



TOWARDS ENVIRONMENTALLY SAFE FAECAL SLUDGE MANAGEMENT IN INFORMAL SETTLEMENTS OF BANGLADESH: A CONTEXT- SENSITIVE MODEL

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KUS: ICSTEM4IR-22/0059

Manuscript submitted: August 11, 2022

Accepted: September 25, 2022

Abstract

Informal settlements suffer health issues due to inadequate toilet facilities and unsafe faecal sludge management (FSM). In addition to the people's unsafe management, sweepers provided emptying services informally with unsafe methods, and authorities adopted city-wide vacutug-based services where informal settlements are excluded. This paper explores factors causing unsafe FSM and develops a contextual model that includes informal settlements with environmentally safe city-wide services. It took Notun-Bazar Char Khulna as a case, and purposefully sampled toilets, settlement people, sweepers, and key persons for interview and group discussions. These responses located some existing sanitation intervention factors responsible for unsafe containment, emptying, conveyance, and discharge practice. This paper proposes equitable, impenetrable, and emptiable containment, periodical emptying and conveyance, adaptive equipment, adaptive health safety kit, and proximal safe discharge location as components of a context-sensitive model to include informal settlements with a city-wide environmentally safe FSM system.

Keywords: Containment, conveyance, emptying, environmental safety, informal settlement

Introduction

Cities are a habitat for more than half of the planet's people, where 30% of all city dwellers live in slums, which means one in eight people live in slums worldwide, and the number is continuously swelling (UN-Water, 2018). With overcrowding and a high-density population, informal settlements have more potential for spreading diseases than less crowded areas; but building traditional toilets is rarely possible (Isunju et al., 2011). Sanitation prevents faecal-oral contamination pathways by providing facilities and services where the FSM challenge is inevitable to support the remarkable growth of on-site sanitation facilities in developing countries (ISF-UTS and

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DOI: <https://doi.org/10.53808/KUS.2022.ICSTEM4IR.0059-se>

SNV, 2019; WHO, 2018). The agenda 2030 of sustainable development goals (SDG-6) advocates for sustainable sanitation for all, acknowledging FSM as a more significant challenge than basic toilets (UN-Water, 2018). The sanitation service chain, which articulates FSM, has been understood as a de-facto framework for embracing all settlements in city-wide FSM systems and identifies distinctive, interdependent phases of the system: (a) containment, (b) emptying, (c) transport, (d) treatment, and (e) disposal (Kong & Bartell, 2018; Scott, 2019). Besides, City-wide inclusive sanitation means safely managing human waste, ensuring benefits, including slum areas, from good service considering adaptive and varied technical solutions responsive to context-specific realities (ADB, 2018). Un-Habitat recommends that local governments acknowledge and coordinate small-scale, informal operators and service delivery in sanitation service provisions for slum areas (UN-Habitat, 2016).

FSM is a second-generation sanitation challenge but inevitable for sustaining on-site sanitation systems (ISF-UTS and SNV, 2019). The need for suitable technology and service provision for emptying and transportation of FS is growing globally with experiments and technological innovations. Like many developing countries, Bangladesh struggles to find context-sensitive solutions for FSM services (Opel & Khairul Bashar, 2013), but different FS emptying services arrays depend on on-site infrastructures (Scott, 2019). Contextual differences and varied demands cause a single technology or service model to be inapplicable everywhere (Opel & Khairul Bashar, 2013). The emptying process entirely depends on on-site sanitation facilities, containment substructure, disposal site availability, service providers apparatus, and level of expertise and local availability of sludge emptying methods are becoming top criteria for developing countries (Chipeta et al., 2017). However, the domination of vacutug-based mechanical emptying service provision ignores existing contextual practices and informal settlements. It induces households' reliability on manual emptying, which is not developing with reduced health risks and environmentally safe FS management. A pragmatic, bottom-up, context-sensitive emptying, transportation, and disposal provision are needed to include the emptying challenges of informal settlements in the city-wide sanitation plan (Blackett et al., 2014; Chipeta et al., 2017).

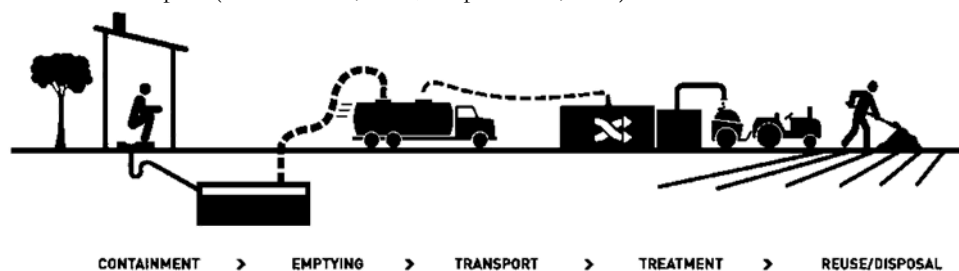


Figure 1. Sanitation Service Chain (Gates Foundation, 2010).

Literature review

FSM is articulated with the sanitation service chain, a de facto framework to embrace all settlements with a city-wide inclusive sanitation system (Kong & Bartell, 2018; Scott, 2019). Primary components are containment, emptying, transport, treatment, and disposal, widely expressed in a simple diagram (Figure-1)(Gates Foundation, 2010). Although vacutug-based emptying, transportation, and disposal models are not reaching many settlements, informal settlements are being excluded from the FSM system; since it has access to limited contexts, still city authorities are adopting vacutug-based safe FSM service (Frenoux & Tsitsikalas, 2015; Opel & Khairul Bashar, 2013). As people rely on manual FSM services, which are environmentally unsafe, many researchers acknowledged the need for context-sensitive, bottom-up solutions for environmentally safe FSM to reduce faecal health risks in informal settlements (Blackett et al., 2014; Chipeta et al., 2017). Since the primary weakness of vacutug is the limited access for emptying to varied settlements, this study reviewed conventional technologies for emptying FS from on-site Sanitation facilities and identified the process, advantages, and limitations in (Table 1) (Figure 2) from previous literature. Since many technologies and practices are

available, emptying depends significantly on the locations of toilets, so the spatial dimension of toilet premises, sanitation facility type, filling rates, emptying duration, and conveyance opportunity impact the development of conventional emptying models (Greene et al., 2021; Thye et al., 2011). All stages of the service chain need proper care for excreta spillage because it affects the health of sweepers and community people (Boot, 2007).



Figure 2. Various emptying technology; (a) Manual emptying; (b) Vacuum Tanker (source: SNV); (c) Vacutug (source: author); (d) MAPET (source: Eawag & Spuhler, 2012); (e) Gulper (Source: GTO 2015).

Table 1. Advantages and limitations of emptying technologies (GTO et al., 2015; Kabange, 2019; Thye et al., 2011)

	Manual emptying	Vacuum tanker	Vacutug	MAPET	Gulper
process	Dig out FS using hand tools	The vacuum pump carried on a motorized tanker	Self-propelled mechanized vacuum pump	Manual hand-powered pump with pushcart mounted Tank	Manual hand pump
advantage	<ul style="list-style-type: none"> • can access most locations • Affordable and easy-to-use • available equipment 	<ul style="list-style-type: none"> • Safe for less contact with FS • Emptying takes a few times 	<ul style="list-style-type: none"> • can access most locations • Safe for less contact with FS • mobile than vacuum tanker • Faster than manual methods 	<ul style="list-style-type: none"> • can access most of the locations • Cheaper than motorized equipment's • It can be made locally 	<ul style="list-style-type: none"> • Can access most locations • Cheap • It can be made locally • lightweight; Easy for hand carrying
limitation	<ul style="list-style-type: none"> • No means of disposing of sludge off-site Sometime destroys squatting slab • Risk of health • risk of spillage • protection gear is necessary • Slow emptying • Associated social stigma 	<ul style="list-style-type: none"> • access constraints on narrow roads • expensive equipment and operations • high maintenance required • cannot empty hard material and dense sludge 	<ul style="list-style-type: none"> • access constraints in dense areas • cheaper than vacuum tanker but expensive • operation progress is slow • less capacity for storage 	<ul style="list-style-type: none"> • long distance FS transportation is tough • repairing is not simple 	<ul style="list-style-type: none"> • No carriage option for FS off-site • Cannot empty the entire pit (if the pit is deep) • Slow emptying times

The faecal-oral disease can transmit from unsafe steps in sanitation service chains with flies, animals, water bodies, fields, and groundwaters and get into the human body with drinking water, finger, feet, objects, floor surfaces, and toilets premises (WHO, 2018). The safety of emptying and collecting FS is classified according to FS conveyance after emptying and the containment type (Kabir & Salahuddin, 2014). This study prepared a list (Table 2) from the literature to identify unsafe FSM activities from the case study.

Table 2: List of FSM activities that are considered Environmentally Safe (Gautam et al., 2017; Kabir & Salahuddin, 2014; Simanjuntak et al., 2020; WHO, 2018)

-
- Open defecation is not at all
 - Using sealed containment restricting flies and water access
 - monitoring containment to avoid excreta overflow
 - Using well-sealed pipes to connect with sewer or digestion systems
 - Not discharging FS to the drains, toilet, settlement premises, crop fields, or open grounds
 - Timely emptying awareness, minimum every three years
 - Emptying without entering the containment
 - use of protective gear and types of safe equipment
 - measures for avoiding direct inhalation of the pathogen
 - Disposing of FS only after treatment and six months' storage
 - Applying sufficient pathogen removal process in FS treatment
 - Burring FS to the ground but not in crop fields
 - Maintaining cleanliness after emptying operations
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Methodology

Study area

This study selects an informal settlement named Notun Bazar chor, in Khulna city, as the least likely case that consists of pit toilets, hanging toilets, and toilets with septic tanks. There were 1134 settlements in Khulna city, and Notun Bazar chor is the largest, with 3480 people (854 households); most populations are Muslims with few Christians. The study area is in a shared land of Christian Service Society (CSS) and riverbank government land. People's primary income sources are small businesses, construction works, day labor, rickshaw or van pulling, and anonymous services. The location of Notun Bazar chor settlement also has the potential to identify the relation between FSM and urban water for having ponds and a nearby river named Rupsha. It has a 23' wide road connecting with the city and internal alleys width ranging from 1'- 6" to 12' -0" made with Concrete pavements and drainage facilities. People do not pay rent but pay taxes to KCC (Khulna city corporation) and electricity bills. Peoples maintains social organization based on alleys and uses names such as Christian alley, Sat-vai alley, Kashem alley, school alley, Masjid alley, etc. Each alley has tube wells, but people collect drinking water from the nearest Ferighat (Ferry terminal). Besides, they maintain a garbage management system paying 20 takas per month, which the CDC (Community development committee) monitors.

Toilets and populations

Maximum variations of toilets are studied, consisting of one twin pit toilet, seven single pit toilets, two hanging toilets, and seven toilets with septic tanks, where alley-based social organization and single or shared user type are considered (Figure 3). Respondents were interviewed from 4 single toilet users, and with the snowball

method, 13 users were sampled from shared toilets. Shared toilet user numbers varied from 3 to 56 among toilet samples, and six groups were randomly selected for group discussion where respondent numbers varied from 3 to 6 persons female dominated. A local Sweeper was interviewed, who knows about emptying practices of the settlement. A group discussion was also conducted with Harizan (a caste of Hinduism) sweepers. Besides this study interviewed 3 (non-Government organization) NGO personnel, 3 CDC member, and one vacutug manager at their convenient time. Before starting, the first author clearly explained the research to the participants, and after the interview and discussion sessions, the documented information was briefly conveyed to respondents, and verbal consent was taken.

Data management and analysis

Interviews were conducted in semi-structured questions with single toilet users, local sweepers, CDC members, and NGO personnel, and group discussions were conducted with shared toilet users and Harizan sweepers. Interviews with users were recorded on audio devices with respondents' permission, and information about toilet construction, containment condition, and management was collected from users. Information about Underground infrastructure's location and condition, FS flow lines, and discharging practices were noted from respondents' handly indications on a hand-carried map. Information provided by local sweepers, NGO personnel, Harizan sweepers, and CDC members are used to triangulate users' information, create an overall scenario of the FSM practices and city-wide context, and find influencing factors. Photographs of toilet premises and living areas were taken, alleys and streets were measured with digital devices, recorded videography to supplement preparing FS flow, and the study area built-environmental maps. Required drawings were produced using AutoCAD 2017 using the base map that was converted from the GIS file from KDA (Khulna Development Authority). Analysis of data followed thematic content and factoring approach. Initially, this research explored people's FSM activities to introduce environmentally unsafe practices; after that, it identified factors behind their activities, and finally, it developed a model based on contextual variables.



Figure 3. Sample toilets (a) Single HH, Single pit; (b) Shared HH, Septic tank; (c) Shared HH, single pit; (d) Single HH, Hanging Toilet (source: author).

The FSM practices in the informal settlement

Three types of FSM activities are found in the study area in the whole sanitation service chain. People are engaged with containment management, emptying operation, and conveyance of FS.

Containment management

Hanging toilet users

Users constructed hanging toilets over the pond without containment, and excreta goes directly into the water, which is environmentally unsafe. They use a concrete squatting pan over a wood, bamboo frame, CI sheets, or bamboo fences toilet enclosure. Sometimes a high pile of excreta accumulates under the squatting pan when

the pond dries, and users pour water from buckets to eliminate the blockage. However, users monitor the FS accumulation periodically to avoid emergency overflow.

Pit toilet users

People construct pit toilets with local masons. Single household pit toilets are self-funded and shared toilets are provided by CDC with the assistance of (United Nations Development Program) UNDP Khulna. Pits are constructed using 12" high, 2" thick, and 3'-2" diameter 6-10 concrete rings, which are locally available that get six to ten feet deep. The pit bottom is unlined, which is environmentally unsafe that leading FS to dissolve with the water at the upper shallow aquifer (Khulna's upper shallow aquifer water level fluctuates from 1'-9" to 7'-1" below ground level (Asian Development Bank, 2011)). Due to the land crisis, almost all pits are constructed under the toilet floor without any service hole. Only one Toilet has an offset pit with a service hole among eight pit toilet samples. People usually connect pits with drains with PVC pipes and connect with the pond where available. Shared pit toilets face a high accumulation of FS and pipe blockage and require frequent emptying.

Septic tank toilet Users

Septic tanks are two-chambered, properly sealed (informed by NGO personnel) brick masonry constructions in the study area. Septic tanks are placed under the main toilet floors with one or two service holes following the specified design. NGOs or KCC provided shared toilets with septic tanks, and three types of shared toilets with septic tanks were available, i.e., single alley user toilet blocks, two alley user toilet blocks with two separate containments, and two alley user toilet blocks with single containment. However, people connected tanks as three types: settlement Tank connected with the city drain, settlement drain, or pond to manage sludge accumulation. That is causing nearly no containment in the Tank; black water regularly and FS goes periodically to the environment through drains. The city drain faces the tidal effect of the nearest river, Rupsha. The settlement drain is shallow and outspreads a foul odor of FS to the premise when FS emits from the containments, and people scatter kerosene oil to remove it. Tanks become full of FS when some connecting pipe is blocked with any hard sludge or cloth dropped accidentally into the pan. Initially, people attempt to manage the condition self-handed using wooden or bamboo sticks by pricking or pouring buckets of water. However, the worst situation happens when their management does not work, and only at that time do they search for a sweeper. While people from the organization call sweeper.

Emptying operations

Since all sample containments have pipe connections with drains or ponds, this study found only six containments emptied among 17 samples but only in emergencies (Figure 4). These findings indicate that FS emitted from containments goes into the water unsafe and risks people's health. If blockage somehow happens, people practice emptying themselves or call a sweeper, failing to unblock the pipe. However, it has not been found among the selected containments except at Ranga Mia alley. Households are sometimes empty to reduce the cost when it is frequently needed due to over-accumulation of FS. They discharge FS into the settlement drain, pour buckets of water, and scatter kerosin oil into the drain to eliminate the foul odor. The preferred discharge locations are storm drains and river and river-drain junctions, but sometimes sweepers discharge in settlement drains or ponds to reduce over-costing. In emptied samples, sweepers entered the pit to remove the hard sludge without any protective gear but with a spade and work with open buckets for sludge carriage, causing spillage on toilet premises and streets, which are environmentally unsafe activities.

People do not call sweepers during the daytime. People informed that dealing with sweepers is difficult, but people became habituated. Sweepers take less money for emptying are widely accepted. However, they cannot maintain safe emptying due to a lack of proper emptying equipment and protective gears. Vacutug, operation manager of CDC, informed that Vacutug was never used in this settlement because of narrow roads and people unknown about its services and name. Vacutug needs at least an 8' wide road to enter where the most settlement roads are found, widening 1.5' - 6'. However, there are three roads which are more than 8'.



Figure 4. Faecal-water contamination pathways from toilets in Notun-Bazar Chor (source: author).

Besides, the adaptive growth of household spaces makes streets narrower. People extend kitchen and cliff storage over the streets. They often get restrictions from the electric service provider and ward councilor about extending. Peoples of some alleys construct gates near main roads to have privacy, making streets non-vehicular. However, their toilets are seen well maintained rather than other alleys.

Conveyance

Three types of Conditions influence the FS conveyance in the study area: budget of emptying job, transportation medium of FS, and distance of discharge location. People want to send FS away from toilet premises and alleys within the contract budget with sweepers. Usually, sweepers discharge FS unsafe to the nearest river location and use a rickshaw van to carry FS. Streets are too narrow (1'6"-4'6" wide) that even small rickshaw vans do not enter the toilet premises. That condition increases the risk of street spillage and causes faecal health risks. Road surface conditions and evenness also affect the conveyance and spillage of FS in streets. When sweepers find the emptying job more complex due to hard sludge, that situation conflicts with users and results in unmanaged discharge in drains, ponds, and FS spillage. Anyhow, users do not want to cross the budget limit.

Factors causing Environmentally unsafe FSM

FS discharge from hanging toilets

People who use hanging toilets are relatively newer in the settlement. Toilets with septic tanks and toilets are shared in this settlement provided by NGO and KCC for particular alley's listed users; on the lands managed by old settlers. Due to not being listed, transient people often do not get access to shared toilets. Because of that, they were compelled to build new affordable toilets without containments attached to rooms beside the pond, seeing others practice. They did not get toilets from any donations nor CDC and NGOs, and they never got offered for receiving toilets because they needed a good social network with the commissioner's office. These transient people often hear about losing the land, causing no up-gradation of toilets; instead, they prefer to expense money for living and child education.

Installing the unlined bottom pit

Most people in the settlement use pits constructed with unlined bottoms, allowing FS to dissolve to water at the upper shallow aquifer (Figure 5). Among ten individual and shared pit toilets, all are found bottom unlined and constructed as suggestions from local masons. However, CDC provides shared toilets with the membership loan procedure. In architectural construction drawings (Figure 5a) gathered from secondary data sources provided by UNDP personnel, there is no indication of brick soling or concrete casting for lining the bottom of the pit. Besides, people do not know the health and environmental risk and do what is available and easy to construct with a minimum cost of almost 16000/- taka.

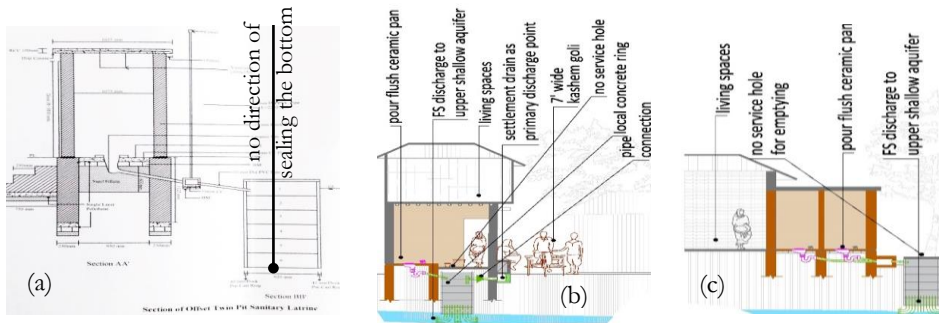


Figure 5. Sample pit toilets; (a) offset pit toilet design document (source: UNDP); (b) offset pit toilet at Kashem alley; (c) Shared twin pit toilet at Christian alley (source: author)

Connecting containment to the drain and pond

Pits and septic tanks are connected to the drain (Figure 5b), or the pond has no nearby street drain (Figure 5c) to avoid the extra cost of a long pipe connection. People do for FS accumulation, and there is no other way for pits without service holes. NGO personnel informed that they do not allow people to connect pipes to the drains; people make this connection independently. People made the connection when the Toilet was constructed; they would not take it without a pipe connection and influenced masons to make that connection. The pond in the settlement is owned by the Christian service society (CSS) Khulna. People never got any resistance to drain connection from CSS, and Christian people also do the same. In recent times, CSS cleaned the pond and took the initiative to grow fish, but still, they are not forcing people to disconnect pipes.

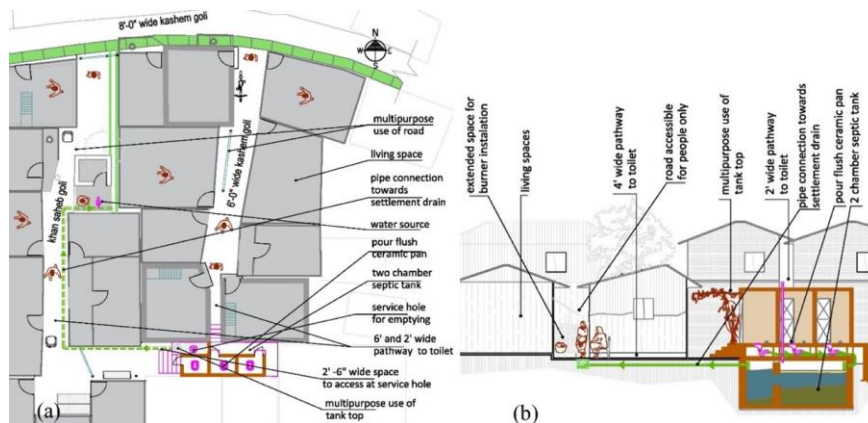


Figure 6. Sample toilet with septic tank used by 20 households from two alleys; (a) plan; (b) section.

hard sludge, and sweepers feel a septic tank is more convenient than pits; containment not emptied within three years has FS like hard soil that needs to be physically entered and spading job for removal. Sweepers decide on emptying mechanism and operation cost, observe containment type and condition, and confirm the contract for a job. They do not have better equipment for digging, so pour water to dissolve sludge, make it liquid, and pick it up with buckets. Sometimes, they do not get a water source nearby because not every household has a tube well, which causes extra labor. Sometimes they struggle with unwanted hard FS but contracted for an entire tank emptying job, and many times they were forced to empty and enter the pit unwillingly, which sometimes causes terrible injuries. There is no available equipment familiar to blend hard sludge with water quickly. If they understand advanced, they do not desire to contract the job containing hard sludge.

No use of safe emptying equipment

There is no practice of using safety equipment for emptying by sweepers. After the work, they clean the premises with water and use their sweep for cleaning. However, there are risks due to not having a vent pipe with containments and accumulated methane gas that can be ignited by lamp fire. Any means of safety equipment are not available for them. They know of vacutug but do not know how it can be their job equipment. Moreover, it can make them jobless. Sweepers can enhance their efficiency with lightweight manual machines for hard FS dissolution and pump up from containments, but they are not introduced yet.

Not carrying FS to the safe discharge location

The treatment plant at Rajband of Khulna is the only one in the city for safe discharge. It is situated on the KCC-owned land used for garbage dumping. However, it is far from the city, and from Notun Bazar Char, it is almost 11km. SNV personnel informed that the treatment plant is accessible for all sweepers, but the location is unknown to many, and travel costs become unbearable to them. Besides, there is no such place where sweepers can discharge FS safely. Sweepers discharge FS in nearby locations due to the lack of safe discharge sites and struggle to carry FS with only a rickshaw van.

FS spillage on settlement premises

Sweepers cannot take the van nearer to the toilet premise for narrow roads, and they put their vans on main roads in the study area. However, it is the reality of informal settlements. They cannot carry drums without vans; small mediums are open buckets or jerricans without sealing. That causes spillage on streets and toilet premises. Sweepers spoke about obstacles in the streets, which people extend space for the kitchen or firewood storage, bamboo posts for cloth drying, making streets narrower. These components become a significant obstacle in the nighttime and cause spillage if they become inattentive. Sometimes topography, street slopes, and uneven surface material cause FS spillage. Sweepers drink alcohol to lose their nerve and often go drunk to ignore the awful smell at work, which causes inattentiveness.

The context-sensitive model

The proposed model is based on factors (Table 3) affecting FSM practice in the informal settlement. FSM challenge varies with the socio-spatial diversity of settlements, and any single model cannot be implemented everywhere. Although the problems are more acute and varied in informal settlements with alley-based organizations, collective emptying mechanisms and conditional conveyances are opportunities to develop a contextual solution. An adaptive co-management process is needed to implement the model using FSM practice-based opportunity. The proposed model has five major themes. Each theme has an individual set of indicators and variables (Table 4). The model's variables can differ with biophysical diversity and socio-spatial situations of different informal settlements.

Table 3. Factors affecting FSM in the informal settlement

	Existing Practice	Unsafety factor
containment	Periodical containment management	1. Inequal allocation
		2. Lack of participation
		3. Lack of environmental concern
		4. Forgetting emptiability
emptying	Collective emptying mechanism	5. No emptying schedule
		6. Alley-based organization
		7. Spatial limitations
		8. Selecting available option
		9. Unfamiliar equipment
		10. Lacking customizable component
		11. Lacking transportability
conveyance	Conditional conveyance	12. No safe discharge site
		13. Disposal site proximity

Equitable, Impenetrable, and emptiable containment

The transient nature of population and tenure influences the growth and release of informal settlements. Providers prioritize the most settled areas of the settlements because of their increase in socio-political networks, whereas less settled areas are being ignored, causing the FSM to be weak and diverse people's practices. Identifying transient people for toilet allocation can make more equitable distribution of access to ensure environmentally safe FSM. Installation of containment can create social issues among people, which affect further management. People using toilets in clusters lack knowledge about containment infrastructure and maintenance. Single households also follow only masons' instructions lacking any expert professional supervision. Educating settlement people about FSM is essential to increase the participatory installation of containments with the supervision of professionals. The pit of the settlements is being installed by self-funded or shared funded with the support of CDC, city authorities, and NGOs. People are unaware of the consequences of penetrable pits. Even pits installed by providers are not correctly impenetrable, contaminating groundwater quickly where the water level is high (Figure 5a). Professional involvement with masons' construction skills is necessary to install environmentally impenetrable containment into the settlement. Only septic tanks are being found with service holes, but pits are installed without means of emptiability. Toilets that do not have offset pits are non-emptiable. Insufficient space hampers service hole installation over the pit, but technical assistance for a few structural customizations from professionals can help to add service holes with pits. Besides Toilet with the offset pit has a top slab that needs service holes and a proper reinforcement design to carry emptying live loads.

Periodical emptying and conveyance

City authorities and NGOs are promoting periodical emptying widely for urban FSM; in that case, making an emptying schedule can confirm the periodical emptying with the participation of people. The emptying schedule can be created with users' participation by identifying containment capacity and FS fill rate. The schedule can be maintained with alley-based organizations and CDC members; the way they manage community-led garbage management and pays monthly. Besides, labeling toilets with the next emptying date will increase awareness of emptying. Informal settlement people live organized in alleys and maintain a chain of command and leadership rooted in their alleys, which helps people maintain the settlement process and

informal growth. These organizations can monitor the periodical emptying system to maintain collective emptying. A socially accepted monitoring team can be prepared with users and CDC members for each alley and can be trained for better management.

Adaptive equipment

Properly sealable containers for conveyance are essential to mitigate FS spillage against the obstacles like narrow and uneven streets and topographic variations. Sweepers need to use adaptive safety equipment that separates FS from body contact. Small size manual emptying pumps such as MAPET (Manual pit emptying technology) and gulper can be selected, entering narrow streets. The customized size of the container and pushcarts can enable safe conveyance. Besides, sweepers' equipment needs more research to enhance efficiency and safety. Science, people, prefer nighttime for emptying operations due to foul odor, but it is dangerous to conduct such hazardous work at night. Semi-mechanical hand-powered pumps reduce odors, and if people get informed, they can be motivated by the participation of the CDC and can allow daytime emptying. Also, there is a need for safe tools for working at night, such as battery-powered lights instead of hazardous kerosin lamps.

Science Sweepers prefer locally produced technology for purchasing costs and maintenance; hand-powered emptying machines are simple enough to produce in local workshops (Sugden, 2012). MAPET and gulper can be produced in local workshops with technical assistance and made available in local markets to bring safety equipment affordably. An interest-free loan can be added to purchase the machine, making it easier to purchase by emptiers. With the market adoption of hand-powered safe equipment, it is necessary to familiarize sweepers with equipment. Skill development is essential to ensure the use of safe emptying equipment. There are examples of the skill development program in cities of Bangladesh and even in Khulna. These programs will help sweepers gather knowledge about environmentally safe emptying and the use of safety equipment.

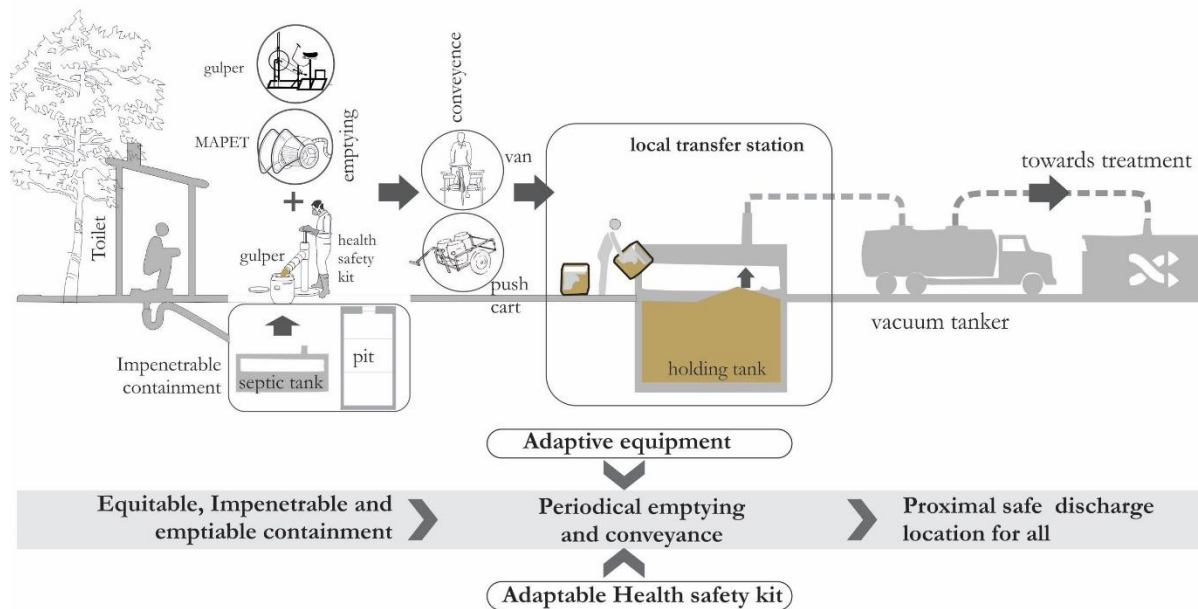


Figure 8. Proposed model for informal settlements (source: author).

Adaptable Health safety kit

The use of protective gear is largely ignored among sweepers and people. Compatibility and availability of protective gears are the main reasons. Hand gloves, masks, dresses, boots, and caps are found as protective gears in the formal FSM context, which are not available, not customizable to the user, and are costly from sweepers' perception. So, to ensure the health and environmental safety, adaptable safety kits need market availability with minimum price, promotion, and user-preferred customization. Building awareness of safe

Table 4. Indicator and variables for the implementation of the model (source: author)

Themes	indicators	Variables
Equitable impenetrable and emptiable containment	Equitable provisioning	<ul style="list-style-type: none"> • prioritizing transient population • separate containment allocation • separate service hole
	Participatory installation	<ul style="list-style-type: none"> • participation of the user, professional, CDC member, and local mason • participatory inauguration
	Impenetrable containment	<ul style="list-style-type: none"> • pit above the upper shallow aquifer • sealable pit ring module • septic tank
	Emptiability	<ul style="list-style-type: none"> • assisted offset pit construction • service hole for the top slab
periodical emptying and conveyance	Organization based monitoring	<ul style="list-style-type: none"> • informing environmental safety • ensuring network with CDC
	Participatory schedule making	<ul style="list-style-type: none"> • enlisting containment • labelling emptying schedule
adaptive equipment	Adaptive emptying technology	<ul style="list-style-type: none"> • road width mapping • hand-powered pumping equipment • hand-powered fluidizing equipment • compatible pushcart or van • sealed carrying container
	Locally produced and maintained	<ul style="list-style-type: none"> • incorporating local industries • technical assistance
	Familiarization and skill development	<ul style="list-style-type: none"> • equipment promotion to sweepers • training program
Adaptive health safety kit	Awareness building	<ul style="list-style-type: none"> • training program • caring manual challenges
	Customizable component	<ul style="list-style-type: none"> • available safety wears • locally tailored
proximal safe discharge location for all	Inclusive allocation	<ul style="list-style-type: none"> • nearest available public land • settlement wise distribution
	Optimized infrastructure	<ul style="list-style-type: none"> • calculating FS accumulation • a transfer station with a holding tank • scheduling vacuum tanker

emptying and health benefits among sweepers is necessary to increase the use of protective gear. Group workshops with community people and sweepers can be conducted for user awareness building.

Proximal safe discharge location for all

Ensuring a safe discharge location is inevitable for sustaining environmentally safe conveyance, and the distance of discharge location adds extra conveyance cost. The plant of Khulna city occupies 1.3 acres of land, and the construction cost was 1.90 crore BDT (240,000 USD). However, it is getting far less than its capacity of FS processing per day. Transporting FS to distant plant locations is costly for sweepers. A transfer station with an underground holding tank is used to reduce the distances of FS conveyance for manual and small-scale emptiers that facilitate intermediate dumping and emptying costs (Tilley et al., 2014). A decentralized transfer station with holding tank projects can be implemented near informal settlements, where sweepers can conveniently discharge FS from informal settlements with reduced cost. Scheduling a running Vacuum tanker provided by city authorities can collect FS from holding tanks for carrying to the treatment plants to increase the FS discharge rate. Land for transfer station can be selected in a participatory process, such as people accepting that sweepers discharge FS near the sluice gate and have available land. Optimized infrastructural design is necessary for an efficient system. It requires calculating the total FS accumulation of the settlement for constructing a holding tank. In Khulna, the city authority works with vacuum tankers as mobile transfer stations for CDC-owned vacutug but could not decide on payment distributions between vacutug and vacuum tankers.

Conclusion

This paper proposes Equitable, impenetrable and emptiable containment, periodical emptying and conveyance, adaptive equipment, adaptive health safety kit, and proximal safe discharge location as components of a context-sensitive model (Figure 8) to include informal settlements with a city-wide environmentally safe FSM system. The model is focused on developing safe manual emptying in informal settlements, and manual emptying is significantly dependent on Harizan sweepers in Bangladesh. However, the social condition of the manual Harizan sweepers was not addressed. In many informal settlements, institutions such as CSS play an influential role in the up gradation of the settlement. However, this study did not cover the role of institutions. Under the main themes, sub-themes are discussed in detail; but variables presented in the model required more multi-disciplinary investigation for social adaptation, technical performance, and more appropriate management procedures. People living in informal urban settlements may lose their land due to climatic and political shock or lose their traditional income due to the growth of capitalist society and migration to the cities. The significant change could not be addressed in a single pinch, but till then, the pieces of matters can be addressed with sensitivity. FSM is that piece, but it is necessary to build a healthy community. Looking from the bottom of the context can answer why top-down approaches like the vacutug-based emptying model do not include informal settlements, which can be a primary concern for the fourth industrial revolution (4IR). Top-down sanitation interventions can harm social organizations but can be used as an opportunity to draw more context-sensitive FSM solutions. When waves of innovations are coming every day, this research states that it should come in a way that may not become a cause of damage to the traditional systems while it should be strengthened.

Acknowledgment

This work is a part of a thesis conducted to fulfill the corresponding author's Master of Science in Human Settlement (MScHS) degree from the Architecture discipline of Khulna University. The authors appreciate the valuable guidance of the board of examiners of the thesis. The authors also want to acknowledge Water aid Bangladesh for the funding for the thesis.

Conflict of interests

The authors informed no potential conflict of interest.

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