraulic and Environmental Engineering
JRP	Joint Response Plan
LSHTM	London School of Hygiene and Tropical Medicine
NGO	Non Governmental Organization
OCTOPUS	Operational Collaborative Tool of Ongoing Practices in Urgent Sanitation
O&M	Operations and maintenance
OPEX	OPerational EXpenditure
Oxfam	Oxford Committee for Famine Relief
PDO	Project Development Objective
PHAST	Participatory Hygiene and Sanitation Transformation
PPE	Personal Protective Equipment
SOIL	Sustainable Organic Integrated Livelihoods
Q & Q	Quantity and Quality
UCD	Urea Cycle Disorder
UD	Urine diversion
UNESCO	United Nations Educational, Scientific, and Cultural Organization
WASH	Water, Sanitation, and Hygiene
WHO	World Health Organization

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1. Background

1.1 Introduction: Five stages of fecal sludge management

Fecal Sludge Management (FSM) in humanitarian response is an important solution to secure public health and a cleaner environment. The main goals of excreta disposal programs for a humanitarian response are: 1) minimization of contamination related high-risk practices; and, 2) reduction of exposures and fecal-oral disease transmission (Reed, 2013) (Johannessen, 2012). Failure to address FSM can lead to public health problems such as the spread of diarrhea and cholera (Grange, 2016) (Harvey, 2007).

However, up until recently, water, sanitation, and hygiene (WASH) programs have focused on water supply and treatment, latrine provision, and/or hygiene, and have neglected FSM. Increasingly, efforts are being made to develop FSM solutions globally, and specifically in humanitarian response (Yates, 2017).

Fecal sludge (FS) is the product of on-site sanitation services that has not been transported through a sewer. Examples of on-site sanitation services include pit latrines, un-sewered public ablution blocks, septic tanks, aqua privies, and dry toilets (Strande, 2014). FS is highly variable in consistency, quantity, and concentration: it is raw or partially digested, a slurry or semisolid, and results from the collection, storage or treatment of combinations of excreta and black water, with or without greywater.

FSM is the collection, transport, treatment, and safe disposal of FS from on-site sanitation services (Strande, 2014) (Figure 1). While FSM is a relatively new field, it is rapidly developing, as it is a critical intervention to *reduce the disease burden.* During the first phase of an emergency, open defecation is a key hazard in refugee camps, and insufficient resources have been invested in sanitation in humanitarian situations in the past (Johannessen 2012). Sustainable FSM is critical to preventing disease outbreaks (EMCRP 2019).

There are five stages of FSM implementation, including:

1) ***capture and storage*** of FS in a safe manner;
2) when the storage becomes full, the FS needs to be ***collected;***
3) and then ***transported;***
4) to a ***treatment*** location, to remove pathogens which may harm public health and the environment; and,
5) lastly, safely ***disposed or reused*** as fuel or fertilizer.

Proper management is needed on each stage to reduce public health risks and keep the environment safe.

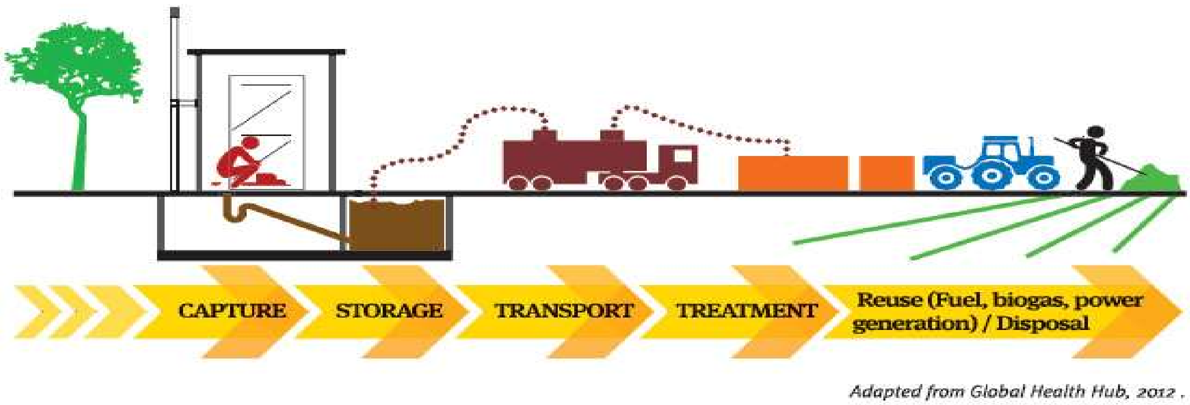


Figure 1: Fecal sludge management chain (Abraham, 2016)

In the following paragraphs, the five stages of FSM are described.

Capture & storage

On-site sanitation refers to the implementation of storage facilities to collect and store urine, excreta, greywater, and/or blackwater contained within the plot occupied by a dwelling and its immediate surroundings. For some systems, (e.g., double-pit or vault latrines), the storage technologies provide a preliminary and often a passive treatment of fecal matter, which is conducted on-site or by extended in-pit consolidation and storage. Containment refers to any structure that stores black or grey water temporarily before it is collected and transported for treatment. There is a certain level of treatment based on the type of technology. The main goal of these systems is to store the on-site generated sludge safely. Below, common storage types are discussed.

- *Pit system storage:*

  In pit latrines, human feces and urine in stored in a hole. There are different types of pit systems available: single or multiple pits, with or without partial or full seal, or composting feces and urine or not. A simple pit latrine is the most common sanitation technology choice adopted in humanitarian settings worldwide. It is simple, quick to construct, and generally inexpensive. Pre-module plastic water tanks make an excellent container for storing excreta to compost. The tanks are placed at ground level or partially buried, with the toilet block on top (Reed, 2010). Waste for pits awaiting collection should be stored no more than 50 meters from the generation point and covered if possible. (Adam, 1995)

- *Temporary storage systems:*

  Single-use plastic bags (sometimes called "packet" or "flying" latrines), buckets, or containers are an immediate excreta disposal response. Although there are various commercial options available, a simple plastic bag will often be satisfactory in the early stages (Reed, 2010).

- *Dehydrated storage systems:*

  Ecological sanitation (Ecosan) methods, such as urine-diverting dehydration toilets, biodegradable bags, and composting toilets, aim to promote safe reuse rather than disposal of excreta and are useful in flood-prone areas and locations where excavation is not possible (Rohwerder, 2017). In Haiti, SOIL designed an EcoSan toilet with a wooden frame, plastic sheeting, a fiberglass UD seat, and a plastic drum to collect the waste, which helps to reduce cost (Kilbride, 2013)**.** The main reason for separating feces from urine is to recover the nutrients, which can then be dealt with separately. The process also reduces the volume of excreta stored, and its moisture content (Reed, 2010).

- *Reduction of FS volume storage system:*

  Some technologies are available to potentially reduce the volume of fecal sludge and the rate of emptying, such as: chemical additives (strong acids and alkalis, organic solvents, ammonia); biological additives (earthworms with vermifilters, tiger worms, and black soldier fly larvae); and, composting worms (Grange 2016).

Collection

Collection services are crucial to ensure FS is safely transporting to a treatment plant. Collection technologies are categorized into manual, mechanized, or manually operated mechanical collection technologies.

- **Manual collection systems:** Manual collection technologies are used to collect FS in with high total solid content, such as from dry pit latrines, when it is not pumpable or when narrow lanes restrict access. As manual collection with buckets or shovels can be unsafe and unhygienic, it is necessary to implement minimum standards and set up systems to ensure safety through licensing, training provision, and capacity development.
- **Mechanical collection system:** Mechanical collection technologies are used to pump larger amounts of FS per trip and day than manually operated technologies. Pumps mounted manually operated trolleys or carts or mechanized options of tractors and trucks increase frequency of the collection process and provide facilities to transport the sludge over longer distances. However, fecal sludge is not pumpable when it is too thick.
- **Manually operated mechanical collection technologies:** In this process, a portable, manually hand pump, which is specially designed for sludge (e.g. Gulper, Rammer, Manual Desludging Hand Pump, or Manual Pit Emptying Technology) is used.

Overall, accessibility, affordability, industrial waste, pumpability, protection of individual health, and solid waste are some of the challenges that need to be faced based on different contexts (Nienke 2019).

Emptying and Transportation

Emptying services in low-and middle-income countries are frequently a mix of mechanical tools and a manual workforce (Reed 2016). Emptying is necessary for the areas where there are any of the following constraints: shortage of land, poor ground conditions, restriction applied by local authorities, and environmental limitations of the affected areas. The choice of appropriate technology is implemented according to the availability of equipment or technical difficulties involved in handling excreta. Emptying can be done either through the mechanical pump (Vacuum pumps, Diaphragm pump, hand-operated pumps, and manual desludging hand pump) or manual emptying (buckets, shovel, hauling rope). The reduction of sludge volume by applying sludge digesting enzymes or insects helps to reduce the frequency of emptying (Reed, 2010). Some facilities of the truck are used to collect the full drums from the toilets with cover materials and drop off clean drums (Kilbride 2013). Drums are emptied into excreta disposal handling trucks and combined with other excreta, which are collected from other camps (Patel 2011).

The eSOS (emergency Sanitation Operation System) Smart Toilet is equipped with sensors and information communication technologies (ICT) for efficient emptying operations in an emergency setting. Its responsive maintenance results in the optimization of operation cost, which increases interest to use (Zakaria 2018).

Before emptying it is important to check the storage tanks. If it is not a lined structure, emptying is not recommended as the storage tank can collapse. So, the implementation of fully lined storage tanks is needed (Nienke 2019).

Low-cost transport equipment, standardized or customized, is therefore often used for the transportation of sludge to the transfer station or treatment facility from collection or storage facilities. The sludge is collected either by gravity or by pumping to the transport. There are mainly two forms of equipment available for transporting sludge: 1) manually operated by human or animal power; or, 2) mechanized option of using a fuel-powered engine. Collectors collect fecal sludge from each of the doorsteps through modified wheelbarrows and three-wheel motorcycles (World 2019).

- Manual transportation:

  Some manual transports consist of standard carts, which are used for general transportation of materials. Besides, some are customized carts, which are designed specifically for transporting FS. Although designs vary widely, standardized carts typically consist of one or more wheels with containers of sludge, which is carried on or in a manually pulled or pushed cart (Still 2012) (Strauss 2002) (Chowdhury, 2012).

- Motorized transportation:

  Although motorized transport is more expensive than manual, motorized transport equipment provides the potential for higher load capacities and increased speed, leading to reduced travel times, and a wider range as compared to manual transport (Nienke 2019). The operation and maintenance of motorized transportation are generally more complicated than the manual transportation system. However, many variations are widely available in low-income countries. Before selecting the type of transport system, it is necessary to verify that the knowledge and skills to carry out repairs are locally available (Mikhael 2014).

The aspects that need to be considered before the implementation of the technologies for transportation of FS include:

- Selection of vehicle depends on the density of shelters, roadworthiness, maintenance, and storage when it is not in service (Reed 2016);
- Selection of sludge removal equipment: hoses, pumps, augers, and other trade tools;
- Selection of spill management equipment: shovels, disinfectants, sorbents, and collection bags;
- Arrangement of training to ensure sufficient operator skills to perform the work;
- Selection of the procedures based on the rules of the road and activities at the treatment plant; and
- Other aspects such as the use of transfer stations, worker health and safety, and emerging technologies.

Treatment

Fecal sludge treatment - through sanitization (killing pathogens) and stabilization (reducing vector attraction) - is needed to prevent the spread of diarrheal diseases (Anderson et al, 2015). The first step in the engineering treatment design approach is to understand the standards for effluent and treated sludge, resources for recovering, and/or available disposal options, as well as cost, operational and maintenance requirements, local context, existing regulations, availability (Tayler 2018) of land, and fecal sludge quantities and qualities (Q&Q) (Nienke 2019). In order to fulfil multiple treatment objectives, treatment technologies need to be interconnected in a series format. For example, if the incoming FS contains a low solids content, it will be more appropriate to be treated with a settling-thickening tank (dewatering) prior to being applied to drying beds (dewatering and drying).

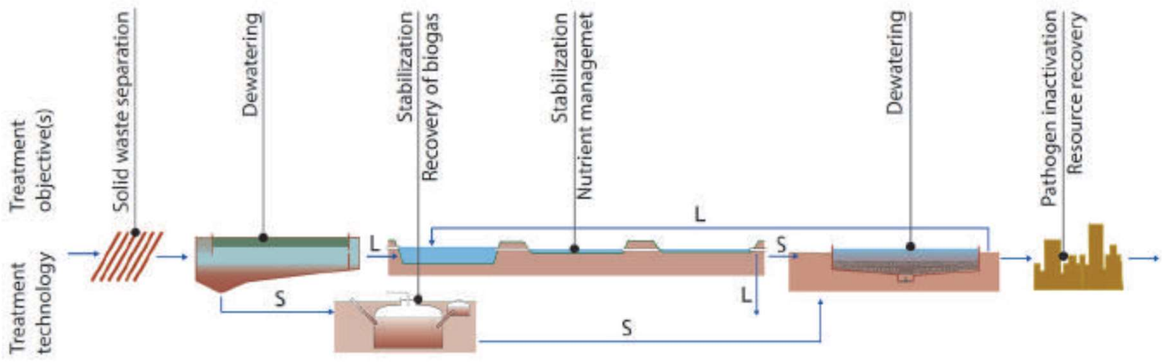


Figure 2: An example treatment plant process flow (Nienke 2019)

Several processes need to take place to treat FS. FS typically contains large volumes of water, which needs to be dewatered. The dewatering process can be achieved on its own, or in combination with solid or liquid separation process. Depending on the use of end product, further treatment needs to include converting organic matter into a stabilised form and/or pathogen reduction form. One of the key fundamentals in designing any particular series of technologies is to keep the final goal of using end product in mind. For making a dry end product to reuse in agriculture, particular care has to be paid to dewatering and pathogen reduction. If the goal is to incinerate the sludge for energy production, then dryness is very important while pathogens do not play a role.

Active drying methods such as ventilation, thermal drying (supplying heat), solar drying, and mechanical or manual turning helps to improve drying time, depending on the availability of electricity. Semi-dried and dried sludge is compressed into pellet form by various existing pelletizing machines. Conventional pelletizers require a binder to keep the pellet together (Nienke 2019).

University of Natural Resources and Life Sciences and partners developed a field laboratory for the process and public health monitoring of fecal sludge treatment plants in emergencies to ensure they operate optimally and dispose of or reuse treatment outputs hygienically. In the immediate phase of an emergency, lime treatment is still considered the appropriate FSM technology choice due to its speed of setup, the stability of the treatment process, and effluent quality. However, due to the high operational expenditure (OPEX) of lime, it is not appropriate to use it as a longer-term solution (Oxfam 2019).

Oxfam GB, UNESCO-IHE Delft Institute for Water Education, and partners developed communal toilets using composting worms that reduce maintenance and treatment requirements and improve user experience. In a trial, 99% of households opted to keep technology instead of reverting to a previous model.

WASTE and LSHTM identified, selected, developed, and tested biological and chemical additives for treating fecal sludge to provide a wider range of treatment options. They also developed a protocol that was used to assess the effectiveness of bio-additives (elrha, 2019).

Disposal

There are different technologies and methods available that can be used as an end-product after passing through the steps of storage, transport, and treatment and return to the environment, either as useful resources or reduced-risk materials. The waste, once collected and transported to a more suitable site, may be either disposed of as it is or treated before disposing into a watercourse or pit. Simple disposal is not recommended due to the high pathogen content of the waste. Some treatments require an emphasis on pathogen reduction usually. Direct disposal may be the only option in the initial stages of an emergency, and the risk may be mitigated by the addition of lime to pits (Harvey 2007).

The return of products to the environment should be done in such a way that it minimizes risks to public and environmental health. On the contrary, for the best case, the aim is to maximize the benefits of reuse by improving soils, as fertilizer. It is recommended to follow the World Health Organization (WHO) Guidelines for the Safe Use of Wastewater, Excreta, and Greywater in the technology information sheets.

The following are four types of options of End-use (Tayler 2018)

1. Dewatered solids content which is disposed to a landfill.
2. After implementing the Black soldier fly process, used as animal feed.
3. After treatment used as fuel.
4. After composting used as a soil conditioner.

Compost produced and sold to organizations and individuals (World 2019) is mixed with soil and disposed to open space (Uddin 2019). It is important to test the end product before reuse and disposal on the environment. Once the treatment process is completed and the resulting fertilizer is produced, the quality of the fertilizer needs to be tested by a skilled team to compare the nutritional quality of the fertilizer produced with chemical fertilizer and without fertilizer. (Cavalazzi 2016)

In previous reviews and gap analyses of WASH in humanitarian contexts, key FSM gaps were found to be desludging issues, including lack of appropriate equipment, how to extend the use of latrines through desludging, and how to treat the sludge or reuse it for energy advantage (e.g. biogas, compost, and recycling of wastewater) (Bastable 2013) (Rohwerder 2017).

1.2 Gaps in fecal sludge management in refugee camps

The Rohingya people have confronted regular discrimination, statelessness, and violence in Myanmar’s Rakhine State for years. Oppression has driven Rohingya refugees to cross the border into Bangladesh. Significant refugee migrations have occurred previously 1978, 1992, 2012, and 2016. In August 2017, the largest and fastest refugee influx (711,460 people) occurred from Myanmar into Bangladesh. Some 860,494 Rohingya refugees currently reside in 34 densely-populated camps formally designated by the Government of Bangladesh in Ukhiya and Teknaf Upazilas of Cox’s Bazar District. (UNHCR, 2020). In the Rohingya refugee camp, 290,000 people are getting with a FSM facilities whereas present population is 864,281. (UNHCR, 2020) Therefore, implementation of proper FSM intervention in the Rohingya refugee camps is needed to improve the WASH condition.

Despite the numerous innovations and technologies for a variety of humanitarian contexts that have emerged, there is still a gap in managing the disposal of FS during the first phase of rapid-onset emergencies and longer-term period of emergencies. (Bastable 2013) study found some of the key gaps around excreta disposal issues: latrines in areas where pits cannot be dug, desludging latrines, no-toilet options, and the final treatment or disposal of the sewage’. Some gaps and challenges around FSM include:

- **Lack of local capacity:** Lack of local capacity of desludging and disposal of fecal sludge is common. A combination of equipment is required in emergency contexts to manage fecal sludge effectively. Innovative solutions have developed for desludging in emergency areas.
- **Indiscriminate defecation**: It is important to take immediate steps to prevent indiscriminate defecation. Especially, in areas where contamination of the food chain

or water supplies may happen, such as the banks of water sources and agricultural land planted with crops (Reed, 2013).

- **Limitation of standardization**: Proper planning with communities for excreta disposal is necessary from the start of an emergency. It should be aimed to meet the Sphere Standards on excreta disposal. Sometimes implementation of the minimum standard is not able to reduce public health risk and environmental pollution. Like, toilets and pit latrines usually fill up very quickly and need to be emptied as soon as possible. However, the fecal sludge needs to be transported safely to a dumping site for disposal. (Grange 2016) study also found that lack of standardization of safety protocols and deficiency of equipment are common issues of transporting and disposing of fecal sludge.
- **Lack of available space:** A lack of available space to implement suitable sanitation infrastructure, with potential obstructions including asphalt roads, concrete structures, buildings, and service pipes for water and sewage (Grange 2016) may cause overflowing, leaking, malfunctioning, or dysfunctional toilets (Johannessen 2012). Lack of available land creates enough hindrance to the function of an effective sludge management system. For example, latrines with shallow pits located close to water points may contaminate the water of shallow tube-wells easily (Sector 2018).
- **Less absorbing capacity of soil:** The soil needs to have the capacity to absorb effluent infiltrating directly into the ground, as oversaturation will kill the worms (Furlong 2017) (T'Kint 2014).
- **Difficult to select disposal area:** It is difficult to agree on a designated area for disposal. This has led to dumping fecal sludge in uncontrolled ways.

Technologies identified to improve the gaps for emergencies, include (Susan 2012): 1) Raised latrines; 2) Improved desludging options; and, 3) Sludge disposal and treatment kits. Overall, there is a gap on FSM in refugee camps.

1.3 The importance of this thesis

To reach the potential of WASH interventions, "evidence-based' rather than 'best practice' strategies need to be considered (Yates 2017). The implementation of FSM in humanitarian contexts has not yet been systematically reviewed. While there been literature reviews of individual FSM technologies in the past (Harvey 2007) (Heinss 1999) (Strande 2014), there has been no systematic review including all FSM interventions in emergencies which incorporates information from grey literature. This thesis aims to fill this gap.

The objective of this thesis is to review the available interventions of each stage of a FSM system in emergencies and provide practical, evidence-based recommendations and guidance for designing effective FSM systems in Rohingya refugee camps in Cox's Bazar, Bangladesh.

There are gaps are found in FSM of refugee camps worldwide. The Rohingya refugee camps situated in Cox's Bazar is one of them. Therefore, I reviewed five stages of FSM and found the evidence-based technologies, which are applicable on the Rohingya refugee camps.

2. Methodology

To fulfil the objectives of this thesis, a systematic review was conducted. A detailed description of the study design, search methods used to identify FSM studies, the criteria used for selection of studies, and the filtering process used in reviewing studies are presented in this chapter.

I first conducted a literature review to identify peer-reviewed articles and grey literature on FSM in emergencies. Please note that I did not conduct a review or complete literature review for the term 'FSM' due to the overwhelmingly high volume of non-relevant information doing so would return, and instead used the following keywords:

Emergency	Disposal	Storage
Refugee camp	FSM (FSM)	Transportation
Excreta	Humanitarian crisis	Treatment
Feces	Toilet	Re-use
Sludge	Sanitation	Flood
Disaster	Collection	Earthquake
Outbreak	Latrine	Cyclone
Epidemic	Health impact	Landslide
Diarrhea	Cholera	

I searched ResearchGate, PubMed, Tisch Library, and Academia between 1995 and 2020. Additionally, I searched the authors' reference databases, reviewed technical recommendations of FSM in emergencies, and conducted reference chaining. We reviewed manuscripts for inclusion by first reading titles, then relevant abstracts, and then selecting full texts. Throughout the screening process, references were managed with Microsoft Excel 2010.

To be included, studies needed to meet at least one criteria: 1) being conducted in an emergency context, such as a natural disaster, outbreak, or complex emergency; 2) including interventions in at least one FSM stage; and/or 3) including design considerations relevant to the Rohingya refugee camp context.

Experimental, non-experimental, mixed-methods, quasi-experimental and qualitative methodological designs were eligible for review. Both peer-reviewed and grey literature documents were eligible for review.

In the research process, I: 1) mapped and document the relevant research; 2) filtered and selected the most relevant evaluation of studies for analysis; and, 3) synthesized the evidence in response to three key research question:

1. What are important characteristics for implementing FSM in emergencies?
2. What are the barriers and facilitators that affect FSM technologies in emergencies?
3. What interventions are available and needed to be implemented in the Rohingya refugee camps, Cox's Bazar, Bangladesh?

We supplemented the review with relevant technical information from non-emergency circumstances. This technical information was identified and obtained from the initial emergency specific review, as well as targeted searches of international manuals and guidance documents, manuscripts on FSM in development contexts, reference chaining, and personal reference databases and requests from representing practitioners, researchers, and academics.

As multiple interventions are available for each stage of FSM, and the implementation of these interventions depends on several factors, six factors emerged from the review that are used throughout the thesis to frame the applicability of interventions, including: 1) technical efficacy; 2) acceptability; 3) applicability; 4) cost; 5) health impact; and, 6) ease of operation and maintenance.

During data extraction, I categorized each study by FSM and key factors. For each stage, I summarized the results in a tabular format, based on these key factors.

3. Results and Discussion

3.1 Systematic Review

A systematic review process was used to identity more than 2,371 documents; ultimately, 166 studies were able to fulfil the study criteria. During the Title screening, 931 studies fulfilled the criteria of having the keywords, which are published in 1995-2020. During Abstract screening, I found 305 studies, which were either evidence-based or make positive health and environmental impact or both. Finally, I found 166 studies, which were able to answer any three of my key research questions. Among the 166 studies, 141 were for FSM technologies for different context and 25 studies were based on the context of Rohingya refugee camps.

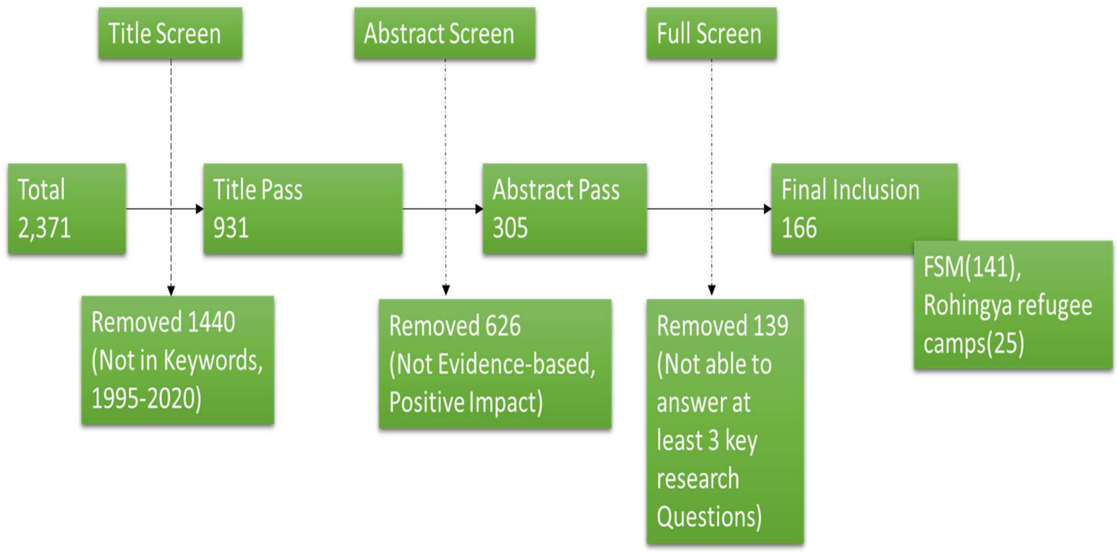


Figure 3: Screening

I summarized the results from the identified documents by:

1) Stages of FSM;

2) Establishing criteria for the Rohingya refugee camp in CXB, Bangladesh

   a) Present initiatives in Cox’s Bazar vis-à-vis FSM

   b) Design Consideration for Implementing FSM in Rohingya refugee camp

   c) Future research on what FSM methods could be appropriate in Cox’s Bazar

An overall summary of information and design considerations for FSM in the Rohingya refugee camp and adjacent area of the camps, by topic, is next presented.

3.2 Results by FSM Stage

Overall, 141 studies were reviewed according to each FSM stage (Table 1).

Capture and Storage

Table 2 describes different types of storage facilities, which are referred by on-site sanitation systems based on the review of 66 studies. These storage structures facilitate to storage of black or grey water temporarily, which can be collected and transported in a routine manner. The Table 2 describes storage system based on a number of parameters to help the reader to understand the system per their requirements. The technologies are organized based on the type of the function: Dry or wet systems, and the category of influent wastewater to the storage technologies. Moreover, this coordination of the table demonstrate different treatment processes during storage period: Biological, chemical, electro-mechanical and nature of treatment process: preliminary and passive treatment process.

Collection

Description of different types of technologies in the Table 3 develops a certain scope of application for getting the best suitable technology based on 20 studies. Since the whole chain of FSM is connected with each other, separate description of collection and emptying & transportation will make it easier to understand. The clogging tendency of solid waste of pit latrine, viscosity of sludge and pit depth are the some of the problems of collection system, which are being faced by the technologies. From the table, it is observed that the vacuum pump technologies are the most reliable comparing to the others. Another crucial issue is also detected that repairing and searching alternative parts of a complex system is challenging in the remote areas.

Emptying and transportation

Emptying and transportation of fecal sludge are closely associated with its collection process. In fact, the emptying procedure determines what would be the pattern of transportation technology. Table 4 shows the emptying and transporting technologies in either container-based, motorized or human-powered categories based on the review of seven studies. The Table 4 compares the technologies based on accessibility, tank capacity and range. The observation shows that not all the factors can be united in a perfect way. As an example, for highly congested areas, implementation of manual process, accessibility is higher than tank capacity and range. In the contrast, the implementation of mechanical process, capacity and range are higher than accessibility for the same congested areas. Another observation is the areas, where treatment and reuse facilities are far from the collection point, transfer stations are being used to reduce the distance of sludge transportation.

Treatment

The Table 5 categorize the technologies based on location-on-site or off-site, state of emergencies, the nature of treatment: natural, physical, chemical, microbial or electro-mechanical, which are reviewed from 44 studies. The comparison of different technologies in Table 5 will help a decision maker to select the appropriate technology according to his preferences. Since the cost is influenced by many factors and parameters, it is very difficult to take a precise decision to choose the perfect technology. Maintenance is also indicated as an important factor to help a decision maker to get an idea about the O&M requirement for each system.

Disposal

Table 6 shows different types of disposal procedures based on the nature of end-product based on 31 studies. There are some disposal process, which are aimed to minimize the risks of public and environmental health, whereas some process are aimed to maximize the aids of reuse, such as fertilizer, biogas etc. Moreover, it is recommended to follow the guidelines, which are given on the WHO Safe Use of Wastewater, Excreta and Greywater are referenced in the technology information sheets.

3.3 Establishing criteria for the Rohingya refugee camp

For establishing criteria for FSM technologies for the Rohhingya refugee camps at first I reviewed the present FSM conditions based on 18 studies and then in Table 7 describes the present requirements needed to establish an effective FSM in the context of Rohingya refugee camps based on 7 studies.

3.3.1 Present initiatives in Cox's Bazar vis-à-vis FSM

Present FSM condition in the Rohingya refugee camps are described in the following four parts: 1) initial conditions; 2) emerging technologies; 3) planned initiatives; and, 4) initiatives takes.

Initial sanitation conditions

Initially, latrines were built to provide safe defecation for the large population. However, latrines are limited in the Rohingya refugee camps as:

- The coverage level for latrines is low (1 latrine for 20 people) (SEG, 2020). On the top of that 89% communal latrines are functional and 11% are non-functional. (UNHCR 2020)
- According to (Hsan, 2019), 84% responders did not have good knowledge about WASH.
- Little space is available to build more latrines, due to density, topography, and lack of allocation of space for defecation. As such:
  - 32% of Rohingya refugee households face problems accessing or using latrines. (ISCG, 2019)
  - 14% of Rohingya refugee households face a problem of distance between the latrines and their shelters (WASH 2019).
  - 22% of the latrines are non-functional, as they are full or quickly fill (ISCG 2019).
  - The content of pits is at least 80% water, and may be 99% water.

- There are few roads that go through the camps, thus pit emptying equipment needs to be carried by hand using drums on bamboo poles.
- 50% of Rohingya refugee women and girls have indicated that latrines and water points are among the areas where they feel unsafe, with inadequate lighting reported as making them feel unsafe in latrines and bathing facilities at night (SEG 2020).

Due to the density and situation with fecal waste, there are risks of communicable disease outbreaks, aquifer contamination, and environmental degradation.

Emerging technologies

In later stages of the humanitarian response, the following FSM technologies being used in the camps were/are:

- Toilet/interface/containment:
    - Twin pits (direct and offset), septic tanks (with drainage field), direct pit.
- Emptying and Transportation:
    - Manual emptying and transporting with buckets.
    - Mechanical emptying and transporting:
    - Centrifugal water pump, generator with wastewater pump, 'Oxfam' motorized diaphragm sludge pump, sludge transfer tank, and vacuum pumps.
- Treatment and reuse/disposal:
    - Planted dewatering beds, vertical flow constructed wetlands, biogas plants, decentralized chemical treatment - lagoon lime treatment with dewatering bed, barrel treatment with gravel bed dewatering, barrel treatment with geotextile and gravel bed, dewatering,

- Covered lagoons into settling beds and ponds with no options for treatment of the sludge from the lagoons.
- Upflow filter.
- Lime stabilization in barrels and subsequent discharge into shallow tank. (Bank, 2019)

According to the study (Oxfam, 2019), the present FSM treatment technologies were being scored against a number of key indicators (technology, treatment process, operation & maintenance, cost, and environmental and social context) and it was found that for the longer-term, decentralized FSM technology, the up-flow filter is considered as an effective FSM technology.

At present, the FSM treatment systems are able to cover around 200,000 Rohingya people. According to Joint Response Plan (JRP) 2018, at least 30 sludge management facilities are needed to process more than 420,000 kilograms of feces per day. (SEG 2018) In addition, there is in need to construct or maintain around 50,000 latrines and 8,000 latrines need to decommission (UNICEF, 20).

Planned initiatives

There are a number of organizations with local government that have taken initiative or are planning to take initiatives (EMCRP 2019). The planning of initiatives are described below:

a. ADB (Asian Development Bank)

ADB has proposed an FSM concept, based on the characteristics of fecal sludge, literature reviews and other significant parameters of the operation and maintenance capacity within the camps. The concept proposes treating a maximum of 10,500 liters of FS every day. The FS received at the treatment facility, using vacuum trucks to be provided by the project, would be treated in various stages using different treatment modules (Bank 2019).

b. The Project Development Objective (PDO)

PDO is established for the displaced Rohingya population to emphasize the Government of Bangladesh systems. The aim of the PDO is to enhance the access of basic services and social resilience of the Rohingya population. One subcomponent of this project is to improve the entire sanitation service chain, which also includes FSM system design. The proposed interventions are expected to improve the quality, resilience, and sustainability of water services on the phases of containment, collection, transport, treatment and safe disposal of fecal matter. The following matters are being taken into account:

- Construct improved individual and chamber community latrines (including measures for gender segregation, with water source, septic tanks and solar lighting system) with resilient superstructure and raised platform (above flood level) to enhance resilience against heavy rainfall and flooding;
- Construct biogas plants to capture and combust methane for energy in the camps with flood protective measures;
- Construct integrated FSM systems, co-composting plants and waste collection facility with solar energy system, resilient superstructure, and raised platform (above flood level);
- Develop hygiene promotion, awareness program on sanitation, FSM, and safe water use;

- Provide training on Operation and Maintenance (O&M) of the WASH interventions including climate vulnerability and disaster risks;
- Complete community mobilization, which will be critical for behavioral change as well as the O&M of the facilities; and,
- Provide technical training of institutional staffs, public health workers and the community of WASH management to improve the camp sanitation as well as FSM.

c. WASH agencies and partners

According to major WASH guidance to WASH sector, improved sludge management requires about 100 acres and on-site fecal sludge treatment options for lower operations burden of latrines. WASH Sector and Inter sector Coordination Group jointly mapped for planned network (WASH 2018) and FSM (WASH 2018) for each group.

The WASH agencies of the active zones will undertake the process of desludging and transporting. The process will be coordinated by the WASH Zonal Focal Agency where necessary. To improve access to resilient and eco-friendly sustainable sanitation, EMRCRP (Emergency Multi-sector Rohingya Crisis Response Project) would execute integrated FSM system, co-composting plants and waste collection facility with solar energy system, resilient superstructure and raised platform. (Rahman 2019)

WASH partners will also place emphasis on quality monitoring and the upgrading of fecal sludge treatment facilities to improve efficiency through full chain treatment processes that address disinfection, separation of liquids and solids, biological treatment processes and the drying of sludge, in line with national guidelines (SEG 2020).

d. Local government

The Government of Bangladesh has proposed relocating some 100,000 Rohingya refugees from the camps in Cox's Bazar District to Bhasan Char, with the objective of decongesting the camps and reducing pressure on the local Bangladeshi communities. At the end of 2019, the United Nations and the Government of Bangladesh were engaged in consultations on the scope and timing of the assessment process. Upon completion of these assessments, the United Nations will be better positioned to decide upon the possibility of operational engagement with the Government's Bhasan Char project. (SEG 2020).

Local government and humanitarian organization have implemented a number of FSM technologies to improve sanitation condition on the Rohingya refugee camp, Cox's Bazar, Bangladesh. The service providers are planning to promote behaviour change based technologies on identified behaviour change determinants, thus contributing to improving waste segregation and waste composting or recycling for reducing disease transmission risks effectively and creating livelihood opportunities (Kurkowska, 2019).

Initiatives taken by the organizations

WASH Sector partners constructed 373 latrines and decommissioned 203 out of 66,615 existing latrines. An additional 15,576 latrines were desludged, 6,972 repaired and 267 upgraded. (ISCG 2020)

a. **Oxfam and UNHCR:** Considering the grave importance of proper management of FS in the refugee camp, Oxfam collaborated with UNHCR and Government of Bangladesh, to run a centralized fecal sludge treatment plant. The plant was functioning effectively by two different sewage collection systems, 1. Trucking, 2. By pipeline through pumping. Initially, this plant would work for 50,000 people, and later it would be transferred for 100,000 people of the refugee camp (OXFAM 20).The way they have initiated the sludge management process that would be very effective. Now, Oxfam is working on processing the sludge (Rahman 2019).

b. **International Federation of Red Cross (IFRC):** Centralized treatment development of the IFRC and Aerobic Fecal Waste treatment Unit for Deployment to acute emergencies Have implemented a primarily aerobic treatment of fecal sludge and wastewater plant. The plant, currently operating in Cox's Bazar, Bangladesh consists of two T45 steel tanks, pumps, aerators, glass bead filters, inline chlorination for supernatant and anaerobic digesters for the treatment of accumulated sludge. This unit currently estimates to serve a population of around 5000 people, with the possibility to scale up. Unforeseen challenges of electrical wiring and the tank panels postponed the project until after the monsoon rains. The most serious setback occurred in January 2019. Due to an incorrect speed setting on the miner, a large amount of foam began to build upon the surface of the reactor tank. However, the personnel solved the problem within a short period. The unit did not even produce any odor or attract insects. Power consumption was low, resulting in low operating costs. The recent review of FSM in Cox's Bazar, Bangladesh carried out by Oxfam and scored the system as high in effectiveness and efficiency. The humanitarian sector determines the nature of human waste, plans an appropriate response, and monitors the performance of a waste treatment method in an emergency field setting. (IFRC 2019)

3.3.2 Design Consideration for Implementing FSM in Rohingya refugee camps

This design consideration is described based on the review of 31 studies. The following steps are needed to design an effective FSM (Oxfam 2019), each further described below:

- Initial assessment
- Guidance
- Site selection
    - Environmental challenges
    - Technical consideration
- Cost
- Health and safety context
- Social consideration
- Behavioral change.

Assessment of initial situation

The objectives of the assessments for the initial stage are to set the scene, understand the context, get to know the stakeholders, and provide enough information to start elaborating on the FSM scenarios. It is important to analyze the profile and practices of the manual and mechanical service providers. Data collection helps to estimate the quantities and qualities of fecal sludge and context to design parameters for future fecal sludge treatment plants. The best way to acquire accurate information is to collect it from different sources and then validate the data. All the existing data can be collected through government documents, old project reports, and existing maps. The data need to be analyzed based on the stakeholder and the enabling environment, which consists of the six following categories:

- Governmental support

    - The legal and regulatory framework
- The gaps
- The available skills, and capacities, especially in terms of human resources and management
- Financial arrangements
- Socio-cultural acceptance of the different context

The data collection should focus on collecting spatial data on the demographics, environment, and technical information and establish fecal sludge quantities and qualities. Data can be collected by the following methods: sampling campaign, household survey, interviews with stakeholders, focus group discussions, and mapping. These data can be analyzed in different formats depending on the form of data collection and the reader. As a result, the data will be displayed and communicated in a meaningful way. These data will help to understand what would be appropriate for the targeted audience (Nienke, 2019).This information is gained by conducting an initial assessment of technical, environmental, and social factors. It is needed to determine whether the implemented technologies will be able to be accustomed to the population. Moreover, it needs to determine the existing environmental conditions, especially the difficult situations (high water-table, difficulty in excavation, flooding, and crowded urban areas) (Harvey 2007).The characteristics of the incoming sludge have an intensive influence on technology choice, treatment efficiency, and costs. It is needed to compare sludge characteristics to typical parameters (from the extensive literature). The (Oxfam, 2019) study has shown that the fecal sludge of CXB is generally within the expected range for pit latrines and septic tanks (in developing countries). The study also gives some confidence that the findings from CXB can apply to other geographical contexts. The site data showed that the FS in CXB has a relatively low proportion of solids, comes in high volumes, and has low levels of nutrients, likely due to the low levels of cleaning products entering the wastewater.

Guidance

The services of providing improved on-site facilities of using to contain excreta, measuring the level of quality, and accessing facilities for each of the stages of emptying, conveyance, treatment, and disposal are collectively called FSM services. These services need to include national sanitation policies. Clear institutional roles and enforceable regulations should be considered before implementing FSM at the local level. The service provides a planning and budgeting process for FSM (Ross, 2016). Any planning should use the internationally-recognized Sphere Standards which set out the minimum service levels for excreta disposal (Reed, 2013) (Grange, 2016). For instance, in the early stages of an emergency the maximum number of people per toilet should be around 50, falling as more sanitation facilities can be built (Grange, 2016). The WASH agencies of WASH Sector of CXB has developed technical guidance notes on the context of the Rohingya refugee camp of CXB. The Operational Collaborative Tool of Ongoing Practices in Urgent Sanitation (OCTOPUS) and BORDA guidance can also be referred to, as well as the Bangladesh Department of Environment (DoE) standards (OCTOPUS, 2019).

Site selection

The average lifetime of a refugee camp is 17 years (Jennings, 2018). To construct an FSM system, raw materials should come from the local area (EMCRP, 2019).

Additionally, a suitable elevation above high flood level needs to be considered in the design by utilizing an accurate topographic survey.

Environmental challenges

Before developing FSM design, some environmental challenges (high water tables, unstable sandy soils, and crowded urban areas) need to be considered (Johannessen, 2012).

The following guidelines for flood-prone areas are given below:

- During flooding time, it is recommended to avoid decommissioning;
- During the ground of a septic tank or leech field is covered with water, it is recommended to desludge the septic tank, improve leech field drainage and prioritize essential sanitation facilities.
- During the post-flooding phase, it is recommended to:
    - Decommission all the latrines in the flooded areas,
    - Perform desludging by wearing PPE,
    - Pump the sludge from the flooded septic tanks,
    - Treat each sludge with lime solution,
    - Carry treated sludge to a safe disposal location,
    - Upgrade all storm water-filled septic tanks and latrines to avoid stormwater infiltration,
    - Disinfect storm-filled latrines and FSM with a mixture of 0.5% chlorine solution. (WASH, 2018)

Technical consideration

For collecting fecal sludge, manual emptying may affect public health. So, the provision of vacuum trucks with pumps and hose are considered in the design for the motorized collection system. The long hose pipe is considered to cover the pits located in the inaccessible hilly area where the collection may be impeded. Disinfectant is used for the spillage if spillage may happen during sludge collection. Spillage of sludge could affect public health and the environment adversely. When thick and sludge at the bottom of the pits is not being pumped easily, a long spade or jetted with a water hose can be used for compacted layers of the sludge. (Sector, 2018) defined the following minimum requirement of desludging:

- Provide protective clothing and immunization to people who deal with the desludging system
- Empty pits or storage tank when those full at 80% in less than two weeks (in the principle of rotational desludging mechanism)
- Follow the safety guidelines provided by the WASH sector for people working in desludging operations

During transportation, spillage may occur that may affect public health and the environment. Chemical disinfectants need to be used to minimize the problems. The daily basis checks of the vacuum trucks before the operation are needed to avoid a traffic accident. Moreover, the speed limit of the trucks needs to be restricted to 20 km/hr. A well- defined schedule and route will help to avoid traffic congestion. (EMCRP, 2019).

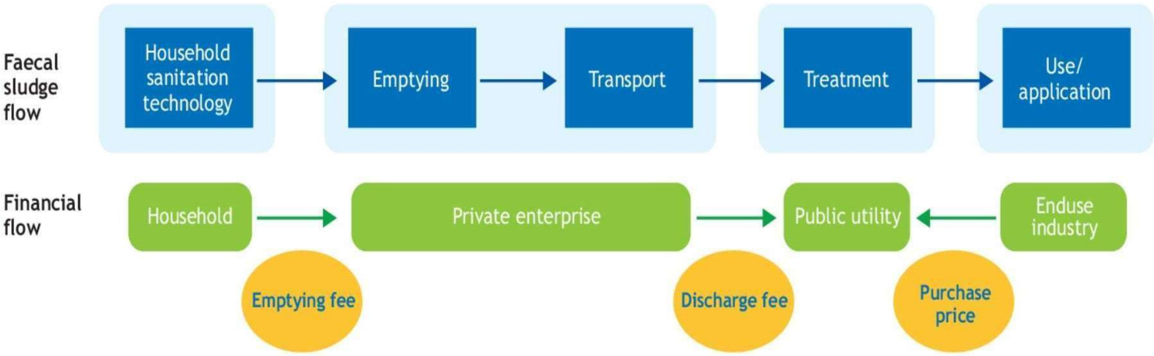
Treatment is required to reduce the pathogen content at a safe level to alleviate the health risk to an acceptable limit (Tayler, 2018). This application has been practiced by using chlorine, lime, and other means. Although the effectiveness of these strategies *in situ* in reducing target microbial contaminants has not been formally assessed and deserves greater attention (Brown, 2012).

The absence of proper management reusal and disposal of compost may increase the risk of environmental degradation and health hazard to the workers and other people. To avoid the risks, the quality of the compost needs to be monitored regularly according to the recommended standards.

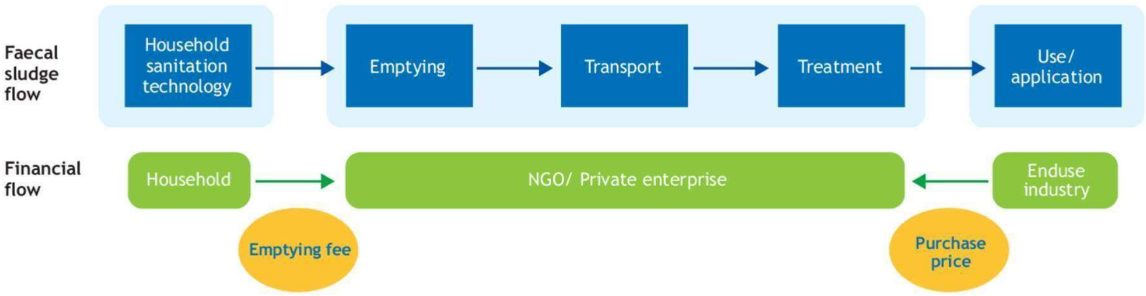
Cost

In CXB, a large portion of construction costs needs to be spent on the slope stabilization work and geotechnical site preparation, which may not be needed in a different location. The cost of FSM plants is also difficult to estimate (geographically) due to the varying cost of local material, equipment, and charges of workers.

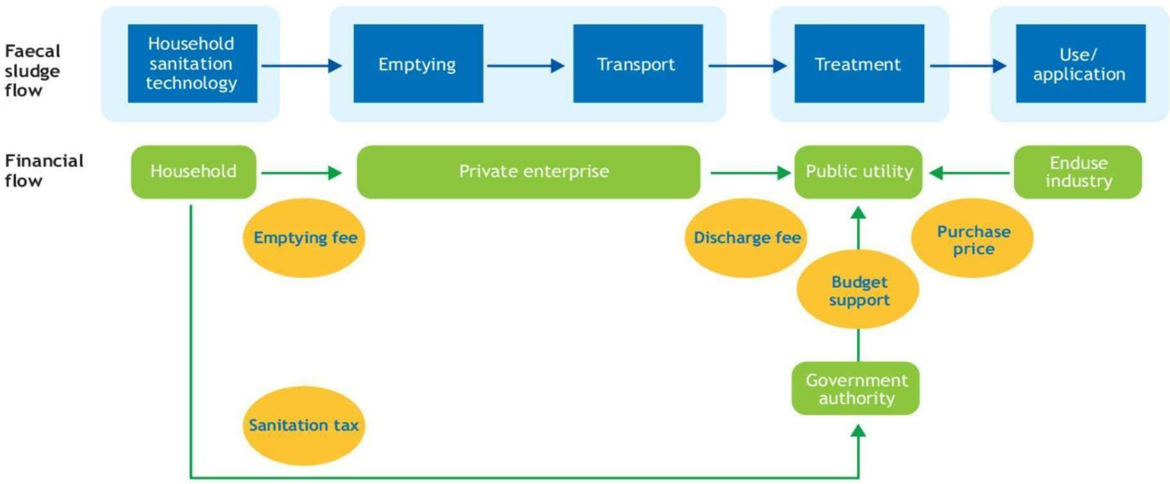
Due to the complex nature of FSM and service delivery, some financial flow models (FFMs) have already been developed (OECD, 2017). These models help to consider what kinds of FFM will apply according to the context of the area.



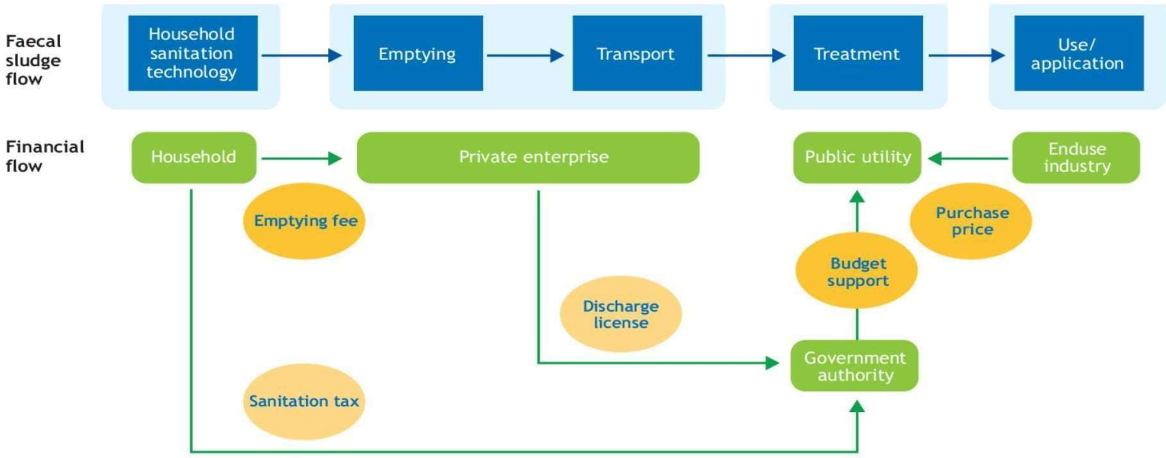
Model 1: Discrete collection and treatment model



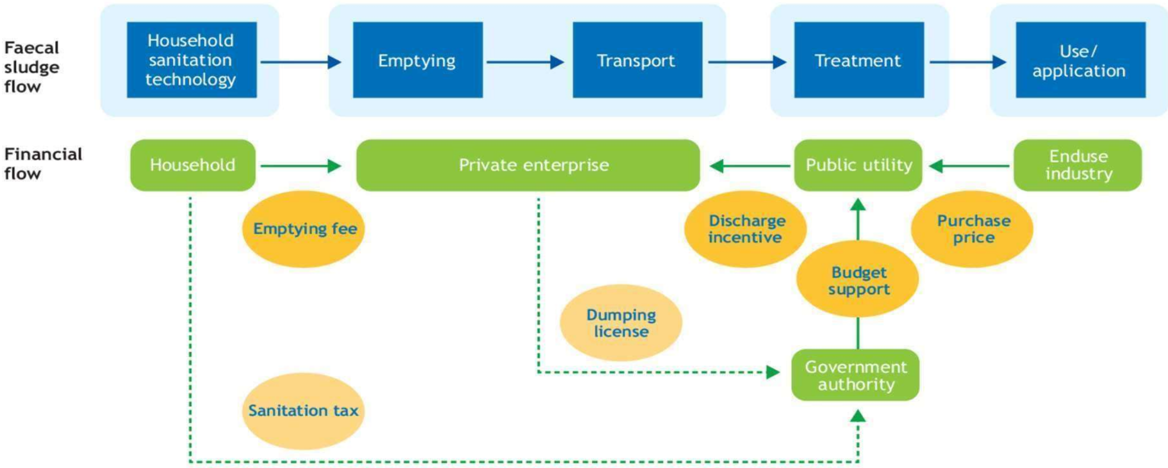
Model 2: Integrated treatment and collection model



Model 3: Parallel tax and discharge free model



Model 4: Duel licensing and sanitation tax model



Model 5: Incentive discharge model (Steiner M., 2003)

Figure 4 Five most common financial flow model in sanitation (Strande, 2014)

Health and safety context

The primary purpose of FSM in emergencies is to sustain or improve health by minimizing the transmission of disease-causing pathogens. Limited access to improved sanitation and improper human waste disposal increases the risk of diarrhea-related morbidity and mortality. With the rapid influx of refugees and constrained sanitation options, conditions in refugee camps are challenging (Breiman, 2009) (Biran, 2012) Kalipeni, 1998).

Implementing well- designed sanitation solutions that aim to decrease exposure to human fecal waste can prevent diarrheal disease in refugee camps (Clasen 2015), (Fewtrell, 2005).

Health and hygiene issues, therefore, have particular relevance when conducting any assessment. These are especially important to determine the key risks to the affected population and to identify intervention priorities. The current health status of the affected people and potential threats to health are key assessment indicators. In an emergency, Crude Mortality Rate (CMR), in death per 10,000 people per day, is the most efficient indicator of the health status of a population. Morbidity rates for excreta-related diseases can also be useful indicators. Assessment of the available clinical data helps to determine the relative prevalence of diseases to identify the key risks and priorities. It is hard to assess whether all sections of the population are aware of priority hygiene practices (Harvey 2007).

The provision of adequate sanitation facilities is a key measure to ensure that morbidity and mortality are low immediately after a disaster (WHO, 2006). Fecal-oral diseases are the reason for more than 40% of deaths in the acute phase of an intervention (Anderson, 2015). (Lin, 2008) showed that cases of diarrhea dropped from 11.2 cases/1000 to 3.6 cases/1000 within nine days after implementing interventions of latrine repair with other flood response measures. Moreover, latrine coverage helped to reduce diarrhea cases from 6.6 cases/100 people to 3.5 cases/100 people in a refugee camp formed in Nepal (Puddifoot, 1995).

Social consideration

In the context of social acceptability, awareness campaigns need to organize emphasizing the requirement for sorting at source, waste collection, and participatory role of residents in waste management in an area. Implementation of proper waste handling practices helps to reduce foul smell and the impact of odors. Acceptability also can be increased by providing job opportunities for local people during the construction and operation phase of an FS (Bank, 2019).

Cultures, acceptance, and socio-economic benefits need to be considered before designing FSM facilities. The users need to be aware of or involved in the type of treatment or disposal system. More thoughts should be given to using mechanical means to prepare defecation areas. The local community should be aware of precision of the function of the technology. For example, for trench latrine cutting a deeper trench, controlling the width, the weight to move the latrine structure. The entire community should be motivated and made aware by working teams of the camp who provide basic messages on general hygiene and appropriate use of water and sanitation facilities. Safe disposal off-site should be chosen after consulting with the local authorities. The consultation helps to find out what is culturally acceptable and how much awareness of sanitation the community already has. Before implementing FSM technologies, the following social issues need to be considered:

- Previous experience of refugees in sanitation;
- Sanitary habits in the country of origin (disposal of wastes including garbage and excreta);
- Taboos (water use, reuse of excreta as a fertilizer, gender issues),
- Religion(s);
- Health education; understand the linkage between the environmental sanitation and health (water contamination linked to gastroenteritis, soil pollution linked to intestinal parasites) (Adam, 1995).
- Conception of the communities, which helps to promote self-respect and self-reliance for the community

These issues help to increase the contribution of improving sanitary and hygiene conditions in the camps where soil and water contamination may occur due to untreated fecal discharge to the environment. As a result, the motivation helps to produce agricultural fertilizer and a safe renewable energy source for community use (EMCRP, 2019). According to (Johannessen, 2012), it is also important to understand how the available technical options help to support the community by providing emergency excreta disposal facilities.

Interviews in the rapid assessment include current beliefs and traditions concerning excreta disposal, especially regarding women and children's excreta; where are people prepared to defecate, and whether disabled and elderly use these facilities; and what are the environmental conditions to consider (Rohwerder, 2017).

Some technologies have been introduced based on social consideration. As an example, the implementation of the peepoo bag helps to reduce shame for women and sexual abuse. It is in-home to use technology and helps to contain odor (Patel, 2011).

Behavioral change

A framework is designed for behavior change before implementing the interventions. It has a pathway to change through the following five components:

1. Promoting the designed behavior;
2. Implementing among the priority and/or influencing group;
3. Focusing on the determinants, which are the most critical barriers and facilitators;
4. Promoting the bridges to activities;
5. Implementing the activities.

Some key findings on the context of behavior change of population are analyzed in (Jennings, 2018) paper. Due to the extra cost involved in lining the latrine, desludging is a rare occurrence.

Implementation of the provision of latrines helped to change behavior in a refugee camp formed in Nepal. There, 98% of beneficiaries reported that they stopped their traditional practice of open defecation. On the other hand, latrine provision in the Andaman islands after the tsunami in 2004 was unaccepted by the population and did not stop open defecation. Because, the latrines were 'too far', 'poorly lit', and lacked privacy. (Pinera, 2006)

In Ugandan camps, housing South Sudan refugees, some users – especially women, the elderly, pregnant mothers, people with disabilities, and children – do not consider sanitation facilities appropriate, which leads to vandalism and conflicts. The project team focused on how to adapt the superstructure built over the pit to meet user preferences.

The team has developed a hybrid participatory hygiene and sanitation transformation (PHAST), a user- centered design methodology that includes a toolkit adapted from cognitive-behavioral theory, and a nudge theory to promote behavioral change. These interventions were developed, prototyped, and tested by the WASH field staff. The toolkit specified a process for identifying culturally recognizable WASH icons. (elrha, 2019)

Human attitudes with sanitation facilities are complex and culturally varied. Oxfam subsequently monitored and evaluated five pilot projects implemented by Qatar Red Crescent Society in Lebanon, Save the Children UK in Bangladesh and Iraq, and Welthungerhilfe in Uganda with each partner testing different UCD and community engagement projects. These findings indicate that a lack of time, accessible guidance and construction constraints result in limited community engagement. Findings also indicate that by enhancing projects, community consultation, and building sanitation facilities according to which suit users' better, result in increased satisfaction (Gensch 2018). (elrha, 2019)

To address these challenges, the following steps need to be considered before starting to design (elrha 2019):

1. Develop interventions rapidly to design better sanitation facilities for the affected communities;
2. Develop alternative solutions for fecal sludge storage, collection, transportation, treatment, final disposal, and reuse;

3. Develop and effectively disseminate guidance on determining fecal sludge disposal sites in emergencies; and,
4. Develop interventions to increase social acceptance like understanding the link between lighting in latrine areas and gender-based violence.

3.3.3 Future research on what FSM methods could be appropriate in Cox's Bazar

In the future, research needs to be done to develop criteria and assess technologies for each stage of FSM based on the following six criteria for the Rohingya refugee camps' context:

1. Technical efficacy

This section gives a concise indication of the main features and functions of specific technologies. It also provides general direction for the immediate evaluation and classification of technologies and their suitability for an envisioned FSM context.
To describe technical efficacy, this section pointed out the effective functions of FSM technologies of different stages. Apart from other influential factors, this factor is described only the technical function of the technologies. This section gives information on the potential for replicability, scalability and the speed of implementation. It described the nature of techniques of the technologies, like whether the simplicity of infrastructure, how easily that would be handled, how long it take to set up work and function of each part of the technology. After reviewing the present management of Fecal sludge condition of the Rohingya refugee camps, I found what kinds of technical efficacy of FSM technologies is needed in the context of Rohingya refugee camps at CXB, Bangladesh, which is described in Table 7.

2. Cost

Costs are another key decision criteria to consider. Each technology has costs associated with constructional, operational, maintenance and management costs. Moreover, each technology has cost effects for other technologies in a FSM chain. For example, a single pit latrine requires regular emptying and therefore equipment, workers and time are needed for the task of emptying, which are usually not accounted with the constructional cost of pit latrine alone. Costs are dependent upon the local availability of materials, land and wage of local workers, which are not absolute. However, this section presents the main cost elements associated with a technology by allowing for a first approximation.

3. Applicability

Applicability is a factor that is described based on the contexts in which a technology is the most appropriate. This section indicates a technology's applicability in terms of phases of an emergency, density of population, type of setting, distinguishing between rural or urban, short-term or a longer-term settlement. There are three types of phases of emergency: 1.Acute response phase, 2. Stabilization phase, 3. Recovery phase. (Berlin, 2015) The acute response phase usually covers first few hours and days up to first few weeks immediately following natural disasters, conflicts, protracted crises or epidemics until more permanent solutions can be found. Whereas the stabilization or transition phase usually starts after the first weeks of an emergency and can last several months to half a year or longer. The recovery phase refers as a continuation of already executed relief efforts and be prepared the place for successive development interventions and gradual handing over to medium or long- terms. In addition, other physical considerations of applicability are listed here, including soil conditions required, water availability needed and ground water table considerations.

4. Acceptance

Acceptance is a crucial element when deciding on specific FSM technologies, especially at the storage, or an entire FSM system. There are potential cultural preferences, behavior changes and community engagement as well as local capacities that may be challenging, sometimes impossible or inappropriate to change. Since along with skilled personnel, local community needs to be engaged to operate and maintain an FSM technology, it needs to be accepted by the community.

This factor is described how generally an FSM technology is being well accepted by a society based on their previous experience with that technology or consulting with the community before implementation that.

5. Health Impact

All the FSM technologies have environmental and public health impacts. The health impacts or risks described in this health section, which should be considered during planning to reduce health risks in the local community and among FSM personnel and staff. In addition, this section leads to take decisions of including and excluding a technology by describing an overall risk management procedure. Providing personal protective equipment (PPE) and immunization of workers are listed as a guarantee of personal safety.

6. Ease of Operation and Maintenance

Every technology requires operation and maintenance (O & M) over a prolonged period of time. During design consideration, the implication O & M of each technology needs to be considered. However, without appropriate O & M many technologies may fail. The section of O & M consider main operation tasks and required maintenance to guarantee longer term operation. In addition, this section points out different O & M skills, provides an indication of frequency of O & M tasks and the time required to operate and maintain a technology. A list of possible misuses and drawbacks to be aware of is also provided. For implementing FSM technologies in the context of Rohingya camps, those technologies are preferred which need simple, easy maintenance and low and less skilled personnel.

3.4 Recommendation and opportunities for future research

It is clear from the results of the review that some of the most commonly implemented FSM technologies of different stages in emergencies are severely under-researched. We need additional research for: proper treatment, disposal and transportation system, sludge volume reduction technologies, environmental and public health impacts and cost- effectiveness.

FSM does not become effective enough, as the Rohingya refugee camps do not get enough sanitation facilities at all. The design consideration described above will be able to develop a model to implement an effective FSM on different camps of the Rohingya refugee camps in CXB. This FSM design will consider all the necessary aspects based on the described and analyzed evidence-based FSM technologies, which are context specific. Future recommendation would be:

- Implementing a pilot study of having clean five step of FSM with considering all the design consideration.
- Keeping consistency and robusting evaluation, the result generated from the future modelled pilot study will help to know whether the considered factors are enough to establish an effective FSM or will be needed to consider other factors.
- Identifying intervention factors that lead to more scalable and more timely response.
- Evaluating interventions fulfilling guidelines and maximum satisfactory level.

Although all are evidence-based successful interventions, the intervention will not give the maximum outcome because of the factors of social acceptance, applicability, health outcome, behavior change are varying with time and context.

3.5 Limitations

There are some biases were inherent in the search strategy as defined in the methodology, including: 1) database searching was completed in English and Spanish. It is likely there is additional information in other languages not searched; 2) keywords searched may not have captured all relevant studies with variations of technology names or names in local languages; and, 3) the web-based searches were limited by the fact that organization websites were limited because of its different structures. During reviewing the studies, it was more difficult to:

1) Identify whether an intervention related to FSM technologies or not, as technologies of sanitation such as parts of sewer based management system, waste management system, which has industrial and domestic waste;

2) Assess whether application of FSM technologies in the same geographic location will be same in the context of emergencies; and,

3) Search and extract information from grey literature, as grey literature documents often included information beyond the scope of evaluation and lacked consistency in format, definition, structure and objective.

Despite these limitations, the strength of this review is in its broad inclusion criteria that lead to ability to inform decisions in Cox's Bazar.

4. Conclusions

A systematic review process was used to identity more than 2,371 documents; ultimately, 166 studies were able to fulfil the study criteria. I evaluated 141 studies for FSM technologies for different context and compared that with 25 studies on the context of Rohingya refugee camps. I found that: 1) Description of different types of technologies for five stages of FSM; 2) Present condition of FSM facilities in the Rohingya refugee camps; 3) Several necessary design considerations before implementing FSM technologies; and 4) The criteria for future studies to assess the appropriate FSM technologies in the context of Rohingya refugee camps. In this manuscript, the summary of knowledge on FSM for emergencies, and the design consideration, and the criteria for future studies for FSM of the Rohingya refugee camps provide evidence-based support for improving existing FSM conditions. I hope that this systematic review will be helpful for the future FSM implementers, beneficiaries and researchers of the Rohingya refugee camp, CXB, Bangladesh.

Table 1: FSM stages described in each included document from systematic review

No.	Name of Study	Capture & Storage	Collection	Transportation & Emptying	Treatment	Disposal
1	Adam-Bradford 2016					✓
2	Adams, 2002	✓				
3	Ahrens, 2005					✓
4	Anderson, 2015	✓				
5	Annis, n.d.		✓			
6	Arif, 2020				✓	
7	ARGOSS., 2001	✓				✓
8	Atwijukye, 2018					✓
9	Austin, 2002					✓
10	Ave, 2020				✓	
11	Bank, 2019				✓	
12	Banks, 2014	✓				
13	Blume, 2009	✓				
14	Bhagwan, n.d.		✓			
15	Boot, 2007		✓			
16	Brandberg, n.d.		✓			
17	Brdjanovic, 2015	✓				
18	Burt, 2019	✓				
19	Brikké, n.d.		✓			
20	Chakraborty I., 2014	✓				
21	Cheng, 2014	✓			✓	

No.	Name of Study	Capture & Storage	Collection	Transportation & Emptying	Treatment	Disposal
22	Chowdhry, 2012			✓		
23	Cointreau, 2004					✓
24	Crites, 1998					✓
25	Deegener, 2015	✓				
26	Delft, 2003				✓	
27	Deublein, 2011					✓
28	Dotro, 2017				✓	
29	Eales, 2005			✓		
30	Eastman, 2001				✓	
31	Enayetullah, 2015				✓	
32	elrha., 2019	✓				
33	EPA., 1999					✓
34	EPA, 2000				✓	
35	Evans, n.d.		✓			
36	Eyrard, 2011	✓				
37	Foxon, 2012		✓			
38	Foxon, 2004	✓			✓	
39	Fulford, 1996					✓
40	Furlong, 2015	✓			✓	
41	Furlong C., L. J. 2017	✓				
42	Furlong C., R. N. 2017	✓				
43	Furlong, 2014	✓			✓	

No.	Name of Study	Capture & Storage	Collection	Transportation & Emptying	Treatment	Disposal
44	Furlong, 2014				✓	
45	Gensch, 2018					
46	Gensch, 2010	✓				
47	GIZ.,n.d.					✓
48	Godfrey, 2012		✓			
49	González, 2014	✓				
50	Graham, 2013	✓				
51	Gur, n.d.		✓			
52	Harvey, 2007	✓	✓	✓	✓	
53	Harvey, 2002	✓				
54	Hebert, 2010					✓
55	Heinss, 1999				✓	
56	Hoffmann, 2011				✓	
57	Institute, 1996	✓				
58	Iqbal, 1999					✓
59	Ireland, 1997				✓	
60	Jenkins, 2005					✓
61	Johannessen, 2012	✓				
62	Kayombo, 2004				✓	
63	Kengne, n.d.					✓
64	Kone, 2012			✓		
65	Khatavkar, 2013	✓			✓	

No.	Name of Study	Capture & Storage	Collection	Transportation & Emptying	Treatment	Disposal
66	Kramer, 2013	✓			✓	
67	Ligocka, 2004	✓				
68	Malambo, 2014	✓				
69	Mamani, 2016	✓				
70	Mang, 2010	✓			✓	
71	Mara, 1996	✓		✓		✓
72	Mijthab, 2011	✓				
73	Mikhael, 2014		✓	✓		
74	Monvois, 2010	✓				
75	Morel, 2006	✓			✓	✓
76	Morgan, 2011	✓				
77	Morgan, 2007	✓				✓
78	MSF., 2010		✓			
79	Muellegger, 2012				✓	
80	Nienke Andriessen, 2019				✓	
81	Nordin, 2009	✓				
82	O'Riordan, 2009		✓	✓		
83	Organization, n.d.	✓				
84	Oxfam., 2008	✓				✓
85	Oxfam, 2019				✓	
86	Palada, 2011					✓
87	Paul, 2005				✓	

No.	Name of Study	Capture & Storage	Collection	Transportation & Emptying	Treatment	Disposal
88	Pickford, 1995	✓				
89	Pitt, 2005				✓	
90	Puddifoot, 1995	✓				
91	Ramnarain, 2019				✓	
92	Reade, 2016	✓				
93	Reed, 2014	✓				
94	Reed, 2010	✓			✓	
95	Reed, 2016	✓				✓
96	Rieck, 2012	✓				✓
97	Robbins, 2014				✓	
98	Rose, 1999	✓			✓	
99	Rothenberger, 2006				✓	
100	Schönning, 2004					✓
101	Seiler, 2007					✓
102	Sklar, 2017	✓				
103	Sharrer, 2010					
104	Shilton, 2005				✓	
105	Sozzi, 2011	✓				
106	Spit, n.d.		✓			
107	*Start Thinking PeePoople*. (n.d.).		✓			
108	STILL, n.d.		✓			
109	Still, D. 2012					✓

No.	Name of Study	Capture & Storage	Collection	Transportation & Emptying	Treatment	Disposal
110	Still D. F., 2012		✓			
111	Strande, 2014	✓		✓	✓	✓
112	Strauss, 2003				✓	
113	Strauss, 2002					
114	Tayler, 2018				✓	
115	Tchobanoglous, 2004				✓	✓
116	WASTE, 2015		✓			
117	Tilley, 2014	✓				
118	Tilmans, 2015	✓				
119	Ulrich, 2009	✓			✓	
120	UNHCR, 2018	✓				
121	UNICEF, 2012	✓				
122	University, n.d.		✓			
123	USAID, 2015	✓				
124	Vinnerås, 2007	✓				
125	Vögeli, 2014	✓				
126	Von, 2005				✓	
127	Wall, n.d.		✓			
128	Ward, 2014					✓
129	Ward, 2017					✓
130	WASHCost, 2012	✓				
131	WEDC, 2012	✓				

No.	Name of Study	Capture & Storage	Collection	Transportation & Emptying	Treatment	Disposal
132	WEDC, 2013	✓				
133	WEDC. (2014). Latrine pit design	✓				
134	WEDC. (2014). Latrine superstructure	✓				
135	WEDC, 2017	✓				
136	WHO, 2006				✓	✓
137	Winblad, 2004					✓
138	World, 2019	✓				
139	Zakaria, 2018	✓			✓	
140	Zakaria, F. H. 2016				✓	
141	Ziebell, F. G., 2016				✓	
		66	**20**	**7**	**44**	**31**

Table 2: Information from included documents on storage

Name of intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Deep trench Latrine	Construction occurs rapidly, several cubies aligned up above a trench and lining prevents collapsing	Relatively inexpensive and varies on local facilities	Suitability depends on the soil, climate and water-table condition (not suitable for flood-prone areas, rocky soil and having high water-table)	Knowing the preferences of local users by discussing with the local community before installation	Using and managing well to ensure safe excreta disposal and hygienically emptying trench to minimize the risk of diseases transmission	Regular cleaning, measurement of awareness and monitoring trench filling level routinely	(Reed 2010), (Adams, 2002), (Harvey, 2007) (Harvey 2002) (Reed, 2016)
Bore hole latrine	Boring a hole by either mechanical drilling machine or by manual auger where implementation of larger pit is Difficult	Inexpensive and varies on local facilities; no hard data for prices	Stable soil; free of rock, gravel and boulder, unsuitable for flood-prone, rocky soil and high water-table areas	Knowing the preferences of local users by discussing with the local community before installation	Assessment of permeability of soil and groundwater(GW) level are needed before installation to avoid GW as well as drinking water contamination	Regular cleaning borehole top to reduce odor and flies, preferring decommission instead of desludge	(Harvey, 2007) (WEDC, 2013)
Prefabricated Latrine	Pit is lined with prefabricated material which do not allow to leach waste water through surrounding soil and GW	Relatively low cost technology US$375- 6000	All phases of emergencies and suitable for flood-prone areas and GW table is high	Knowing the preferences of local users by discussing with the local community before installation; appropriate use and facilities increase acceptance	Using and managing well to ensure safe excreta disposal and hygienically emptying trench to minimize the risk of diseases transmission	Carefully emptying the pit to avoid any fracture of prefabricated material	(UNICEF 2012) (WEDC 2012), (Lukas 2016)

Name of intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Single pit Latrine	Limiting the rate of accumulation by allowing the leaching of water and urine into soil, consolidation and degradation of organic matter	Low cost technology basic level service ranges from US$ 1-4 per person	Densely populated area where emptying is difficult, not suitable for rocky, compacted of flood-prone areas.	Knowing the preferences of local users by discussing with the local community before installation; appropriate use and facilities increase acceptance	Using and managing well to ensure safe excreta disposal and hygienically emptying trench to minimize the risk of diseases transmission	Regular cleansing, checking the function routinely; emptying by desludging or removing structure; handling responsibilities of maintenance	(UNICEF 2012) , (Adams, 2002), (Harvey 2007), (ARG01) (Graham, 2013) (Pickford, 1995) (Institute, 1996), (Reed 2014), (Reed 2016), (WASHCost 2012)
Vandalized Improved pit latrine(VIP)	Improvement over single pit latrine with continuous air flow through vent pipe, which prevents odor and acts as a trap of flies	Low cost Technology US$ 70–400	All phases of emergencies and not suitable for rocky and flood-prone areas	Knowing the preferences of local users by discussing with the local community before installation; appropriate use and facilities increase acceptance	Using and managing well to ensure safe excreta disposal and hygienically emptying trench to minimize the risk of diseases transmission	Lack of leaching makes sludge accumulation rate is high, therefore regular desluging by vehicles need to be considered	(UNICEF 2012), (Harvey 2007), (Morgan, 2011), (WEDC 2012) , (WEDC 2014), (WASHCost 2012)
Twin pit composting latrine	Using two pits in altering order with VIP's facilities, which allows to compost the waste for further use	Cost is double of single pit system and operational cost decrease for less frequent emptying	Pit is shallow, so appropriate for flood-prone areas, high GW table areas	Appropriate use and facilities increase acceptance	Due to leaching of GW overflowing during flood time, it is hard to remove health risks completely	Filled pit must be furnished with dry organic material after every term of filling	(UNICEF 2012), (Reed 2010), (Adams, 2002), (Puddifoot, 1995), (Morgan 2007), (Monvois, 2010)

Name of intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Twin pit pour flush(water-seal) latrine	Two altering pit is connected with flush toilet; dewater filled pit with time ; enable manual removal while other pit is being used	Higher than twin dry pit latrine but lower than septic tank system; US$ 75– 212	For clay, tightly soil or rocky soil and not appropriate for flood-prone and high groundwater table areas	Commonly accepted where people usually use flush toilet	Hygienically emptying pit to minimize the risk of diseases transmission and filled pit safely enough to prevent people from falling and animal from entering	Require regular emptying by manual or mechanical desludging; regular cleaning	(UNICEF 2012) (Hussain 2017) (WASHCost 2012)
Bucket Latrine	Collecting of night soil by bucket	Capital cost is low (just cost of buckets)and operational cost depends upon the availability of workers	The places, where development of sewer network system is not possible	Very common in neighborhood but disrupted by the emergency	The health of the workers is a major concern, which should be replaced by hygienic alternatives as soon as possible	Continued collection is encouraged and alternative arrangements made for disposal (e.g.common deep trench) until collection return to normal	(Adams, 2002), (Reed 2016)
Raised latrine	Either be built entirely above ground with a holding tank below the user interface or by raised partially above ground	Relatively inexpensive but for prefabricated versions may be more expensive(particularly costs for stockpiling and transporting)	Flood-prone areas, high water table areas, permanent structures is not allowed, water scarce areas	Reduce acceptability for being seen when users go to the toilet; implementation of handrail and a turning space for wheelchairs increase acceptability.	Considered as a safe excreta containment technology and proper emptying help to reduce disease transmission	A sealed containment facility fill up quickly and need regular emptying or replacement of storage facility and subsequent management of collected sludge	(UNICEF 2012), (Harvey 2007), (Reed 2016), (WEDC 2014) , (WEDC 2017) (UNHCR 2018)
Sand enveloped pit latrine	A sand envelop constructed around a lined latrine to reduce contamination	Relatively inexpensive and availability of workers	The areas where high risk of GW contamination may happen	Acceptable by community as helps to reduce excreta related diseases	Acts as a filter to minimize the transmission of diseases causing micro-organism	Regularly emptying is needed	(Harvey 2007), (Abu 2019) , (Harvey, 2002)

Name of intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Sealed pit or Tank	Disposal pit fully lined or sealed by concrete , blocks, brick, plastic tank	Expensive; US$ 109 approximately	Shallow water table areas	Acceptable by refugee community as helps to reduce excreta related diseases	Help to reduce excreta related diseases	Regularly emptying is needed	(Harvey 2007), (Harvey 2002), (Burt, 2019)
Defecation field	Users should be directed to strips of the land in the defecation field roughly one-meter wide	Low capital and operational cost	Acute phase of emergency; slopes away from camp and any surface water sources; soft soil enough to dig easily to cover excreta	Separate area for men and women increase acceptability	Health education required to obtain the cooperation and understanding of the user population	Cover each filled strip with a least 10 cm of soil and open another strip some meter away	(Brdjanovic, 2015), (UNICEF 2012)
Single Vault UDDT (Urine Diversion Dehydration Toilet)	Urine and feces are collected separately and needs regular emptying, transportation, treatment, reuse and/or safe disposal of collected excreta products	Investments costs are low and operational costs need to be taken into consideration when calculating longer-term costs; US $2.50 approximaately	Flood-prone areas, high water table, water scarce areas	Avoiding regular urine management may increase user acceptance	Considered as a safe excreta containment technology and proper handling of feces containing that minimize risk of disease transmission	Regular emptying and replacing of collection containers with minor repairs; advising on proper use; monitor to prohibit the mixture of water and feces	(Reed 2010), (Harvey 2007), (Organization, n.d.)(Rieck, 2012) (Deegener, 2015) (Kramer, 2013) (Gensch, 2010), (Johannessen, 2012) (Blume, 2009)

Name of intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Double Vault UDDT (Urine Diversion Dehydration Toilet)	Using two vaults with UDDT facilities by altering; when one vault is being used, another vault is used for storage and treatment of feces	Capital costs for constructing varies on the availability and costs of local materials. The operating costs are very low if self-managed	Water-scarce, rocky, high GW or frequently flooded areas, stabilization and recovery phases of emergency	Knowing the preferences of local users by discussing with the local community before installation; avoiding regular urine management may increase user acceptance	Due to keeping vaults dry, flies or odors problems remain are low as well as a significant reduction of pathogen	Regular emptying and replacing of collection containers with minor repairs; advice on proper use; monitor to prohibit the mixture of water and feces	(Harvey 2007), (Rieck, 2012) (Gensch, 2010)
Container-Based Toilet	Feces and urine are collected in sealable, removable containers (also sometimes called cartridges) to seal and store until transport to a transfer station or treatment facility	Moderate expensive to implement, cost depends on frequency of different stages of work; US$32 approximately per household per year	An appropriate solution in all phases of an emergency	Knowing the preferences of local users by discussing with the local community before installation; training or orientation may increase acceptance	During collecting and emptying of containers may increase the risk of excreta related diseases; Personal protective equipment (PPE) and bathing are essential for protection	Regular emptying, cleaning, replacing of the collection containers and require careful cleaning	(World, 2019), (Zakaria 2018) (Organization, n.d.), (Reade, 2016) (Kramer, 2013) (Mijthab, 2011) (Tilmans, 2015) (Sklar, 2017)
Chemical toilet	A single prefabricated plastic portable unit or cubicle to collect human excreta in a sealed holding tank having chemicals to disinfects excreta and/or decreases odors	Medium capital costs and high operating costs; US $125-175 per day	Acute response phase of an emergency and are particularly suitable for flood prone affected areas, where pit digging is difficult	This comfortable and safe sanitation facility are often well accepted, strong odors(without proper setting) during emptying might negatively affect the acceptance	Delaying of removal sludge can become a serious health risk quickly	It is advised to have an attendant, who guarantees the maintenances and cleaning	(UNICEF 2012), (Reed 2016) (Harvey 2007), (Eyrard, 2011)

Name of intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Worm-Based Toilet	A pour flush pan connected to a Vermifilter (filter containing worms)	Over time it becomes viable Financially compared with other pit systems; worms can be costly, but in larger- scale projects worm cultivation becomes merged	Appropriate in contexts where water is available and used for flushing and used in areas with relatively high water tables (approx.1m)	Community needs to sensitize to the worms and toilets by highlighting advantages of the system, i.e. little space required, convenient water-based system, no odor, less emptying	Considered as a safe excreta containment Technology; the effluent from worm-based systems can be considered safer than the effluent from septic tanks	The effluent infiltrates into the soil and the Vermicompost (worm waste) is emptied approximately every 5 years.	(Furlong 2015) (Furlong, 2016) (Furlong C. R. N., 2017) (Furlong C. L. J., 2017)
Communal Septic Tank	A watertight chamber made of concrete, Fibre glass, PVC or plastic, through which black water and greywater flows for storing or partially treating human waste	Low to medium cost option, both in terms of capital and operational costs; additional costs for subsequent regular work; US$ 90–375 (including labour and materials)	Not suitable to construct in areas with high water tables, rocky soil, low permeability soil, water scarcity or flood-prone areas	Very common and well-accepted technology among people who use flush toilets	Under normal operating conditions, users do not come in contact with the influent or effluent but have a risk with GW contamination	Monitor scum and sludge levels to ensure that the tank is functioning well, frequency of desludging depends on the volume of septic tank	(UNICEF 2012), (Reed 2010), (Harvey 2007), (Oxfam, 2008) (Mara 1996) (Ulrich, 2009)
Communal Aqua privies	A large water tight tank direct below toilet cubicles, where a single overflow pipe in the side of the tank controls the water level	Low to medium cost option, both in terms of capital and operational costs; US$ 90–375 (including labour and materials)	Applicable for areas where pit latrines are socially or technically unacceptable and not possible to connect with sewer network	Well-accepted technology among people, who use flush toilets as period extended of tank emptying	Reduce odor; monitor GW contamination to reduce the health risk	Monitor to reduce the risk of GW contamination from overflow and easy to clean	(Reed 2010) (WHO, 2006), (Harvey 2007)

Name of intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Anaerobic Baffled Reactor (ABR)	Treats many different types of wastewater and considered as an 'improved' Septic Tank that uses baffles to optimize treatment	Capital costs is medium and the operational costs are low. Costs depend on the conveyance of technologies, and materials of local availability	Not suitable for the acute response phase of an emergency but are more suitable for recovery and stabilization periods	Anaerobic treatment systems are a well-accepted technology and have most effective footprint area	Effluent, scum and sludge must be handled with care as they contain high levels of pathogens	Relatively simple to operate, check the solid waste monthly; monitor the sludge level every 6 months	(Tilley, 2014) (Ulrich, 2009) (Foxon, 2004)
Anaerobic Filter	Treats many different types of wastewater and is a fixed-bed biological reactor with one or more filtration chambers in series	Capital costs is medium and the operational costs are low. Costs depend on the conveyance of technologies, treatment modules and materials of local availability	Suitable for long term solutions; can be installed in every type of climate but not for flood-prone and high water table areas	A well-accepted technology, awareness raising on eliminating the use of harsh chemicals may increase the awareness of the users	Effluent, scum and sludge must be handled with care as they contain high levels of pathogens	Monitor the scum and sludge levels to ensure the efficiency; clean filters by backwashing or by removing the filter	(Tilley, 2014) (Ulrich, 2009) (Morel, 2006) (Rose, 1999)
Biogas Reactor	An anaerobic treatment technology that produces a digested sludge (digestant) that can be used as a fertilizer or biogas as an energy	Low to medium cost option, both in terms of capital and operational costs, users must be budgeted for until the knowledge is well established	Not recommended to construct in flood-prone and high water table areas	Acceptance may be a challenge for communities that are not familiar with using biogas or digestant	Dangers associated with the flammable gases; partially sanitized but still carries a risk of infection during removal, workers should be equipped with PPE	Remove digestant from the overflow frequently; monitor the use of gas regularly; check water traps and valves regularly	(Mang, 2010) (Cheng, 2014) (Ulrich, 2009) (Khatavkar, 2013) (Vögeli, 2014)

Name of intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Hydrated Lime Treatment	It uses hydrated or slaked lime (calcium hydroxide: Ca(OH)2) as an additive to chemically treat fecal sludge from pits and trenches	A relatively cheap treatment option; costs may vary depending on the availability and costs of local materials, chemicals/lime	Commissioning is fast, so good for rapid response	Suitable for the rapid response phase due to its short treatment time	Hydrated lime is a powder and corrosive to skin, eyes and lungs; follow the health and safety protocols before use; significantly reduce E. coli	Require regular maintenance of the pumps, that are used for mixing	(Strande, 2014) (Chakraborty 2014) (Sozzi, 2011) (USAID, 2015)
Urea Treatment	Urea, with the chemical formula CO(NH2), is used as an additive to create an alkaline environment in the sludge storage device for sanitizing the sludge	A relatively cheap treatment option, to treat 1 m3 of fecal sludge, 20 kg of urea are required and urea is generally available and affordable	A suitable treatment option for the acute emergency phase due to its short treatment time (around 1 week), a relatively simple process	Helps to increase acceptance by ensuring appropriate health and safety protocols, provision of PPE and trainings for the involved staffs	Cautions during removal, as it is a hazardous material when it comes on the contact with skin or eyes, ingestion or inhalation	Regular maintenance of pumps that are used for mixing; requires skilled personnel for handling; follow health and safety protocols	(Anderson, 2015) (Nordin, 2009) (Vinnerås, 2007) (González P., 2014) (Anderson, 2015)
Lactic Acid Fermentation (LAF) Treatment	A biological treatment option using lactic acid bacteria (LAB) with the ability to form significant quantities of lactic acid, which aids in inactivating pathogens of fecal sludge	A relatively cheap treatment option, to treat 1 m3 of fecal sludge an initial amount of 100 L of milk and 200 ml of a probiotic drink	Suitable for acute response phase due to its short treatment time; a relatively simple process; general on-site treatment option for pit and trench latrines	Helps to increase acceptance by ensuring appropriate health and safety protocols, provision of PPE and trainings for the involved staffs	Molasses, milk or the LAF do not pose any significant health risk; high reduction of pathogens (6 log removal of E.coli i.e. pathogen count is 1 million times smaller)	Require regular maintenance of pumps, especially due to the corrosive nature of the treated sludge	(Anderson, 2015) (Ligocka, 2004) (Malambo, 2014)

Name of intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Caustic Soda Treatment	Uses caustic soda also known as lye (sodium hydroxide: NaOH) as an additive to create a highly alkaline environment for sanitizing sludge from human waste	A relatively cheap treatment option and caustic soda is twice as expensive on the market as lime and vary depending on the costs of local materials, soda	Suitable for rapid response phase, safe, cost-effective and extremely fast treatment of fecal Sludge	Helps to increase acceptance by ensuring appropriate health and safety protocols, provision of PPE and trainings for the involved staffs	During handling adequate PPE must be available, as Caustic Soda is corrosive to the skin, eyes and lungs	Due to its high alkalinity, require a regular maintenance of pumps and must be kept dry during storage	(Mamani. G., 2016)
Tiger Worm Toilet	The communal toilets using composting worms to reduce maintenance and treatment requirements by reducing total volume of fecal waste	Low initial and operating cost	Applicable in high water table environments, but are dependent on soil infiltration rates; in stabilization of the recovery emergency phase	A total of 99% of households testing the Communal Tiger Worm Toilets preferred them over previous, high user acceptance	Less odor and better in cleanliness	Estimate emptying frequency; require higher quality control of build to prevent predators from entering; require community engagement	(elrha, 2019), (Watako, 2016), (Furlong 2017)
Bio-additives	Adapting Two types process: biological and physical to increase the decomposition rate of pit latrine content or stabilize the sludge	A relatively cheap treatment option because it reduces the frequency of emptying	Chemical additives are suitable for long term solutions in the pit and septic tank; response phase of emergency	Discuss with community before installation, which reflect local users preferences	Able to reduce smell and flies	Performs laboratory tests of properties to determine the quality	(Reed 2016), (elrha, 2019)

Name of intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Black soldier Fly larvae(BSFL)	Convert fresh human waste into larval biomass under difficult feeding regimes	Economically Viable	Emergency response unlikely to present	High in protein, can be used as animal feed, which increase acceptability	Waste reduction; not fully pathogen inactivation; reduce the risk of disease transmission	Develop a monitoring optimal process condition (temperature and nutrient), where it works fully	(Reed 2016), (Banks, 2014)
Value recovery system(VRS)	Grinding, water evaporation, waste reduction through dehydration and sterilization of organic wet waste	High Cost	Areas, where electricity is available	Portable and short treatment cycle	Reduce the risk of disease transmission through fecal waste	Regular O&M are needed to monitor the entire process	(Reed 2016)
Biomax System	Convert all types of organic waste into fertilizer though biodegradation by adding enzymes at 80^{o}C for in 24 hours	High Cost	For emergency where electricity is available	Use as a fertilizer, which helps to increase acceptability	Pathogen free and odorless, all harmful microorganisms are killed during the process	Regular O&M are needed to keep the moisturizer and temperature at a required level	(Reed 2016) (Technologies n.d.)

Table 3: Information from included documents on collection

Name of intervention	Technical Efficacy	Cost	Applicability	Acceptance	Health impact	Ease of O&M	Study
Peepoo Bag	A single use bag with urea that unfolds to form a wide funnel to receive urine and feces; contents break down into carbon dioxide, water and biomass to use as a Fertilizer	Low cost; US$ 10 per Person per Year	No toilet access areas; flooded areas, areas with a high water table; toilet unsuitable Areas	Well accepted for remaining odor-free for at least 24 hours after use; after 2-4 weeks, sludge use as a fertilizer	Safe and secure, when properly managed; lack of proper disposal may produce a strong odor or cause danger for human and Environment	Properly monitor the distribution of bags and after used ; collect individual bags into larger bags or other containers prior to Composting	(PeePoople n.d.) (Wirseen n.d.) (Gur n.d.), (Harvey 2007)
Portable Chemical Latrine	Flat and stable surface with chemical solution to aid digesting and reduce Odor	High; US $125-175 per day	Areas, where big trucks are Accessible	Acceptable as helps to reduce odor	Proper hygiene is maintained	Regular servicing and Emptying	(Harvey 2007), (Portable n.d.)
Bucket Latrine	Typically consists of a seat on the top and an easily sealable bucket beneath to contain urine and feces	Low cost for bought locally	No toilet access areas; flooded areas, areas with a high water table; toilet unsuitable Areas	Can be used anywhere but some users may find using bucket latrines to be unacceptable	Disinfectant can be added to reduce odor and kill pathogens; lack of proper management leads to high potential for spread of diseases	Buckets are replaced by workers on a daily basis; transported to a central location for emptying and disinfecting before being re-used ; workers needed to be equipped with PPE	(Harvey 2007), (WASHplus, 2010)
Manual tools	Hand tools like buckets, long handle rakes, spades and corers are used dig and pull out FS	Capital costs are low and operation costs depend on the context	Areas where access is difficult ; applicable on the all types of Sludge	Although use of simple tools is very sustainable, in some contexts socially unacceptable, resulting in stigmatization of Workers	Without proper management potential serious health risks may arise to the workers and community	Clean after each use to protect tools from corrosion; manufacture and repair locally	(Bhagwan, n.d.) (Wall, 2020) (Annis, 2020)

Name of intervention	Technical Efficacy	Cost	Applicability	Acceptance	Health impact	Ease of O&M	Study
Gulper	A piston or lever type handle, which opens and closes a set of valves that lift FS up a riser pipe where it is discharged through a spout into a Container	The cost varies from 40 to 1,400 USD	Suitable for more liquid FS; areas where access is difficult such as narrow streets and alleys	Well acceptable for ease to transport; fabricate and repair with locally available skills and materials	Without proper management, splashing of sludge in the vicinity of the pump leading to public health risks	Requires careful cleaning and disinfection after use	(Evans n.d.),(Annis, 2020) (Boot, 2007) (Godfrey, 2012), (Foxon, 2012) (Mikhael, 2014)
Diaphragm Pump	A flexible diaphragm is alternately pushed and pulled by a rubber plunger to unblock a toilet or sink	The cost varies from 380 to 850 USD	Performs well with more liquid FS	Well acceptable for it's simple design with relatively few moving parts and can be transported by one person	Proper management can reduce the diseases transmission through feces	Must be thoroughly cleaned internally after use to avoid blockages	(Evans n.d.), (Annis, 2020) (Mikhael, 2014)
Motorized Diaphragm Pump	Operates on the same principle as a manual diaphragm pump but is driven by electric or hydraulic motors or petrol or diesel engines	Cost's range from 2,000 to 20,000 USD	Suitable for liquid sludge, containing solid particles ranging from 40mm to 60mm	Well acceptable for it's simple, low cost easy transportation	Proper management can reduce the diseases transmission through feces	Similar to a manual diaphragm pump with Additional requirements of fuel or electricity to operate the motor/engine	(Evans n.d.), (Mikhael, 2014) (Spit, 2020) (O'Riordan, 2009) (WASTE, 2015)
Trash Pump	Function is similar to centrifugal impeller water pumps, where the sharp blades cut up material of sludge to improve Pumping	500 to 2,000 USD	Can pump approximately 1,200 L/min and maximum pumping heads are 25 to 30 m	Good for pumping sludge with a high liquid content	Proper management can reduce the diseases transmission through feces	Usually simple and easy to remove; use as a rapid unblocking tool, if and when Required	(MSF, 2010) (Mikhael, 2014)
Gobbler	A small electric motor of rotary action pump turns a double chain drive which rotates metal scoops to lift FS up a riser pipe	1,200 USD	Suitable for pumping higher viscosity sludge	In some cases, it is unacceptable for it's heaviness and unable to empty due to it's fixed length	During operation sludge can block the drive chains and health hazard occur, so proper management is needed	Is supported and moved into position on a tripod and the sludge is discharged into a drum or bucket	(STILL, 2020) (Mikhael, 2014) (Still, 2012)

Name of intervention	Technical Efficacy	Cost	Applicability	Acceptance	Health impact	Ease of O&M	Study
Pit Screw Auger	Consists of an auger placed inside a riser pipe and a hydraulic motor mounted on top of the riser pipe turns the auger, the separate power pack reduces the weight of the auger and allows for forward and reverse drive	4,500 USD	Designed to work best with denser sludge	Unsuitability for use in situations where there is large amounts of solid waste	Proper management can reduce the diseases transmission through feces	Operated by one person of 20-40 kg; Cutting blades at the bottom of the auger picks fecal sludge and lifts up along the auger flights and a spout discharges the material into a collection Container	(University, 2020) (Berlin, 2015)
Vacuum truck	FS is pumped into the tank and transported to the treatment/disposal point	10,000 to 100,000 USD Depending On specification	In planned settlements where the septic tanks and pit latrines are easily accessible and FS is fairly liquid without solid waste	Not acceptable in high density areas due to vehicle size and in low-income contexts due to specialized parts	Proper management can reduce the diseases transmission through feces	Park close to the system as possible, connect the hoses from the truck to the tank or pit to be emptied, pump out sludge, transport sludge to treatment/disposal point to discharge	(Harvey 2007), (Mikhael, 2014) (Brikké, 2020)
Vacuutug	Vacuum tank and a pump run by a small petrol or diesel engine and the FS is pumped into the tank and transported for disposal	10,000 to 20,000 USD	For emptying FS from areas where conventional tanker trucks cannot access due to space limitations	Acceptable in high density settlements and availability of spare parts and the machine can be manufactured, not acceptable for hilly areas	Proper management can reduce the diseases transmission through feces	A vacuum setting is used to pump FS into the tank and a pressure setting is used to empty FS from the tank and to assist in unblocking the suction pipe as required	(Brandberg, 20) (WASTE, 2015), (Evans n.d.)

Table 4: Information from included documents on emptying and transportation

Name of intervention	Technical Efficacy	Cost	Applicability	Acceptance	Health impact	Ease of O&M	Study
Manual Emptying and transport	There are two ways of manual emptying :(1) Buckets and shovels for solid sludge, or (2) Portable, manually operated hand pump or a vacuum truck (e.g. Gulper, Rammer or Manual Pit Emptying) for liquid sludge	Capital costs are low, operational costs depend on the fee of the Workers; US$ 20-40 per Household per year	In the dense, urban and informal settlements; all phases of emergencies; difficult to access mechanical transportation	Spillage and odor may make Unacceptable socially; by avoiding these incidents can increase the Acceptability	Workers tend to serious health risk, if they do not follow proper protection guidelines	Determine the frequency of emptying according to storage capacity; equipment need Regular Maintenance (cleaning, repairing and disinfection	(Mikhael 2014) (Strande, 2014)(Eales, 2005) (Kone 2012) (Ross, 2016)
Motorized Emptying and Transport	A vehicle equipped with a motorized pump and storage tank for emptying and transporting fecal sludge; the pump and the hose are operated by technicians but the sludge is not manually transported.	Investing in a vacuum truck can be expensive and major operational cost is fuel, which depends upon the Distance; Initial Cost US$ 3000	In areas accessible to vehicles	Due to high cost and uncertainty of final discharge location may Increase unacceptability; minimization of difficulties may increase the Acceptability	A vacuum truck presents a significant health improvement over manual emptying	Regular maintenance avoids high maintenance, fuel costs and major repairs; careful using disinfection avoids corrosion of equipment	(Mikhael 2014), (Kone 2012) (Strande, 2014) (Chowdhry, 2012) (O'Riordan, 2009)
Transfer Station and Storage	To avoid difficulties (long travel time) of transporting fecal sludge to a final treatment facility, semi-centralized storage facilities such as Transfer Stations, bladders or sewer discharge stations are Necessary	Helps to reduce the costs of Transportation distance and waiting times in traffic jams	Suitable for areas, where treatment facilities are away from settlements	Acceptable because it minimize illegal dumping of sludge, odor and problems of Residents	Regular emptying of pits minimize illegal dumping, which improves overall health of a community significantly	Regular maintenance to keep function well; helps to minimize odor, nuisance	(Strande, 2014) (Chowdhry, 2012), (Mikhael 2014)

Table 5: Information from included documents on treatment

Name of Intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Pre-Treatment Technologies	It helps to prevent the accumulation of solids and the minimization of subsequent blockages, preliminary removal of sludge components, such as oil, grease, and solid Materials	Capital and Operating costs(electric cost) are relatively low	The places, where, grease traps are available, and grit chamber for unpaved roads or storm water entry into the sewer system	Not pleasant, so source control at the household or building level can reduce the loads and keep the treatment Efficient	Adequate protection with PPE helps to reduce diseases transmission of involved people	Frequent maintenance required: For screens sludge should be removed regularly, and for larger grease interceptor, to be pumped out every 6–12 months	(Robbins, 2014), (Tchobanoglous 2004) (Ulrich, 2009)
Settler	Removal suspended solids by sedimentation: low flow velocity in a settler allows to settle lighter particles at the Bottom	Capital costs are medium and operational costs are low	The treatments which requires preliminary removal of solids in order to function properly	A well-accepted Technology	Sludge and scum must be handled with care as they contain high levels of pathogenic organisms	Frequent scum removal is important and sludge should be disposed of appropriately in a treatment system or Buried	(Reed 2010), (Nienke 2019) (Tilley, 2014) (Ulrich, 2009) (Ireland, 1997)
Anaerobic Baffled Reactor (ABR)	An improved Septic Tank, where pollutants are biologically degraded in an active sludge layer at the bottom of each chamber of a series of Chambers	Capital costs ($342/m^3) are medium and costs (USD0.06/m^3) low	Not appropriate for the acute response phase, high GW and flood-prone areas; suitable for the stabilization and recovery phases as a longer-term solution	A well-accepted technology, because of the delicate ecology in the system	Effluent, scum and sludge must be handled with care as they contain high levels of pathogens	Monthly check solid waste; monitor the sludge level every six months; desludging every two to four years, depending on the accumulation of Sludge	(Oxfam, 2019), (Bank, 2019) , (Tilley, 2014) (Ulrich, 2009) (Foxon 2004)
Geotextile	Permeable fabrics that have the potential to dewater sludge more efficient than drying beds sold by several manufacturers in a tube or bag form	$1,300 per GeoTube bag including approximate construction costs and operational cost(USD 2.80 per cubic meter)	Potentially suitable for decentralized FS treatment; the areas, where large amount of area is available to develop the treatment Facilities	Simple process and technology, increase its Acceptability Locally	Although very good at helminth removing, not so good at coliform removal	Operate by gravity; modular in operation, Site maintenance is required per day, regular monitoring avoid blockage of Filter	(Oxfam 2019), (Ave, 2020)

Name of Intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Anaerobic Filter(AF)	A fixed-bed biological reactor with one or more filtration chambers in series: during flow through the filter, particles are trapped and organic matter is degraded by the active biofilm, attached to the surface of the filter material	Capital costs(USD 330 per cubic meter) are medium and operational costs(USD 10 per year per cubic meter) are low	Not appropriate for the acute response phase, high GW tables or flood-prone areas; more suitable for the stabilization and recovery phases as a longer-term solution	A well-accepted technology, because of the delicate ecology in the system	Pathogen and nutrient reduction is low, therefore additional treatment technology needs to be added to achieve the effluent standard	Monitoring the scum and sludge levels to ensure that the tank is functioning well; clean the filter material by backwashing or by Removing	(Harvey 2007) (Tilley, 2014) (Ulrich, 2009) (Morel, 2006) (Rose, 1999)
Upflow Filter	A series of filtration chambers for solid-liquid separation; solid buried with disinfectant; liquid pass through two chamber for further filtration and final Treatment	Operational expenditure is lowest per cubic meter treated; Capital cost US$ 10,710 per cubic Meter, operational Cost 0.87 per cubic meter	Earthquake resistance and good for flood-prone areas	Acceptable Because construction is rapid; usable at multiple scale; easy to add more units; environmental Friendly	Inactivate pathogens through infiltration and solid storage in a closed plastic tank to limit vectors	Daily site check with skilled labor; replace filter media per year; solid discharge at burial pits per month	(Oxfam, 2019) (Tayler, 2018) (Delft 2003) (Pitt, 2005) (OCTOPUS, 2019)
Waste Stabilization Ponds	The ponds can be used individually, or linked in a series of three types of ponds: anaerobic, facultative and aerobic, Anaerobic and facultative ponds are designed for BOD removal, while aerobic ponds are designed for pathogen Removal	Investment costs (USD330 Per cubic meter)to purchase land and dig the ponds may be high, but O&M(USD12 per cubic meter) are are costs relatively low	Appropriate for rural and peri-urban communities that have large, unused land, at a distance from homes and public spaces; suitable for the phases of stabilization and recovery phase	May generate bad odors, so construction far from settlements Or Artificially aerated the ponds may increase Acceptability	Effluent is generally low in pathogens; installing a fence ensures safety of people and animals by staying away from the area	Regularly remove scum, aquatic plants sludge by a raft Mounted sludge pump, a mechanical scraper or drain and dewater the pond	(Reed 2010), (Shilton, 2005) (Von 2007) (Von 2005) (Kayombo, 2004), (Mburu,2013)

Name of Intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Biogas Reactor	An anaerobic treatment technology that produces a digested sludge that can be used as a fertilizer or biogas	Low to medium cost for capital(US$3,655) and operational costs($84/year);	Suitable for the stabilization and recovery phases as a longer-term solution, not recommended high GW tables or flood-prone Areas	Social acceptance might be a challenge for communities, where biogas or digestant are unfamiliar	Digestant is partially sanitized, still carries a risk of infection, during digestant removal, workers should be equipped with PPE	Remove digestant routinely; monitor gas regularly; check water traps, valves and gas piping regularly to prevent corrosion and Leaks	(Reed 2010), (Mang, 2010) (Cheng, 2014) (Ulrich, 2009) (Khatavkar, 2013)
Constructed Wetland	Engineered wetlands designed to filter and treat different types of wastewater mimicking processes found in natural environments	Costs are lower than other conventional treatment systems; USD 8000 per cubic meter for construction	Applicable only for waterborne sanitation systems, large land and longer period of time are not problem	Easily accepted by locals since minimal mechanical capacity is required	Users do not come in contact with the influent or effluent; scum and primary sludge must be handled with care	Regular removal of primary sludge is the most critical routine O & M activity; distribution pipes should be cleaned once a year	(Reed 2010), (Dotro G., 2017) (Muellegger, 2012) (Hoffmann, 2011)
UV-C light irradiation	Ultraviolet germicidal (short wavelength UV-C) light was studied as surface disinfectant in an Emergency on smart toilet to aid the work of manual cleaning	-	All phases of emergency	Clean within three minutes of time and easily handle	Removal of E.coli tested in the lab and inactivate total coliform on field test, which reduce public health risk	Smart monitoring system by remote controlling and by tracking the usage	(Zakaria 2016), (Zakaria 2018)
Trickling Filter	A fixed-bed, biological reactor that operates under aerobic conditions where wastewater is continuously 'trickled' or sprayed over the filter that percolates through the pores of the filter and degrade the organics material	Capital costs(USD 1.06 per cubic meter) are moderate to high depending on the filter material and costs for O&M is USD1.25 per cubic meter	Applicable only for waterborne sanitation systems; not appropriate for the acute response phase and more suitable for the stabilization and recovery phases	To improve acceptability, be built away from homes and businesses to reduce odor and fly problems	In order to reduce health risks, appropriate pre- and primary treatment of effluent discharge and solids are needed	To monitor the filter, a full-time skilled operator is required; filters need periodical wash to prevent from clogging	(Tchobanoglous 2004) (Ulrich, 2009), (EPA 2000) (Ziebell, 2016) (Zahin, 2014)

Name of Intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Sedimentation and Thickening Ponds	Settling ponds to thicken and dewater sludge, both the effluent and the thickened sludge are removed to treat further in a subsequent technology	Operating costs are low(USD 8700 per year), capital costs(USD4000 approx.) are Medium	Most appropriate where there is inexpensive, available space located far from homes and businesses	To improve acceptability, be built away from homes and businesses to reduce odor and fly problems	As thickened sludge are pathogenic, workers should be equipped with PPE when handling	After sufficient thickening, the sludge must be removed mechanically	(Strande, 2014) (Heinss, 1999), (Sharrer, 2010)
Planted Drying Bed	Similar to an Unplanted Drying Bed, but does not need to be removed after each feeding/drying cycle since the fresh sludge can be directly applied onto the previous layer	Medium capital cost(USD 350), low operating costs(USD 180);	Appropriate for towns or camps, where generation of sludge supply is constant; locate as close as possible to avoid high transport costs	A few problems with acceptance for the pleasing aesthetics, especially dense housing located away sufficiently	workers should be equipped with PPE during handling; leachate needs further treatment	Thin or harvest plants periodically; sludge removal each three to five years manually or mechanically; trained staffs distribute the sludge to manage the plants properly	(Reed 2010), (Nienke 2019)
Unplanted Drying Bed	A simple, permeable bed that allows the sludge to dewater by filtration and evaporation; separates and drains the percolated leachate, then dry sludge is removed and ready to receive liquid sludge	Capital costs are medium and operating costs are low; less than planted drying bed as do not need to spend money for plants and harvesting	Particularly adapted to warm climates; inexpensive areas; available space far from homes and businesses	For bad odors and flies problem, the technology need to locate away from residential area	Workers should be equipped with PPE during handling; further treatment or storage may require for securing sanitation	Require s trained staff for O & M; depending on climatic conditions dried sludge can be removed periodically after 10 to 15 days	(Nienke 2019) (Strande, 2014), (Tchobanoglous 2004)
Co-Composting	Controlled aerobic degradation of organics under thermophilic conditions, which ensure the elimination of pathogens and rapid decomposition of the waste material	Depends on the method chosen, the cost of local materials and overall operation requirements; Investment cost USD 150-200 per person	As high level of organization and labor needed, it is appropriate for stabilization and recovery phases of an emergency rather than acute response phase of an emergency	Knowing the preferences of local users by discussing with the local community before installation	Adoption of basic precautions, hygienic practices and wearing PPE minimize health risks, ensure pathogens and helminth eggs at a safe level	Well-trained staffs must monitor quality and quantity of the entire process; turning must be periodically done with either a front-end loader or by hand using a pitch fork or shovel	(Reed 2010), (Nienke 2019) (Strauss, 2003) (Kramer, 2013) (Rothenberger, 2006) (WHO, 2006) (Enayetullah, 2015)

Name of Intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Vermicomposting and Vermifiltration	Earthworms, which are used as bio filters; the end-product is worm cast or Vermicompost, which contains reduced levels of contaminants and the processes can reduce volume of fecal sludge up to over 90 %	Depends on the method be chosen, like the cost of local materials, overall operation requirements, scale and design of the system; Capital costs are USD 914/m^3, operation cost USD 0.06/m^3	As high level of organization and labor needed, it is appropriate for stabilization and recovery phases of an emergency rather than acute response phase of an emergency	Knowing the preferences of local users by discussing with the local community before installation	Adoption of basic precautions, hygienic practices and wearing PPE minimize health risks; further treatment may be required to produce a pathogen-free compost	Low mechanical and manual maintenance requirements; well-trained maintenance staff must monitor quality and quantity of the entire process; turning must be periodically done with either a front-end loader or by hand using a pitch fork or Shovel	(Furlong, 2018), (Bank, 2019) (Furlong 2014) (Furlong 2015) (Eastman, 2001) (Ramnarain, 2019)
Activated Sludge	A multi-chamber reactor unit that uses highly concentrated microorganisms to degrade organics and remove nutrients from wastewater to produce a high-quality effluent	Capital and operational costs are high; Annual capital and operational cost USD0.2 per cubic meter	An appropriate solution in the stabilization, recovery phases of an emergency and in more densely populated urban areas or larger camp contexts of water-based systems	Depends on the cultural context and existing regulations	High reduction of BOD and pathogens (up to 99 %); having a public health risk, so it should not to handle directly	Maintaining mechanical equipment (mixers, aerators and pumps) constantly; monitor influent and effluent continuously; control parameters by trained technical staffs	(Harvey 2007) (Heinss, 1999) (Strande, 2014) (Arif, 2020)
Tertiary Filtration and Disinfection	A Post-Treatment step may be required to remove pathogens, residual suspended solids and/or dissolved constituents to achieve standard	Sand filtration, chlorine and ponds are relatively cheap while activated carbon, Ozonation and membrane filters are costlier	Only be applicable effectively after functioning a secondary treatment; depends on the quality requirements for desired end-use and/or national standards	Professionals are needed to operate and manage Post- Treatment technologies	Very effective in removing pathogens; disinfection by-products may form and threaten environmental and human health, so proper care is needed	Require continuous monitoring (influent and effluent quality ,head loss of filters, dosage of disinfectants, etc.); frequent cleaning (backwashing) or replacement of filter material	(Tchobanoglous 2004) (Robbins, 2014) (WHO, 2006)

Name of Intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Membrane bio-reactor	Combination of a membrane process like microfiltration or ultrafiltration with a biological wastewater treatment process, the activated sludge process	Extremely high initial capital costs and the daily O& M costs including availability and cost of highly trained technical personnel; Annual capital and operational cost is USD0.43 per cubic meter	Rapid, complex (and urbanized) emergency situations, where severe land limitations or underlying-soil/GW conditions, pit latrine not applicable but high cost is not a problem	Easy to maintain, and acceptable where high cost is not a problem	Adoption of basic precautions, hygienic practices and wearing PPE minimize health risks	Easy to operate by unskilled (but trained) labor; robust with little chance of breakdown; reliable in effluent quality produced	(Harvey 2007), (Paul, 2005) (Arif, 2020)

Table 6: Information from included documents on disposal

Name of Intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Application of Dried Faces	Faces are stored in the absence of moisture kept at between of 2-20 °C for 1.5-2 years to inactivate helminths and pathogens according to WHO Guidelines	The potential transport cost from the toilet to the field and costs for labor, agricultural equipment and PPE.	Usually not considered a priority in acute emergencies, but might be an option during the stabilization and recovery phases	Handling and using of dried faces may not be acceptable in some cultures but using of crumbly, and odor free dehydrated feces easier to accept than manure or sludge	Organisms and most pathogens die off relatively quickly; flexible multi-barrier approach should be consulted to achieve the standard of WHO Guidelines	Care must be taken, when removing dehydrated feces from dehydration vaults, which should be kept as dry as possible	(WHO, 2006) (Schönning, 2004) (Austin, 2002) (Rieck, 2012) (Winblad, 2004)
Application of Pit Humus and Compost	Pit humus is generated from double pit systems and compost, which is resulted from controlled aerobic degradation of organic material and composition are different from each Other	The capital costs for tools to apply pit humus and compost are generally low, the operating costs are low if self-managed	Both pit humus and compost are appropriate for the stabilization and recovery phases of an emergency	May be a challenge for communities who are not familiar with	Although having low risk of pathogen transmission, unprotected handling should be actively discouraged	Workers should wear PPE; training is best methods of gardening and food production; quite difficult to remove of dewatered and consolidated sludge mechanically	(Adam-Bradford, 2016) (Jenkins, 2005), (Morgan 2007)
Burial	The superstructure is removed and placed over a new excavation site and is filled to ground level with some of the originally excavated soil	Low operational and capital cost	In rural areas, where population densities are low, unsuitable for high density areas	The most common disposal method for human excreta	For high density areas, health and pollution hazard arise; workers must be provided appropriate tool and PPE	Emptied fecal sludge is buried in the yards of the house, where the emptying was carried out	(Reed 2010), (Hawkins, 2015)

Name of Intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Briquettes	Capture solar energy to reduce the pathogens levels thermally, in the effluent to an environmental safe standard	Low operational and capital cost	Emergency areas; refugee camps	Well accepted as the charcoal can be used for heating and cooking	Inactivate pathogens to reduce the risk of diseases transmission	Easily handle fecal waste; should conscious about full inactivation of pathogens	(Ward, 2017), (Atwijukye, 2018), (Ward 2014)
Application of Sludge	Depending on the treatment type and quality, digested or stabilized sludge can be applied in agriculture, home gardening, forestry, sod and turf growing, parks, golf courses, mine reclamation, as a dump cover, or for erosion control	Main cost is transportation of the sludge to the fields; can save money when it replaces commercial fertilizers	Applicable in the stabilization and recovery phases of an emergency, when a Functional Sludge Treatment system is in Place	Social acceptance may be low in some areas; if farmers or local industries do not accept sludge, municipal projects use it and gain significant savings	Odors may be noticeable, depending on prior treatment and may pose public health risks, depending on its quality and application	The equipment requires regular maintenance; the rate of sludge application should be monitored to prevent nutrient from overloading of both the soil and water bodies	(WHO, 2006) (EPA 1999) (Strande, 2014)
Fill and Cover: Arborloo and Deep Row Entrenchment	Untreated (fecal) sludge and excreta are disposed in a Deep Row Entrenchment, which is covered with soil to decommission over time	The main cost is for tools, machinery and staffs, where fill and cover is a low-cost solution, trees and edible crops generate income or reduce food expenses	Applicable where there is land available with adequate size, no chance of GW contamination risk and in all phases of Emergency	Participation of community members are useful to display the ease of the system; its inoffensive nature and the nutrient value of human excreta helps to increase acceptance	Very low risk of pathogen transmission, as users do not come in contact with the fecal material	A cup of soil and/or ash should be added to the pit after each defecation; leaves should be periodically added; little maintenance is needed to take care of the tree or plant	(Hebert, 2010), (Morgan 2007) , (Still D., 2012)

Name of Intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Surface Disposal and Sanitary Landfill	Material of Surface Disposal and Sanitary Landfills are not used later to protect the environment from pollution	The associated costs for lands are substantial, other costs for operating and maintaining	Not applicable flood-prone and high GW table areas; applicable for areas away from human contact and waterbodies during an acute response phase	Constructed away from population centers; managed with the help of local communities; effectively informed of the dangers for protection of public health	Storage may render the product more hygienic but for odor and vector problems, Vermin and pooling water can exacerbate	Low technical skills required for O&M but may require special spreading equipment and control over the traffic and hours of operation	(EPA 1999) (Strande, 2014) (Cointreau, 2004)
Use of Biogas	Anaerobic digestion of sludge and other organic matter produces biogas, which is used for cooking, heating, lighting and electricity production	The costs depend on the chosen application for the biogas and the appliance required	Suitable for the Stabilization and recovery phases as a longer-term solution, not recommended high GW tables or flood-prone Areas	Users find cooking with biogas acceptable but may not be appropriate in all cultural contexts; training and orientation help to increase user acceptability	Although the digestant is partially sanitized, still carries a risk of infection; during digestant removal, workers should be equipped with PPE	Removal of digestant frequently; monitor gas regularly; check water traps, valves and gas piping regularly to prevent corrosion and leaks	(Fulford, 1996) (Deublein, 2011) (GIZ, n.d.)
Co-Combustion of Sludge (Emerging Technology)	A process of incineration that kills the pathogens to make the sludge sanitized and energy is generated to dewater the fecal sludge	Capital costs for small-scale pyrolysis or gasification reactors are low to medium while O & M costs are relatively high	Applicable for acute phase of an emergency; construct within an acceptable distance to keep transportation costs down	May not be accepted in all cultural contexts, so awareness is needed to be raised	Effective pathogen reduction but further treatment needs to reduce hazardous to human and environmental health	Highly skilled workers are needed to O&M; regular monitoring of the plant or reactor is needed	(Kengne(n.d.)), (Stelmach, 2008)

Name of Intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Leach Field	A network of perforated pipes that are laid in underground gravel-filled trenches to dissipate the effluent from a water-based collection and storage/ treatment on a wider surface area	Costs depends upon the availability of local material	Not appropriate for dense urban flood prone, high GW table areas	Percolation of wastewater into the soil can become a concern to the local community, so safety and effectiveness of this technology needs to be well communicated	To avoid negative impact on soil and groundwater, it constructed away from any potential potable water source	Low maintenance requirement if operated without mechanical equipment and monitor that no heavy traffic above it	(Crites, 1998) (Morel, 2006)
Fish Ponds	Fish, which are raised in ponds, feed algae and other organisms that develop a nutrient-rich water and are eventually harvested for consumption	Capital costs are relatively low, operating costs should be offset by production revenue	Appropriate from the Stabilization phase and where there is enough land (or a pre-existing pond), a source of fresh water and a suitable Climate	Social acceptance may be low in some Areas	Fish may pose a health risk if improperly prepared or cooked	Should be drained periodically; maintain a suitable biomass while maintaining the availability of fish for consumption over time	(Iqbal, 1999) (WHO, 2006)
Soak Pit	A covered, porous-walled chamber set in the ground that allows water to slowly percolate and infiltrates into the surrounding soil	Capital and operational costs are very low	Appropriate for rural and peri-urban settlements; soil with a sufficient absorptive capacity	Odorless, low cost and low-tech solution increase its acceptability	When functioning well, health concerns are minimal; to avoid contamination, potential potable water source needs to keep away	Generally last between 3 and 5 years without maintenance; to avoid clogging, the pit need to be cleaned or moved regularly	(Ahrens, 2005) (Mara 1996) (Oxfam, 2008)

Name of Intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Irrigation	To reduce the dependence on freshwater and maintenance, wastewater of varying quality can be used in agriculture and horticulture for irrigation	Overall costs are highly dependent on the system applied	Can be an option in the stabilization and recovery phases of emergencies	Social acceptance may be low in some areas; municipal projects use it such as irrigation of parks, street trees, etc.	Low risk of pathogen transmission if water is properly treated	Periodically flushed to avoid biofilm growth and clogging from all types of solids; check pipes for leaks or any damage	(WHO, 2006) (Palada, 2011)
Water Disposal and Groundwater Recharge	Depending on quality, treated effluent and/or storm water can be directly discharged into receiving water bodies or into the ground to recharge aquifers	No direct costs associated with this technology	Applicable entirely on the local environmental conditions and legal regulations	If water is used for consumption, recharge should be prohibited; develop an information campaign at this location	Discharge may affect natural water bodies and/or drinking water, have long-term impacts; negatively affect soil and GW properties	To ensure public health requirements, regular monitoring and sampling are important; some mechanical maintenance may require	(Seiler, 2007) (Tchobanoglous 2004) (WHO, 2006) (ARGOSS, 2001)

Table 7: The FSM technologies criteria need to fulfilled in Rohingya refugee camps

Name of intervention	Technical efficacy	Cost	Applicability	Acceptance	Health Impact	Ease of O&M	Study
Rohingya Refugee Camps recommendation	Construction occurs rapidly; Prevents collapsing; Allow degradation; Do not leach into surrounding soil or GW; Odor and insects free; Above the ground, Additives to reduce the volume and sanitize the sludge	Inexpensive; Workers cost comparatively lower than other area; construction cost is preferred low	Unconsolidated sedimentary rocks prone to land sliding; GW contamination due to uncontrolled latrine system; Stable emergency phase; Densely populated area 40000 people per km², which is much higher than most other refugee camps across the world. (Mohammad Mainul Islam, 2020)	Evidence-based framework for measuring satisfaction; Build consensus on a plan for regularizing process and parameter; Address pressure on local livelihood, environment and services to mitigate; Set up a working group on host communities to support (Programme, 2017)	Do not leach into surrounding soil or GW; Odor and insects free; Additives to reduce the volume and sanitize the sludge; Immunization of workers; Check the end-product according to guidelines	Organize a detailed FSM training practitioners or implementers to build capacity in the local organizations; Take care of concerned services; Engage the maintenance group in each block to address complaints; Implement smooth operation to meet raised challenges; Observe field level staff capacity continuously (BRAC, 2020)	(Islam, 2020), (Programme, 2017), (BRAC, 2020), (Akhtar, 2020), (Ahmed, 2015), (Chan, 2018), (Islam, 2018)

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