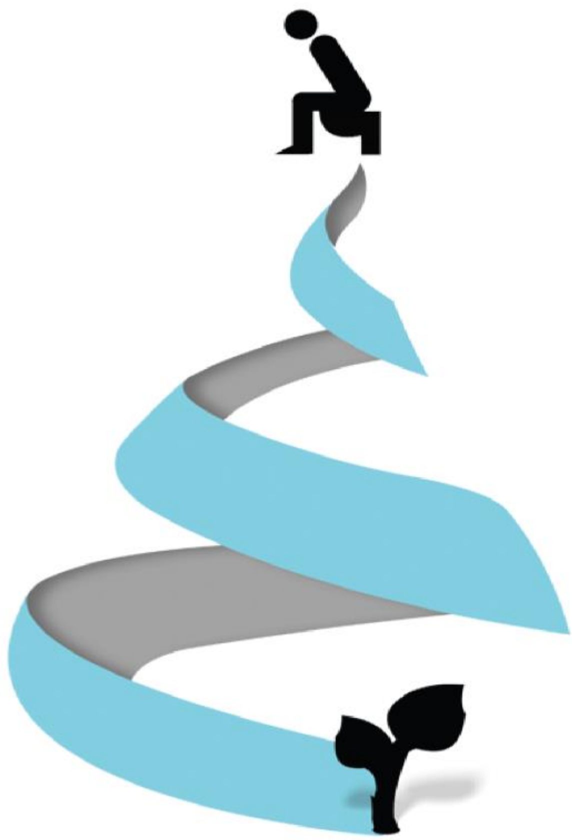
Technology Options for the Sanitation Value Chain



July 2016

Technology Options
for the Sanitation Value Chain

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Center for Study of Science, Technology and Policy (CSTEP)
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About the Compendium

The purpose of the compendium is to provide information on sanitation technologies from across the sanitation value chain. The compendium details the characteristics, advantages and disadvantages of the different technology options, and also describes the different types of systems formed as a combination of the technologies, addressing all stages of the value chain. These technologies have been included in the Technology Decision support Tool for Sanitation (SANITECH), developed by the Center for Study of Science, Technology and Policy (CSTEP). The document was compiled based on literature review and expert validation. The compendium is intended to be a live document, updated as and when new technologies and relevant data become available.

Abbreviations and Acronyms

ABR: Anaerobic Baffled Reactor	TP: Twin Pit
AD: Anaerobic Digester	TSS: Total Suspended Solid
AF: Anaerobic Filter	TVS: Total Volatile Solid
ASP: Activated Sludge Process	U: User Interface
BD: Biogas Digester	UASB: Upflow Anaerobic Sludge Blanket
BFP: Belt Filter Press	UDB: Unplanted Drying Bed
BOD: Biological Oxygen Demand	USEPA: US Environmental Protection Agency
C: Emptying and Conveyance	WSP: Waste Stabilisation Pond
CAPEX: Capital Expenditure	
COD: Chemical Oxygen Demand	
CST: Conventional Septic Tank	
CW: Constructed Wetland	
D: Disposal	
FS: Faecal Sludge	
HE: Helminth Egg	
IST: Improved Septic Tank	
IT: Imhoff Tank	
KM: Kilometres	
L: Litres	
LPCD: Litres per Capita per Day	
MBR: Membrane Bioreactor	
MD: Mechanical Dewatering	
MLD: Million Litres per Day	
OPEX: Operational Expenditure	
PDB: Planted Drying Bed	
S&T: Settling & Thickening tank	
S: Collection	
SBR: Sequence Batch Reactor	
SS: Suspended Solid	
T: Treatment	
TKN: Total Kjeldahl Nitrogen	
TN: Total Nitrogen	
TP: Total Phosphorous	

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Part A: Introduction

Sanitation

Sanitation refers to the maintenance of hygienic conditions by proper treatment and disposal of human urine and faecal sludge (FS). Inadequate sanitation is a major cause of diseases worldwide, and improved sanitation is known to have a significant positive impact on health both in households and across communities. At present, there is a lack of access to affordable sanitation in India. About 53.1% of the households do not have a toilet and 38% of urban households in India use septic tanks as onsite sanitation facilities. "In Africa, more than 60% of the population does not have access to improved sanitation, with 40% of the rural population practising open defecation" [1]. Figure 1 shows the overview of sanitation in developing countries. Building a mechanism for the safe disposal of septage[1] from these onsite sanitation systems often remains a neglected component. Poorly and unscientifically designed onsite disposal facilities affect the sources of groundwater and surface water with substantial environmental and health hazards.

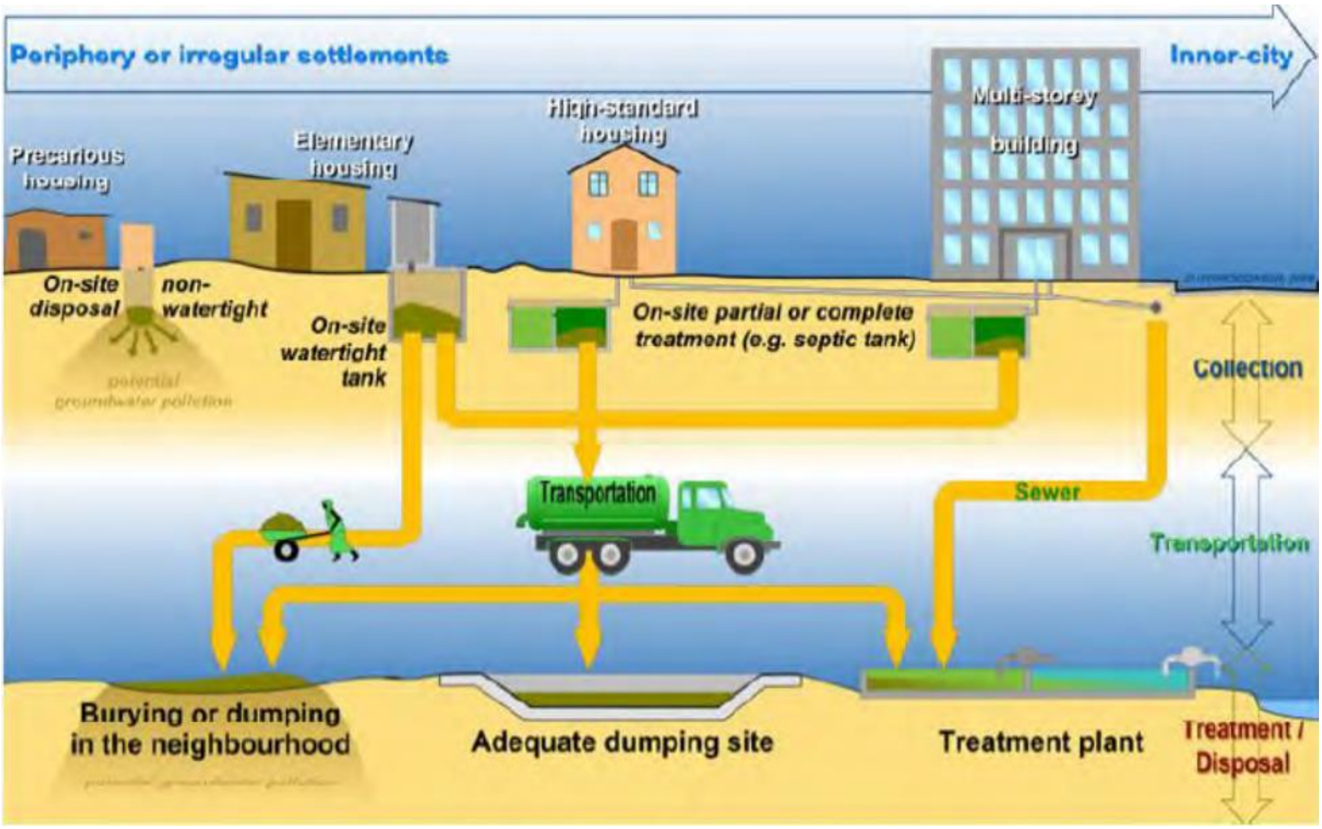

Figure 1: Overview of Sanitation in Developing Countries

Source: Hydroconseil

Health Effect of Poor Sanitation

Malnutrition is thought to have a role in about 50% of all deaths among children worldwide [2]. In less developed countries like India, bad nutritional status and poverty promote mortality and morbidity associated with excreta-related diseases. Excreta and wastewater disposal accounted for the "second biggest percentage of DALYs after malnutrition"[2]. It is estimated that there are approximately 4 billion cases of diarrhoea per year (resulting in 2.2 million deaths) worldwide; 200 million people suffer from schistosomiasis and 400 million people are affected with intestinal

[1] Septage means the partially treated sludge stored in a septic tank or pit latrine. It is a type of faecal sludge and a by-product of the pretreatment of household wastewater in a septic tank where it accumulates over time.

worms[3] [4] [5] [6]. All of these diseases are caused mainly by excreta disposal. In children, below age 5, most deaths are attributed to diarrhoea [6]. A higher risk of mortality has been observed in children with low weight (for their age) [7]. The health impacts of water and sanitation are mainly due to the specific pathogen *Shigella* spp. [8] [9]. Thus, exposure to excreta and wastewater is an environmental and health hazard, and so minimising this exposure in each and every part of the sanitation value chain becomes paramount.

This document is an attempt to compile details of existing technologies that may be relevant for adoption in developing countries to minimise the exposure to FS and wastewater. Part B introduces some concepts, details the sanitation value chain and explains the two different categories of sanitation technologies. Part C details the characteristics, advantages and disadvantages of the different technology options for each part of the value chain. Part D details the different types of systems formed as a combination of the technologies described in Part C, addressing all parts of the value chain. Part E highlights the benefits of treated excreta and wastewater.

Part B: Introduction to the Sanitation Value Chain

This part outlines some of the basic definitions and concepts used to determine technologies for sanitation.

Sanitation Value Chain

The five things that are covered under the sanitation value chain are user interface, collection, emptying and conveyance, treatment and disposal (Figure 2). Each aspect has a set of different technologies, which is explained in Part C. The technologies of the five groups can be chosen to build a system (Part D).

User Interface

User interface explains the type of toilet construction—pedestal, pan or urinal—with which a user comes in contact; it is the way in which the user accesses the sanitation system. In most of the cases, the choice of the user interface depends on the availability of land and water and, also sociocultural factors. Only excreta and black/yellow water and wash water originate at the user interface, and not grey water (grey water is generated from domestic sources).

Collection/Storage/Treatment

Collection/Storage/Treatment explains the collection, storage and, sometimes, partial treatment of products that are generated from the user interface. The treatment that is provided by these technologies is often a function of storage and is usually passive (e.g., no energy inputs). Thus, products that are "treated" by these technologies often require subsequent treatment before use and/or disposal. The collection/storage/treatment component has limited capacity beyond which it cannot function effectively, and needs to be emptied.

Emptying and Conveyance

Emptying and conveyance describes the removal and transportation of FS from one place to another (e.g., septic tank to treatment plant). This becomes necessary when the collection/storage/treatment component has reached its capacity. In developing counties, trucks and small bores are mainly used for the transportation of sludge.

Treatment

The treatment part describes the treatment technologies that are generally appropriate for the ward level and city level. The CAPEX, OPEX, land and energy requirements of the technologies of the treatment group are generally higher than those of the storage group. The treatment group is divided into four categories: (1) primary treatment (separation of solid–liquid), (2) treatment of effluent, (3) treatment of sludge and (4) treatment of post-effluent.

Use and/or Disposal

Disposal describes the safe disposal or use of the treated product for some benefits.

Figure 2: Five Groups of the Sanitation Value Chain

Some Concepts

Faecal Sludge

FS is a slurry or semisolid that is raw or partially digested, and comes from the collection, storage or treatment of a mixture of excreta and black water, with the presence or absence of grey water. Examples of sources of FS generation are onsite technologies,[2] which include dry toilets, pit latrines, septic tanks, unsewered public ablution blocks and aqua privies. FS contains organic and inorganic matter, microorganisms and other contaminants that can have serious impacts on human health and the environment. It is, thus, necessary to manage FS in a manner that mitigates and minimises these adverse impacts.

Faecal sludge management (FSM) mainly includes five stages, namely, storage, collection, transport, treatment, and safe end use or disposal of FS. Safe treatment and disposal of excreta act as the primary safeguards to protect the community from pathogens and for pollution from entering the environment. Once pollution/ contaminants/ pathogens enter the environment, they can be transferred via the mouth (e.g., through eating contaminated vegetables/food or drinking contaminated water) or the skin (as in the case of the schistosomes and hookworms), although in many cases adequate personal and domestic hygiene can reduce such transmission. FS and wastewater contain a high amount of excreted pathogens. For maximum protection of health, it is very important to understand the treatment of human excreta.

Method to Estimate Faecal Sludge Generation

An estimation and projection of the generation of FS is an important aspect for the proper scheming of infrastructure required for the development of collection and transportation networks, discharge sites, treatment plants, and end-use or disposal options [10]. Two theoretical methods that have

[2] Onsite technology means the treatment of waste at the point of generation either fully or partially, i.e., within the household premises. Poorly maintained on-site systems can increase the potential for health hazards.

been developed for the quantification of FS are the sludge production method and the sludge collection method [10]. The methods depend, respectively, on whether the goal is to determine the total sludge production or the expected sludge loading at a treatment plant. In the sludge production method, survey starts at the household level with an estimate of excreta production (i.e., faeces and urine), the volume of water used for flushing and cleansing and in the kitchen, and accumulation rates based on the type of onsite containment technology. In the sludge collection method, the survey focuses FS collection and transport companies (both legal and informal), and uses the current demand for services to make an estimate of the volume of FS. Due to lack of available information and data, many assumptions have to be made in both methods. It is important to make a note of the changes that could take place in the service area, which would affect the FS volume. These include population growth, increased coverage of sanitation, changes in on-site collection/storage methods, changes in emptying methods/frequency, water use, weather, climate, among others.

Sludge Production Method

The quantity of faeces produced daily can vary significantly based on dietary habits. Quantity also depends upon the type of food. Generally, high-fibre-content food produces a high quantity of faeces than food with low fibre content [10]. The faeces production rates in low- and high-income countries are presented in Table 1.

Table 1: Reported Faecal Production Rates in Low Income and High Income Countries

Location	Wet Weight (g/person/day)
High-income countries [11] [12] [13] [14]	100–200
Low-income countries, rural[12]	350
Low-income countries , urban[12]	250
China[15]	315
Kenya [16]	520
Thailand [17]	120–400

Daily urine production can also vary significantly based on factors such as water consumption, diet, climate and physical activity [11] [12]. The general values for adults and city-wise urine productions are presented in Table 2.

Table 2: City-wise Urine Production Rates

Location	Volume (g/person/day)
General value for adults [12]	1,000–1,300
Sweden [14]	1,500
Thailand [17]	600–1,200
Switzerland (home, weekdays) [18]	637
Switzerland (home, weekends) [18]	922
Sweden [19]	610–1,090

The FS accumulation rate also depends on dietary habits, patterns of societal cohesiveness and frequency of toilet use. The following data are required to obtain an accurate estimation of FS production, i.e., number of users, types and number of various onsite systems, location, FS accumulation rates, and population of socio-economic levels. An accurate estimation of FS production requires intensive data collection at the level of household questionnaires. In some cases, detailed demographic information is available, whereas in others it does not exist.

Sludge Collection Method

The quantity of FS collected from onsite systems depends on the FSM infrastructure, which is based on factors such as acceptance and promotion of FSM, demand (or regulation) for emptying and collection services, and availability of legal discharge or treatment sites. The volume of FS collection can be estimated through interviews, site visits, and a review of the internal records of FS collection and transport companies. Estimation will be based on the number of collections made each day, the volume of FS per collection, the average emptying frequency at the household level, and the estimated proportion of the population that employs the services of collection and transport companies [20]. Informal or illegal collection activity should also be taken into account, as the volumes collected can be quite significant. This method for the estimation of the generation of FS is complicated by many factors such as the presence of a legal discharge location or treatment plant, whether the discharge fee is affordable, and whether there are enforcement measures to control illegal dumping. If all of these factors are in place, then it is possible that the majority of FS collected will be transported and delivered to a treatment site.

Characterisation of Faecal Sludge

To obtain the FS characteristics, the chemical oxygen demand (COD), total solid (TS), biochemical oxygen demand (BOD), nutrients, pathogens and metals should be considered. These parameters are almost the same as parameters that are considered for domestic wastewater analysis, although it needs to be emphasised that the domestic wastewater and FS characteristics are very different. Table 3 presents the characteristics of FS and also provides information about comparison with sludge from a wastewater treatment plant. The total solid, organic matter, ammonia and helminth egg (HE) concentrations in FS are ten or hundred times higher than that in wastewater sludge [21]. Currently, there is a lack of detailed information on the characteristics of FS due to low research conducted in this field.

Table 3: Reported Characteristics of FS from Onsite Sanitation Facilities and Wastewater Sludge

Parameters	FS Sources		WWTP Sludge
	Public Toilet	**Septic Tank**	
pH	1.5–12.6[22]	–	–
	6.55–9.34 [23]		
TS	52,500	12,000–35,000 [24]	–
	30,000	22,000 [25]	–
	–	34,106[22]	–
	≥3.5%	<3% [26]	<1%
TVS	68	50–73 [24]	–
	65	45[25]	–
COD	49,000	1,200–7,800 [24]	–
	30,000	10,000[25]	7–608
	20,000–50,000	<10,000[26]	500–2,500
BOD	7,600	840–2,600[24]	–
	–		20–229[25]
TN	–	190–300[24]	–
	–	–	32–250 [25]
TP	450	150	9–63[25]
TKN	3,400	1,000[27]	–

Parameters	FS Sources		WWTP Sludge
Nitrates	–	0.2–21[28]	–
Ammonia	3,300	150–1,200[24]	–
	2,000	400[25]	2–168
	2,000–5,000	<1,000[26]	30–70
Faecal coliform	1x105	1x105	6.3x104–6.6x105[25]
HE	2,500	4,000–5,700[29]	
	20,000–60,000	4,000	300–2,000[26]
	–	600–6,000[30]	–
	–	16,000 [31]	–

Wet and Dry Sanitation

Sanitation technology can be described as either "wet" or "dry". The wet technology means it requires water to flush the excreta. Most urban sanitation in India is wet (flush toilet connected to a septic tank, leach pit or sewer). The dry technology does not need water for flushing the excreta. Dry technologies include a range of different types of traditional pit latrines, ventilated improved pits, as well as contemporary designs that promote the safe reuse of excreta. Ecosan is a form of dry sanitation that separates the urine and faeces at the point of generation of excreta, which is reused after co-composting. Ecosan has some advantages like a reduced water demand for flushing and also reduced wastewater management problems (because of no black-water generation). However, the water availability in most of the Indian cities, and the cultural preference to anal cleaning methods, makes the flush toilet the preferred option for most households.

Basically, there are three types of sanitation systems in India: (1) onsite sanitation system (holding waste in the vicinity of the toilet in a pit, tank or vault), (2) offsite sanitation system (waste is removed from the vicinity of the toilet for disposal elsewhere) and (3) hybrid sanitation system (retaining solids close to the lavatory, but removing liquid for off-site disposal elsewhere). On-site sanitation technologies are dependent on the periodic removal of FS from vaults, pits and tanks. The most common practice, adopted by households, is to pay sweepers to empty out the pits manually. This imposes vulnerabilities to health risks and is banned by the Constitution of India. In order to achieve complete sanitation in a city/town, consideration must be for minimising exposure at all parts of the value chain. It is very important to understand that only collection of FS is not enough; it needs to be treated before disposal. Hybrid and off-site systems need to connect with systems of sewer for transporting wastewater from the toilet to the treatment facility. Sewers consist of a network of buried pipes that carry wastewater from a house to the point of disposal. If the sewage is connected to piped sewerage, there must be sufficient water to make the sewage flow along the pipe. In hybrid systems, the toilets are connected via interceptor tanks. Blackwater and sullage[3] are normally combined on-plot and discharged to the sewer through a single household connection. Normally in all cases, the treatment of sewage is a prerequisite before its discharge to the open environment or use for irrigation or aquaculture.

Anaerobic and Aerobic Sanitation Systems

Anaerobic sanitation systems like single-pit latrines, septic tanks, biogas settlers, small- and large-scale anaerobic digesters, and wastewater stabilisation pond systems produce less sludge than aerobic sanitation systems (e.g., trickling filters, activated sludge, etc.). Anaerobic sanitation is the treatment of wastewater and waste by a process called anaerobic digestion. During anaerobic

[3] Sullage/grey water is the wastewater generated in households or office buildings from streams without faecal contamination.

digestion, the organic matter in the waste and wastewaters is converted to biogas, a mix of methane (CH_4) and carbon dioxide (CO_2), and a nutrient-rich sludge. The sludge generated from an anaerobic sanitation system is stabilised and is much better with respect to odour than an aerobic sanitation system. Biogas can be used for power generation and has therefore great potential as a renewable energy source.

The choice of sanitation systems for a city should particularly depend on the local conditions and the priorities of the town with regard to sanitation, such as coverage, environmental and health benefits, elimination of open defecation, etc. Variation in population density, water usage and availability, soil type, level of water table, availability of capital, ability to pay and uncertainty about growth patterns will strongly influence the decision-making for the sanitation system.

Part C: Brief Introduction of the Functional Groups of a Sanitation System

(A) User Interface

Four kinds of user interfaces are described below i.e. pour flush toilet, cistern flush toilet, urine-diverting dry toilet and composting toilet (Table 4).

Table 4: General Descriptions of User Interface

Options for User Interface	Advantages	Disadvantages
Pour Flush Toilet[4]	1. Water is sealed in a pour flush toilet, effectively preventing odours. 2. Robust and rarely requires repair 3. Suitable for all type of users like squatters, washers and wipers. 4. Low CAPEX and OPEX; suitable where there is insufficient or inconsistent piped water supply. 5. Approximately 2–3 l water is usually sufficient for flushing out the faeces. Pour flush toilets are appropriate for almost all climates.	1. It requires provision of water. 2. Dry cleansing materials may block the water seal and cause clogging.
Cistern Flush Toilet[5]	1. No serious problems with odours if used correctly. 2. Suitable for all type of users like squatters, washers and wipers. 3. Easy to use and clean.	1. The high capital and operating costs (depends on the price of water). 2. Requires a constant source of piped water. 3. May be difficult to build and/or repair locally with available materials. 4. Generates a large volume of sewage to be discharged.
Urine-Diverting Dry Toilet[6]	1. It does not require a constant source of water. 2. It is suitable for all types of users	1. Difficult to use for small children. 2. User requires cultural

[4] In a pour flush toilet (Figure 3), water is poured by the user. When water supply is not continuous, a cistern flush can become a pour flush toilet [32].
[5] A cistern flush toilet use large amounts of water and also provides a high level of convenience"[33]. Latest toilet models use 6–9 l of water per flush, whereas older models use a high amount of water of up to 20 l for a flush (Figure 4).
[6] A urine-diverting dry toilet (UDDT) is a simple, low-cost technology, but it is difficult to clean as compared with other toilets due to lack of water and the need to separate the solid faeces and liquid urine (Figure 5) [36].

Options for User Interface	Advantages	Disadvantages
	like squatters, washers and wiper. 3. Urine can be used directly as fertiliser. 4. It is suitable for high ground water levels, hard rock soil areas and areas prone to flooding. 5. When used correctly, no serious problems with odours and vectors (flies) occur. 6. It can be built with locally available materials. 7. Low CAPEX and OPEX.	awareness/ adaptation / acceptance through education and training to use correctly. 3. Excreta pile is visible. 4. Further treatment of excreta is required before disposal.
Composting Toilet[7]	1. It can be built with locally available materials. 2. Low CAPEX and OPEX. 3. Urine can be used directly as fertiliser. It does not require water. 4. No problems with vectors and odours.	1. A model of this type of toilet is not available everywhere. 2. User requires cultural awareness/ adaptation / acceptance through education and training to use correctly.

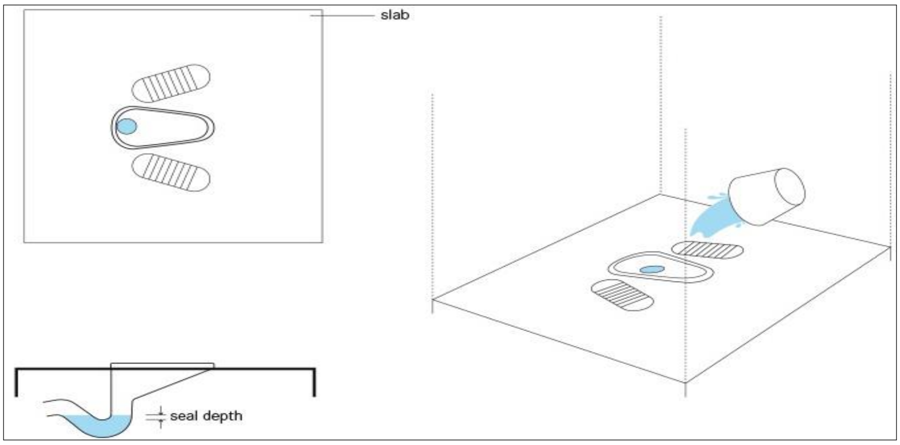

Figure 3: Overview of a Pour Flush Toilet
Source: Tilley et al. (2014)

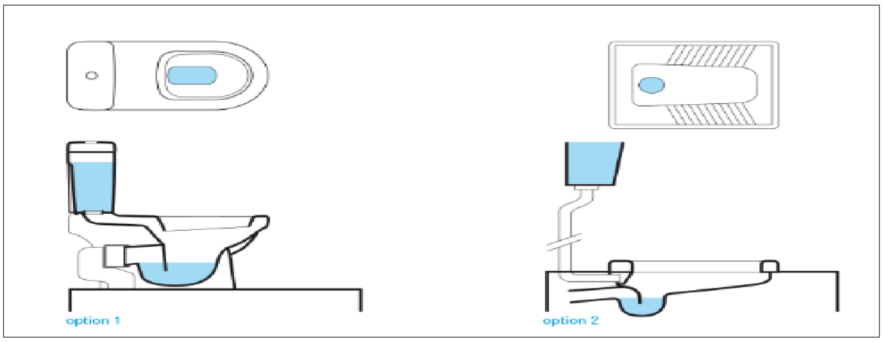

Figure 4: Overview of a Cistern Flush Toilet
Source: Tilley et al. (2014)

[7] It is a dry toilet and does not need water for a flush. Composting toilets produce compost by aerobic decomposition (Figure 6) that can be used for agricultural soil. Composting toilet is suitable for areas where water is not available.

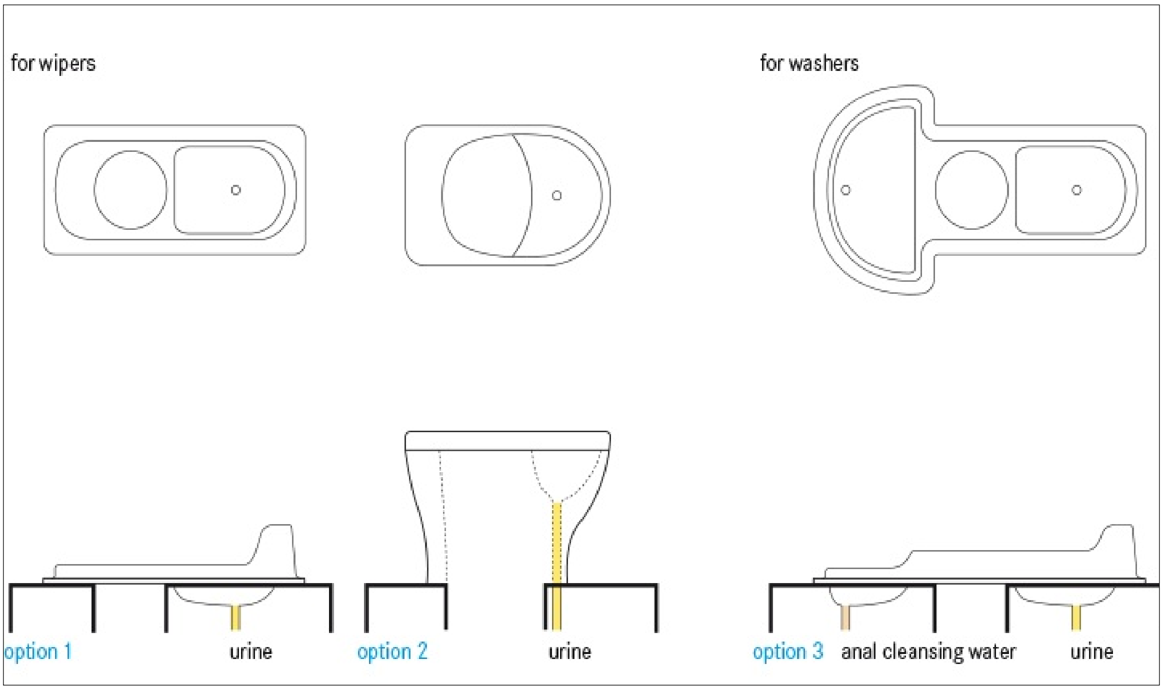

Figure 5: Overview of a UDDT

Source: Tilley et al. (2014)

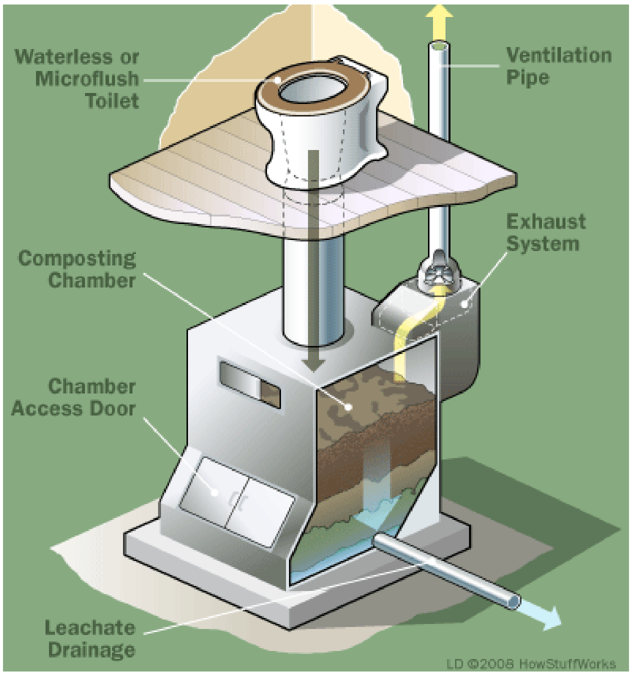

Figure 6: Schematic View of a Composting Toilet

(Source: Google Image)

(B) Excreta Storage

Twin pits, septic tanks and biogas digesters are used for the storage, collection and treatment of excreta (Table 5).

Table 5: General Descriptions of Storage Options for Excreta

Treatment option	Advantages	Disadvantages
Twin Pit[8]	1. Locally available materials can be used for building and repairing. 2. Easy to maintain and de-sludge. 3. Sludge from twin pits can be reused. 4. Low CAPEX and OPEX. 5. Reduction of pathogens in case of full digestion.	1. Needs greater space for construction in comparison with a single-pit system. 2. If water supply for flushing is low, the toilet/pipe can get clogged. 3. If the sludge is not digested fully, further action is required. 4. Groundwater contamination risk. **5.** No black water treatment.
Conventional Septic Tank[9]	1. It can be built and repaired with locally available materials. 2. If used properly, flies or odours are not an issue. 3. Simple and robust technology. 4. Energy is not required. 5. Low operating cost. 6. Small land is used for construction. 7. The septic tank lifetime is 50 years.	1. Low reduction of organic matter. 2. Regular de-sludging must be ensured. 3. Not conducive for areas with a high water table and flood-prone areas. 4. Manual emptying of septic tank is hazardous and an inhumane task, whereas mechanical emptying (vacuum trucks) requires sophisticated instruments. 5. Further treatment and/or appropriate discharge of effluent is required.
Improved Septic Tank[10]	1. Energy is not required 2. Long service life 3. Higher reduction of organic matter as compared with a CST 4. Moderate capital and low maintenance costs ensure high acceptance among users.	1. Sludge and effluent require further treatment before discharge. 2. Low reduction of pathogens. 3. High space required compared with a CST.
Biogas Digester[11]	1. It can be built with locally available materials. 2. Energy is not required. 3. Renewable energy and fertiliser production. 4. It can be used for the treatment of human waste, animal waste and solid waste. 5. Moderate capital cost, and low operating and maintenance costs. 6. Long service life. 7. Reduces the use of wood burning for cooking fuel.	1. Expert design required along with skilled labour for construction. 2. Slurry and sludge require further treatment. 3. Long start-up time.

[8] A twin pit is basically two pits that store the excreta (faecal matter) (Figure 7). It provides a long period for the digestion of faecal matter. The cost estimated for the construction/installation of a twin-pit system is US$50– US$75 for a single household with five persons.

[9] A septic tank (a settling and decomposition chamber) is made of concrete, fibreglass, polyvinyl chloride (PVC) or plastic. It is a water-tight chamber (Figure 8) [38] [39]. The removal efficiencies of a septic tank are as follows: BOD, 30–50%; TSS, 40–%; *Escherichia coli* , 1 log unit [39].

[10] The basic difference between an improved septic tank (IST) and a CST is that removal efficiency is higher in an IST. This is the disadvantage of a CST (Figure 9). The cost of an IST with a soak pit ranges from US$750 to US$1,250 for a household size of five persons.

[11] Biogas technology is basically used for the digestion of organic matter in the presence of anaerobic bacteria (Figure 10). The removal efficiency of BOD is 40–60%, whereas removal of suspended solids is 50–70% [39]. The cost of a biogas digester ranges from US$500 to US$1,000 for a household size of five persons [39].

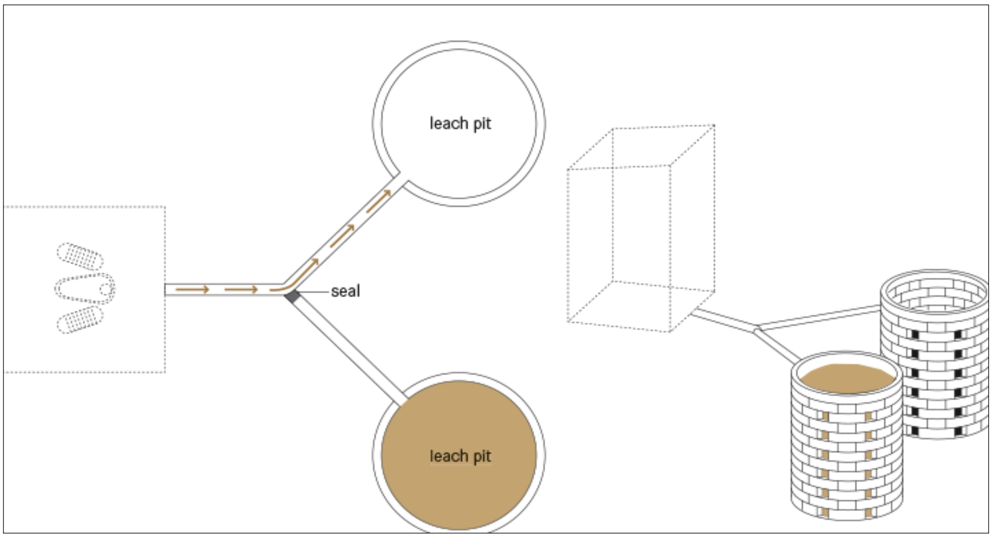

Figure 7: A Pour Flush Toilet Linked to a Twin-Pit System
Source: Eveleigh (2002)

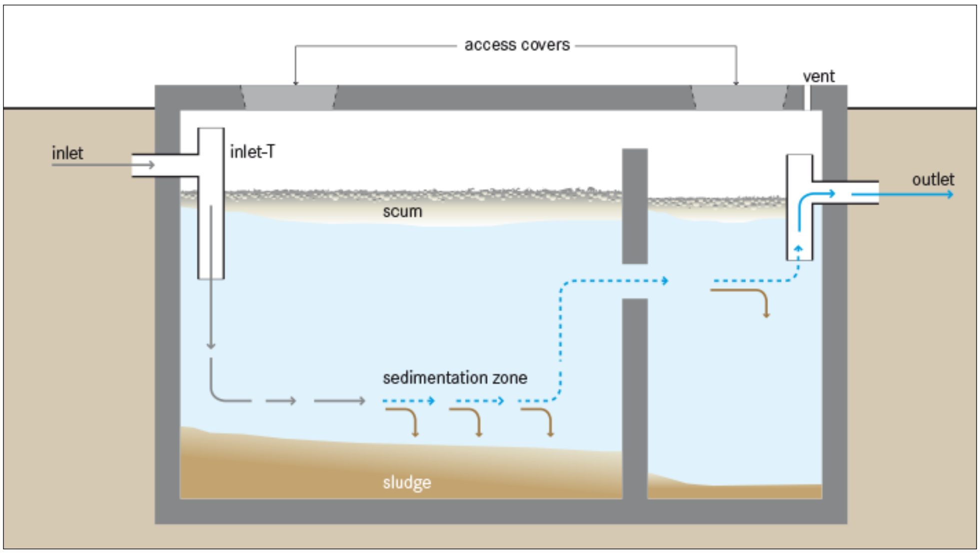

Figure 8: Overview Scheme of a Septic Tank
Source: Tilley et al. (2014)

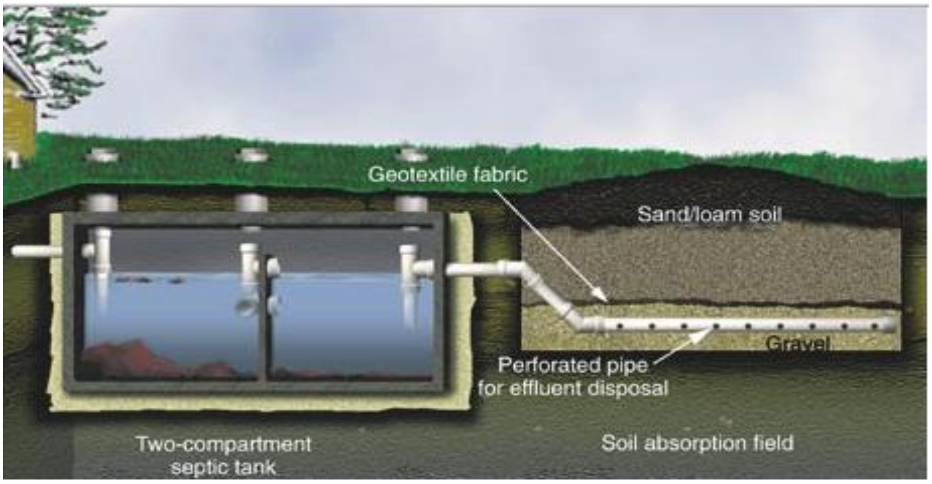

Figure 9: Overview Scheme of an IST (Two Compartments) with a Soak Pit
(Source: Google Image)

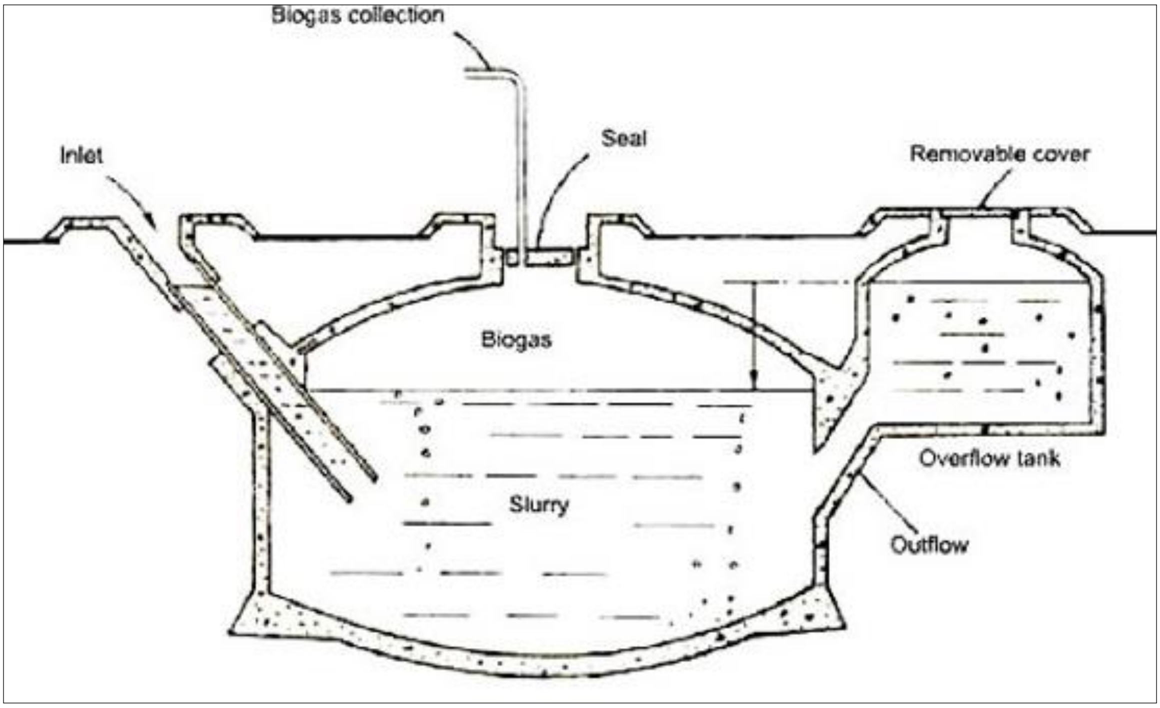

Figure 10: Overview of a Basic Biogas Digester
Source: Kangmin and Ho (2006)

Decision matrix for Storage/Collection/Treatment

Based on the technological options, a decision matrix was prepared with respect to land availability, energy requirement, skill requirement, CAPEX, OPEX, groundwater depth and discharge standard (Table 6). The matrix ascertains the favourability of a technology in comparison with those of other identified technologies. The green symbol denotes low favourability, yellow shows moderate favourability and red shows high favourability with respect to the constraints. (For example, if the user chooses the biogas digester option for storage, then the land requirement would be higher than those of the twin pit and conventional septic tank.)

Table 6: Decision-Making Matrix for On-Site Collection/Storage/Treatment

Constraint	Legend		TP	IST	ST	BD
Land Requirement	Low	[green]	[green]	[red]	[yellow]	[red]
	Medium	[yellow]				
	High	[red]				
Ground Water Level	Shallow	[green]	[red]	[green]	[red]	[green]
	Deep	[red]				
Require Specific Soil Type	Yes	[green]	[red]	[red]	[red]	[red]
	No	[red]				

TP, Twin Pit; IST, Improved Septic Tank; ST, Septic Tank; BD, Biogas Digester.

(C) Options for Removal and Transport of Faecal Sludge and Septage

Manual and mechanised techniques like hand tools, vacuum trucks, pumping systems or mechanical augers can be applied for the removal of FS. Before collection and transportation of FS, it is necessary to understand its properties. These properties are primarily influenced by water content, sludge age, presence of non-biodegradable material and organic material.

Generally in developing countries, the service providers use the manual collection method. Four most common types of manually operated mechanical pumping equipment, i.e., the sludge gulper, the diaphragm pump, the nibbler and the manual pit emptying technology, have been developed and trialled. Fully mechanised technologies such as motorised diaphragm pumps, trash pumps and some types of vehicle-mounted vacuum equipment are powered by electricity, fuel or pneumatic systems.

Table 7 summarises the main aspects of the manually operated mechanical equipment and mechanical sludge-emptying equipment

Table 7: Comparison of Manually Operated and Mechanical Sludge-Emptying Equipment

Equipment Type	Performance	CAPEX (INR/Piece)	OPEX*(INR/ Month)	Challenges
Gulper	• Emptying rate: 25–30 l/min • Operation depth: 1–3 m • Maximum pumping head is dependent on design	15,000–20,000	200–300	Difficulty in accessing toilets with a small superstructure; clogging at high non-biodegradable material content; PVC riser pipe prone to cracking; splashing of sludge between the spout of the pump and the receiving container
Manual diaphragm pump	• Maximum flow rate, 100 l/min • Maximum pumping head, 3.5 m–4.5 m • Flow range from 0 LPH up to 1,150 LPH for different models • Pressure: maximum 4 kg/sq.cm	15,000	200	Clogging at high non-biodegradable content; difficult to seal fittings at the pump inlet, resulting in entrainment of air; pumps and spare parts currently not locally available
Nibbler	May be suitable for pumping higher-viscosity sludge	-	-	May be unsuitable for dry sludge with high non-biodegradable material content
MAPET	• Emptying rate: ○ 20 l/min ○ 100 l/min • Operation depth: >3 m	For varying emptying rate • 20,000 • 2,00,000	200	Requires strong institutional support for MAPET service providers; reliance on the importation of a key spare part; MAPET service providers unable to recover maintenance and transport costs from emptying fees
Motorised diaphragm	• Max flow rate: 270 lpm	18,000–30,000	500–1,000	Blockade due to non-biodegradable waste in the

Equipment Type	Performance	CAPEX (INR/Piece)	OPEX*(INR/ Month)	Challenges
pump	(72 gpm) • Inlet: 38.10 (1½ " BSP) • Discharge: 38.10 (1½ " BSP) • Suction lift: • Dry: 4.57 mm (15'), wet: 7.62 mm (25')			sludge; spare parts not available locally
Trash pump	• Operating depth = 5–7 meters • Weight = 12 kg Size = L, 170 mm; W, 220 mm; H, 400 mm • Discharge = 14,000 litres/hour • Type of energy = fuel/electricity	10,000–20,000	500	Difficult to find spare parts; Requires a containment system; Potential for clogging
Pit screw auger	• Emptying rate: ○ <20 l/min; ○ 25–50 l/min; ○ 50–125 l/min	For varying emptying rate: ○ 20,000 ○ 45,000 ○ 1,20,000	500	Fixed length of auger and riser pipe; Unsuitable for use with dry sludge and large quantities of non-biodegradable waste; Difficult to clean after use; Difficult to manoeuver due to weight and size
Gobbler	• Blocks easily due to sludge build-up in the working parts • Pumping head of at least 3 m • Difficulty emptying from variable depths • Operation depth: 2–3 m	40,000	500	Weight of the pump; Length not adjustable

Note: Gulper can be only used for de-sludging pits and not for septic tanks, and if the volume increases, it becomes a tedious task. Also, it can be used only in places where FS is watery in nature and not for dry FS.
*OPEX only includes the general cost for oiling, applying grease and fixing of screws.

Transport of Faecal Sludge

Low-cost transport equipment is used for the transportation of FS from the generation point to the treatment point. This equipment can be categorised into two main forms: (1) manually propelled by human or animal power, and (2) motor-propelled using a fuel-powered engine.

(a) Manual Transport

Manual transport equipment is low-cost and generally has a small load capacity, a limited and low travel range, and low speed. Standard carts and customised carts are designed specifically for the transport of FS in many low-income countries, an example of which is shown in Figure 11. Although designs vary widely, standardised carts typically consist of a load-bed mounted on a single axle with one or more wheels. Containers of sludge with capacities of up to 200 L can be carried on or in a manually pulled or pushed cart [43] [44] [45]. Generally in developing countries, a small truck or a big truck is used for the transport of FS, and a small bore is used for the transport of waste water. A cost comparison for conveyance is summarised in Table 8.

Table 8: Summary of Cost for Transport of FS

<table>
<tr><th>Conveyance</th><th>CAPEX (INR)</th><th>OPEX</th></tr>
<tr><td>Small truck</td><td>10,00,000–12,00,000</td><td rowspan="2">5,38,000</td></tr>
<tr><td>Big truck</td><td>15,00,000–20,00,000</td></tr>
<tr><td>Small bore</td><td>Not available</td><td>Not available</td></tr>
<tr><td colspan="3">*OPEX: 5,38,000 is a sum of the following:
Fuel Cost (@ INR 1,50,000 per vehicle); Driver (@ INR 15,000 per month); Operator (@ INR 9,000 per month); Helper (@INR 5,000 per month) and Maintenance of Vacutug (every three months or after every 10,000 km, whichever is earlier) (@ INR 10,000 per servicing per vehicle)
*Assumptions made:
• Maximum distance travelled by a de-sludging vehicle per trip is 20 km.
• Mileage of the vehicle is 7 km per litre.
• Fuel price is INR 68 per litre.
• Vehicle makes three trips per day.
• Vehicle works for 250 days a year.</td></tr>
<tr><td colspan="3">Constraints:
A combination of all vehicles should be used for a city-specific scenario, as the lanes in a city are of three types:
Low accessibility: lanes with width less than 2 meters
Medium accessibility: lanes with width between 2 and 3 meters
High accessibility: lanes with width more than 3 meters</td></tr>
</table>

(b) Motorised Transport

Motorised transport equipment generally has a high load capacity, high speed and longer distance. Motorised transport equipment lead to reduced travel times and a greater range as compared with manual transport. The operation and maintenance of motorised transport is generally more complex than that of manual transport; however, many variations are widely used in low-income countries. Before selecting the type of transport system, it is important to verify that the knowledge and skills to carry out repairs are locally available. Motorised tricycles are the smallest type of low-cost motorised transport used to move FS. They vary in size and power, and are able to access narrower streets than larger motorised vehicles. Some models are capable of carrying loads of up to 1,000 kg. Sludge can be transported either in drums on the load bed of a tricycle [41] or in a tank fitted to the back (Figure 12). More expensive motorised transport equipment has also been used for the collection of FS. Examples include pickup trucks with load capacities ranging from 2,000 to 5,000 kg, but these are not always affordable for small-scale service providers [46] [47]; trucks can sometimes be fitted with additional options such as cranes with hook lifts [41]

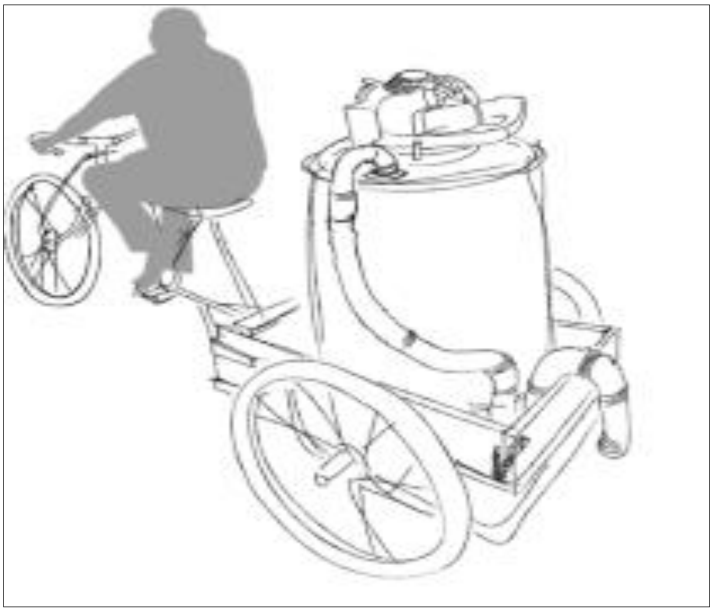

Figure 11: Schematic of a Human-Powered FSM Transport Technology
Sources: Strande et al. (2014)

Figure 12: Automated FS-Receiving Station at Manila, Philippines
Sources: Strande et al. (2014)

Decision Matrix for Emptying and Conveyance

A decision matrix was prepared with respect to CAPEX and vehicular accessibility (Table 9).

Table 9: Decision Matrix for Emptying and Conveyance

Constraint	Legend		G + T	MAP+T	MAPET + T	MDP+T	TP+T	MPSA+T	Gr+T	SB	LP
CAPEX	Low	Green	Yellow	Yellow	Red	Red	Red	Yellow	Yellow	Yellow	Red
	Medium	Yellow									
	High	Red									
Vehicular accessibility	Yes	Green	Green	Green	Green	Green	Green	Green	Green	Red	Red
	No	Red									

G+T, Gulper + Trucks; MDP+T, Manual Diaphragm Pump +Trucks; MAPET+T, Manual Pit Emptying Technology + Trucks; MDP+T, Motorised Diaphragm Pump + Trucks; TP+T, Trash Pump + Trucks; MPSA+T, Motorised Pit Screw Auger + Trucks; Gr +T, Gobbler + Trucks; SB, Small Bore; LP, Large Pipes.

(D) Treatment Technologies for Effluent and Sludge

Treatment describes the treatment technologies that are generally appropriate for any spatial area (city, ward, block, etc.). Each technology has different fields of application. Before treatment of FS(which is discharged by collection and transport trucks), a preliminary screening is needed for most treatment technologies because of the presence of high content of coarse waste such as plastic, tissue and paper. Also, the characteristics of FS collected at industrial and commercial facilities should be checked as they can be contaminated with metals; have high concentrations of fats, oil and grease; or have other concerns. The treatment part is divided into four steps: (1) primary treatment (separation of solids and liquids), (2) treatment of solid part/sludge (solid which is generated from the primary treatment) (3) treatment of liquid part/ effluent (liquid which is generated from the primary treatment) and (4) treatment of post-effluent (final treatment of the liquid part). After treatment, three types of end products will be produced, i.e., screenings, treated sludge and liquid effluents.

Step 1: Technology for Primary Treatment (solid–liquid separation)

The technologies used for primary treatment are unplanted drying bed (UDB), planted drying bed (PDB), anaerobic digester (AD), centrifugation, settling-and-thickening tank (S&T), Imhoff tank (IT), anaerobic baffled reactor (ABR), belt filter press (BFP) and geobags. General descriptions of the technologies used for primary treatment are presented in Table 10 while schematic overview of technologies is presented in Figure 13 to Figure 20.

After primary treatment, the sludge is removed from the bed manually or mechanically, and is used as manure by co-composting. Sludge cannot be used directly as an end product due to the presence of pathogens, and so Step 4 is needed for the final treatment of sludge.

Table 10: General Descriptions of Primary Treatments

Treatment Option	Properties	Removal Efficiency					Advantages	Disadvantages
		TS (%)	SS (%)	BOD (%)	COD (%)	*E. coli* (%)		
UDB	Solid–liquid separation as well as treatment of the solid–liquid part	-	-	-	-	-	1. Ease of operation and low cost 2. Good dewatering efficiency, especially in dry and hot climates 3. Skill and Energy is not required.	1. High land requirement 2. Odours and flies are normally noticeable 3. Limited reduction of pathogens 4. Liquid part requires further treatment.
PDB	Solid–liquid separation as well as treatment of the solid–liquid part	70–80%	96–99%	-	95–98 %	-	1. It can handle high loading 2. Sludge treatment is better than that in unplanted drying beds 3. Easy to operate 4. Low CAPEX and OPEX 5. Energy is not required 6. Plants and fruits can be grown in PDBs.	1. High land requirement 2. Odours and flies may be noticeable 3. Liquid part requires further treatment 4. Only applicable during dry seasons, or needs a roof and contour bund.
AD/UASB reactor	Solid–liquid separation as well as treatment of the solid–liquid part	60–85%	-	60–90%	60–80%;	-	1. High reduction of BOD 2. It can handle high organic and hydraulic loading rates 3. Low sludge production 4. Biogas can be used for energy	4. Requires skilled personnel; difficult to maintain 5. Needs consistent quantity and quality of input sludge for good performance 6. Usually UASB is used in the co-treatment of waste water and sludge 7. Start-up time is long 8. A constant source of electricity is required to operate the UASB reactor 9. High O&M cost and complexity 10. All components of a UASB reactor are not easily available 11. Sludge removed from a UASB reactor may need thickening before disposal
Centrifugation	Solid–liquid separation	-	-	-	-	-	1. It is an enclosed system 2. It controls odour and moisture 3. Land availability is not a constraint	1. It requires high electricity for operation 2. The centrifugation machine is expensive and internal parts are subject to abrasive wear

Treatment Option	Properties	Removal Efficiency					Advantages	Disadvantages
		TS (%)	SS (%)	BOD (%)	COD (%)	*E. coli* (%)		
S & T	Solid–liquid separation as well as treatment of the solid–liquid part	-	57%	12%	24%	-	1. Relatively robust and resilient	1. Sludge and effluent require further treatment. 2. The end products of settling tanks cannot be discharged into water bodies or directly used in agriculture 3. Low reduction of pathogens
IT	Solid–liquid separation as well as treatment of the solid–liquid part	-	50–70%	30–50%	-	-	1. Solid–liquid separation and sludge stabilisation are combined in one single unit 2. It can handle high organic load 3. Less land required 4. Low operating cost	1. Infrastructure is deep; depth may be a problem in case of a high groundwater table 2. Requires a skilled operator 3. Low reduction of pathogens 4. Effluent, sludge and scum require further treatment before disposal
ABR	Solid–liquid separation as well as treatment of the solid–liquid part	80–90%	-	70–95%	65–90%	-	1. Energy is not required 2. It can handle high organic load 3. Low operating costs, moderate capital 4. Service life is long 5. High reduction of BOD 6. Sludge production is low 7. Land requirement is medium	1. Requires skilled designers and labourers 2. Sludge and effluent require further treatment 3. Pathogen reduction is low
BFP	Solid–liquid separation	-	-	-	-	-	1. Good dewatering capacity	1. Difficulty in controlling odours 2. Skills required 3. Capital costs are high 4. Operating costs are high 5. (Costs can be higher if a polymer is used.) 6. Sludge and effluent need further treatment
Geobags	Solid–liquid separation	-	-	-	-	-	1. Requires minimal equipment 2. Economical option (compared with standard procedures) 3. No complicated procedures or parts 4. Can run at all times with minimal labour	1. May need a pump for filling 2. Space for storage over long periods 3. Dried sludge before disposal must be solar-dried to ensure pathogen/helminth eradication

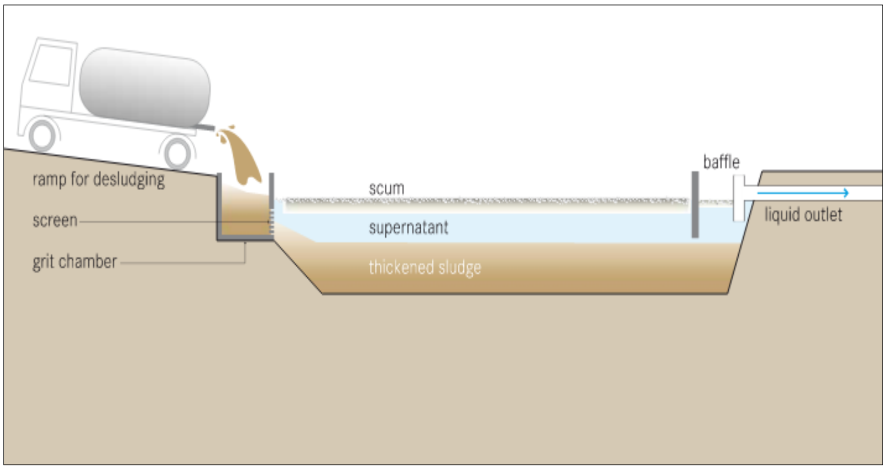

Figure 13: Schematic View of Unplanted Sludge Drying Bed
(Source: Tilley et al. 2014)

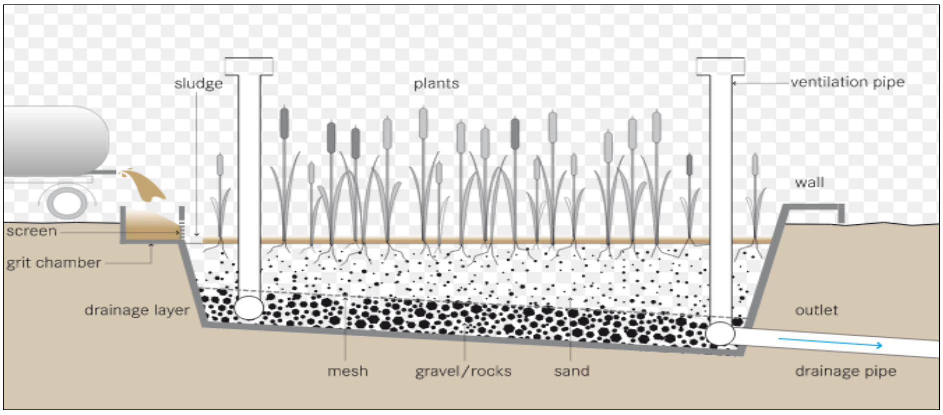

Figure 14: Schematic View of Planted Sludge Drying Bed
(Source: Tilley et al. 2014)

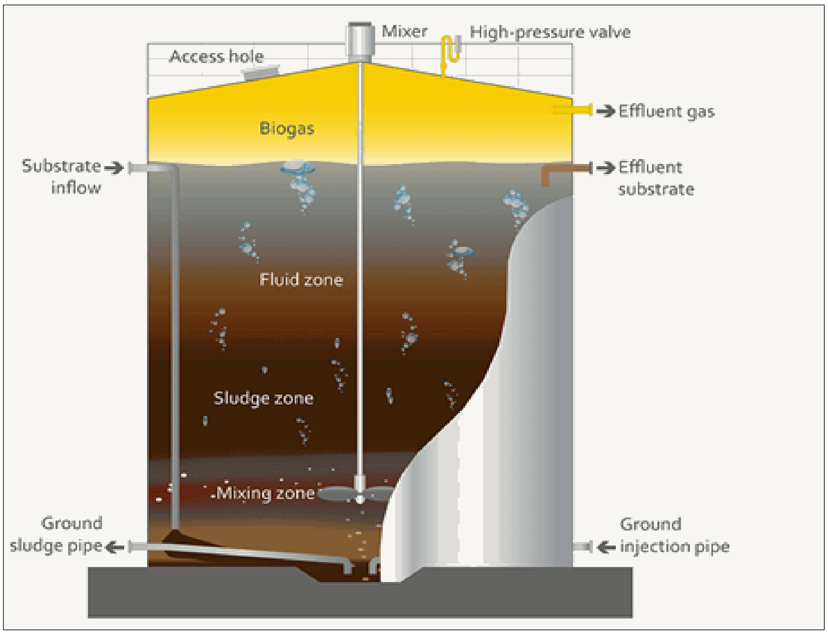

Figure 15: Schematic View of Anaerobic Digester
(Source: HTI Tanks, LLC)

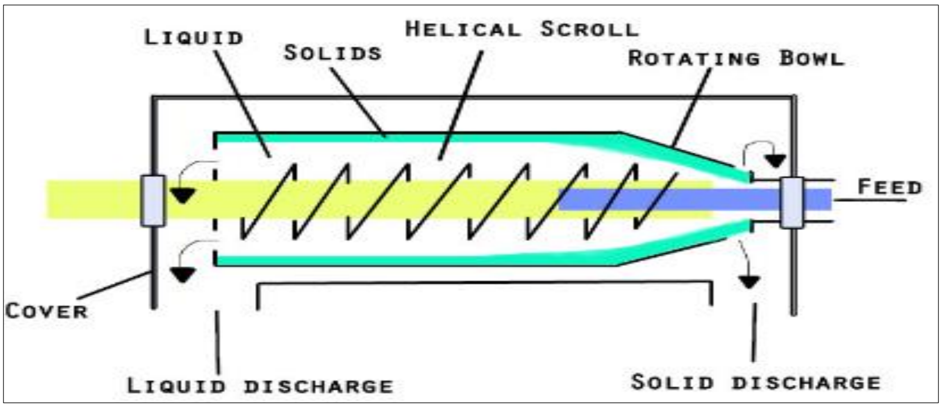

Figure 16: Schematic View of Centrifugation
(Source: Orris and Eugene 1969)

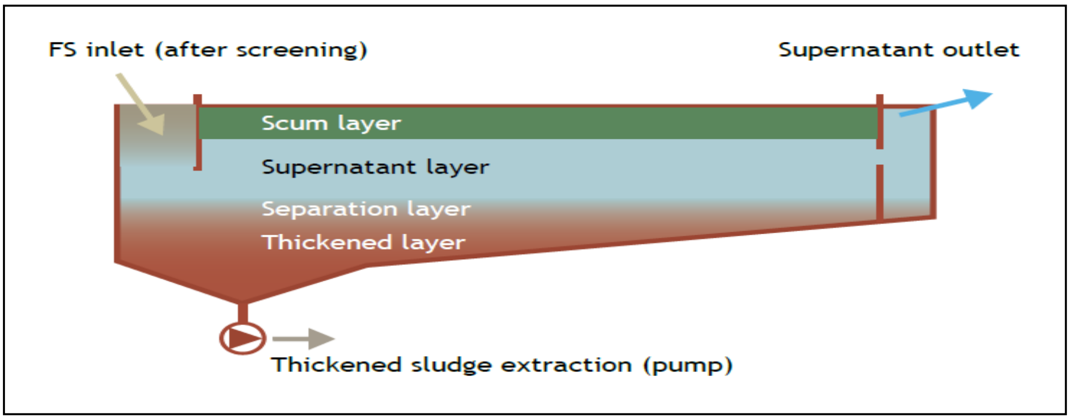

Figure 17: Schematic View of Settling and Thickening Tank
(Source: Strande et al. 2014)

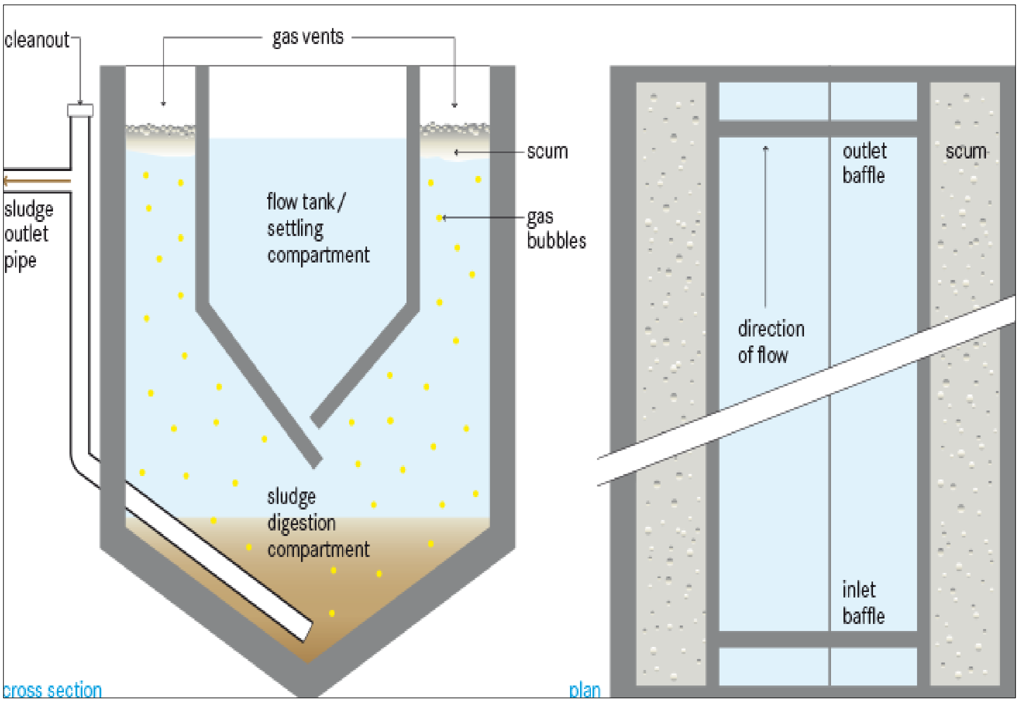

Figure 18: Schematic View of Imhoff Tank
(Source: Tilley et al. 2014)

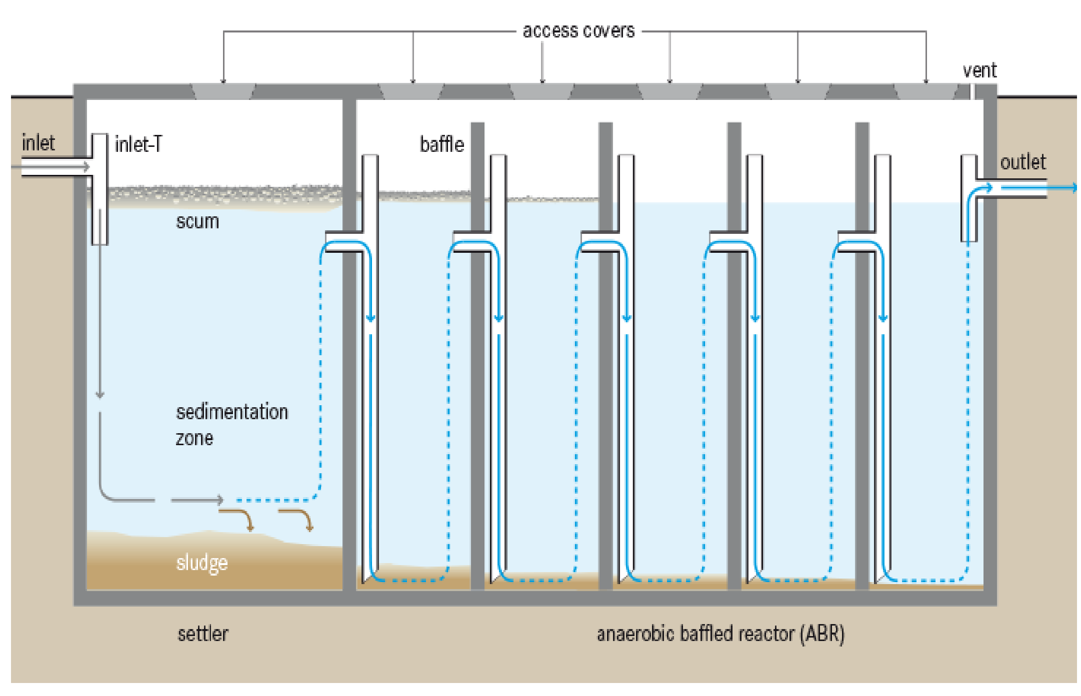

Figure 19: Schematic View of Anaerobic Baffled Reactor
(Source: Tilley et al. 2014)

Figure 20: Schematic View of Geobags in Malaysia

Decision Matrix for Primary Treatment

Table 11 summarises the favourability of the different primary treatment technologies, with respect to different resource requirements and discharge standards.

Table 11: Decision-Making Matrix for Primary Treatment of Sludge

Constraint	Legend	UDB	PDB	AD	Centrifugation	S&T	IT	ABR	BFP	Geobag
Land Requirement	low (green) / medium (yellow) / high (red)	red	red	green	green	green	green	yellow	green	red
Energy Requirement	low (green) / medium (yellow) / high (red)	green	green	green	yellow	yellow	green	green	yellow	green
Ground Water Level (Shallow/Deep)	shallow (green) / deep (red)	green	green	green	green	green	red	green	green	green
CAPEX	low (green) / medium (yellow) / high (red)	green	green	yellow	red	green	yellow	yellow	yellow	yellow
OPEX	low (green) / medium (yellow) / high (red)	green	green	yellow	red	green	green	green	yellow	yellow
Skill	low (green) / medium (yellow) / high (red)	green	green	red	yellow	yellow	red	red	red	green
Discharge standard	low (green) / medium (yellow) / high (red)	yellow	yellow	red	green	yellow	yellow	yellow	green	green

UDB, Unplanted Drying Bed; PDB/RB, Planted Drying Bed/Reed Bed; AD, Anaerobic Digester; S&T, Settling & Thickening tank, IT, Imhoff Tank; ABR, Anaerobic Baffled Reactor; BFP, Belt Filter Press.

Step 2: Technology for Effluent Treatment (liquid part treatment)

A liquid part would be produced after primary treatment. This is a partially treated liquid, which needs further treatment before disposal. The technologies used for effluent (liquid) treatment are waste stabilisation ponds (WSPs), activated sludge process (ASP), sequence batch reactor (SBR), membrane bioreactors (MBRs), anaerobic filter (AF), anaerobic baffled rector (ABR) and constructed wetland (CW). This liquid part is filtered from the first step of solid–liquid separation.

General descriptions of the technologies used for effluent treatment are presented in Table 12 while schematic overview of technologies is presented in Figure 21 to Figure 26.

Table 12: General Descriptions of Effluent Treatments

Treatment Option	Properties	Removal Efficiency					Advantages	Disadvantages
		TS (%)	**SS (%)**	**BOD (%)**	**COD (%)**	***E. coli* (%)**		
WSP	A WSP can be applied at the community level/cluster level/ward and city levels	75–80%	-	75–85%	74–78%	60–99.9%	1. High reduction of BOD, suspended solids and pathogens 2. High removal of nutrients when it is combined with aquaculture 3. Energy is not required except for pumping 4. No real problems with odours and flies if designed and maintained correctly 5. Low OPEX (drying bed would need manual removal of dried sludge cake. Once in 10 years, the pond would have to be de-sludged and the sludge disposed. This could mean a significant cost)	1. Requires a large land area 2. High capital costs depending on the price of land 3. Requires skilled personnel
ASP	The ASP can be applied at the community level/cluster level/ward and city levels	-	75–80%	85–92%	93–94%	60–90%	1. Efficient removal of BOD and pathogens (more than 90%) 2. High nutrient removal possible 3. High quality of effluent produced 4. Less land is required compared with an extensive natural system (e.g., waste stabilisation ponds, constructed wetland, unplanted/planted drying bed, etc.) 5. This machine can be modified to meet specific discharge limits	1. High CAPEX and OPEX 2. Constant energy supply is required; high energy consumption 3. Prone to complicated chemical and microbiological problems 4. Requires skilled personnel
SBR	An SBR can be applied at the community level/cluster level/ward and city levels	-	95%.	95%	90%	-	1. Requirement of land is low 2. Effluent quality is high 3. It can handle high organic load 4. SBR can be modified to meet specific discharge limits	1. High CAPEX and OPEX 2. Constant energy supply is required; high energy consumption

Treatment Option	Properties	Removal Efficiency					Advantages	Disadvantages
		TS (%)	**SS (%)**	**BOD (%)**	**COD (%)**	***E. coli* (%)**		
MBR	An MBR can be applied at the community level/cluster level/ward and city levels	-	>90%	95%	>90%	-	1. This operates at higher volumetric loading rates 2. High removal efficiency of BOD, TSS, etc. 3. Less land required 4. No equalisation of hydraulic and organic loadings required	1. Fouling problem is noticeable on the membrane surface 2. Complex process 3. High CAPEX and OPEX 4. Energy-intensive process
CW	A CW can be applied at the community level/cluster level/ward and city levels	-	-	-	-	-	1. It is cheaper to operate than other treatment systems 2. Energy is not required because the wetland is entirely gravity-operated 3. Low CAPEX and OPEX 4. It provides an environment for a wide range of native animals	1. High land requirement 2. Labour is required for sludge removal 3. Pathogen reduction is low
AF	The AF technology can be used at the household level or the cluster level.		50–80%	50–90%	-	-	1. It is resistant to hydraulic shocks 2. Energy is not required 3. Higher reduction of BOD and TSS 4. It can be built with local materials 5. Moderate CAPEX and OPEX 6. Sludge removal frequency is low	1. Lower reduction of pathogens 2. Requires skilled designers and labourers 3. Clogging of filter material possible 4. Cleaning of AF material is tedious 5. The treated liquid requires further tertiary treatment
UASB	A UASB can be applied at the community level/cluster level/ward and city levels	75–80%	75–85%	60–80%	-		1. High reduction of BOD 2. It can handle high organic and hydraulic loading rates 3. Sludge production is low 4. Biogas can be used for energy.	1. Requires skilled personnel for O&M 2. Start-up time is long 3. High O&M cost 4. Electricity is required 5. All parts and materials are not easily available 6. Sludge removed from the UASB reactor may need thickening before disposal

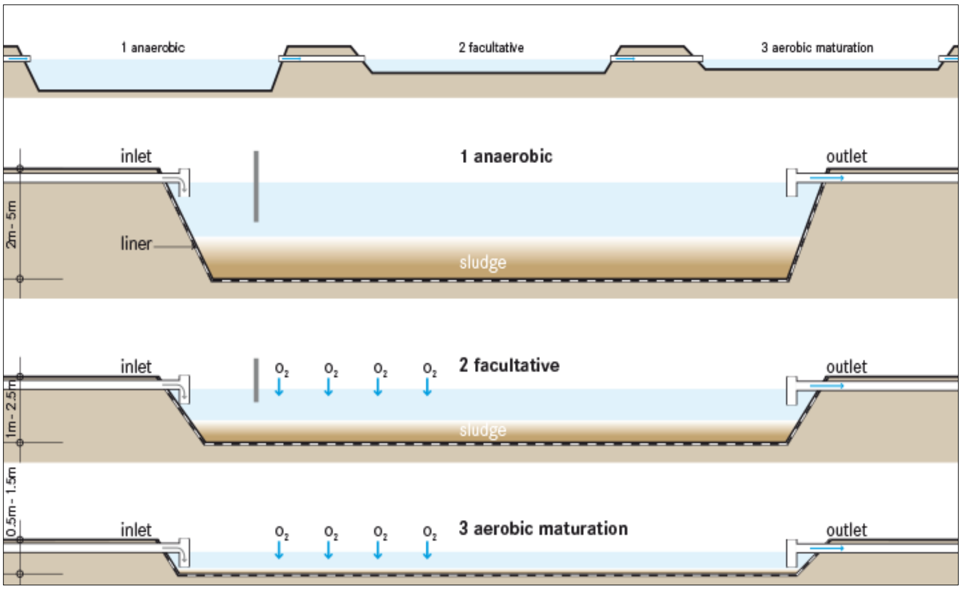

Figure 21: Schematic View of Waste Stabilisation Pond

(Source: Tilley et al. 2014)

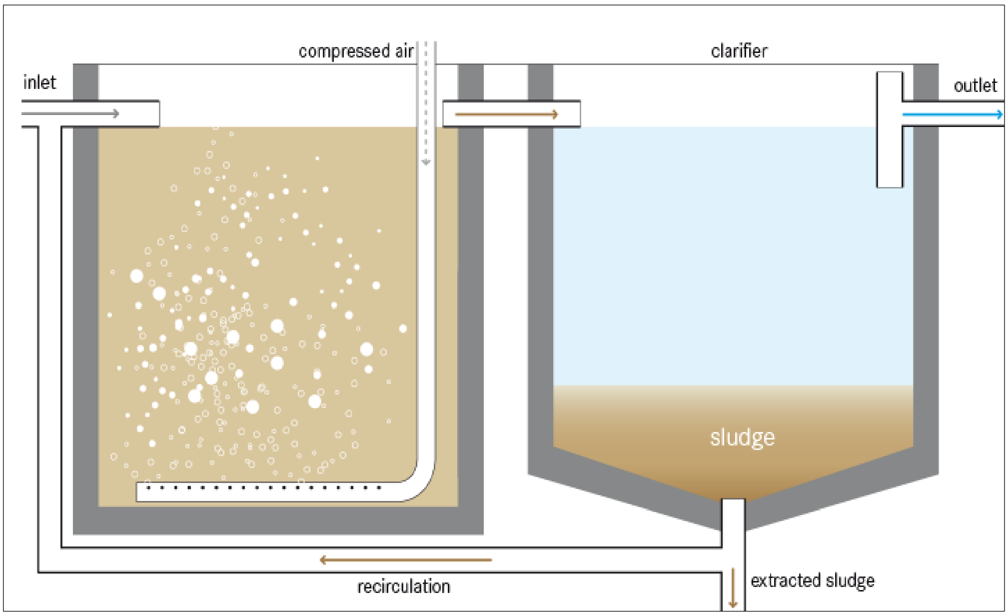

Figure 22: Schematic View of Activated Sludge Process

(Source: Tilley et al. 2014)

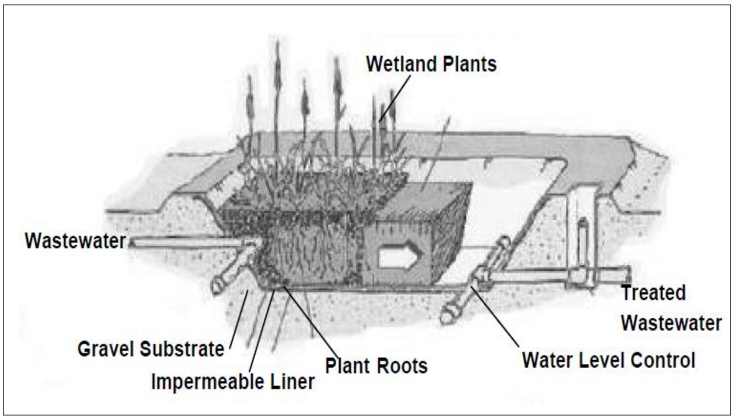

Figure 23: Schematic View of Constructed Wetland

(Sources: USEPA)

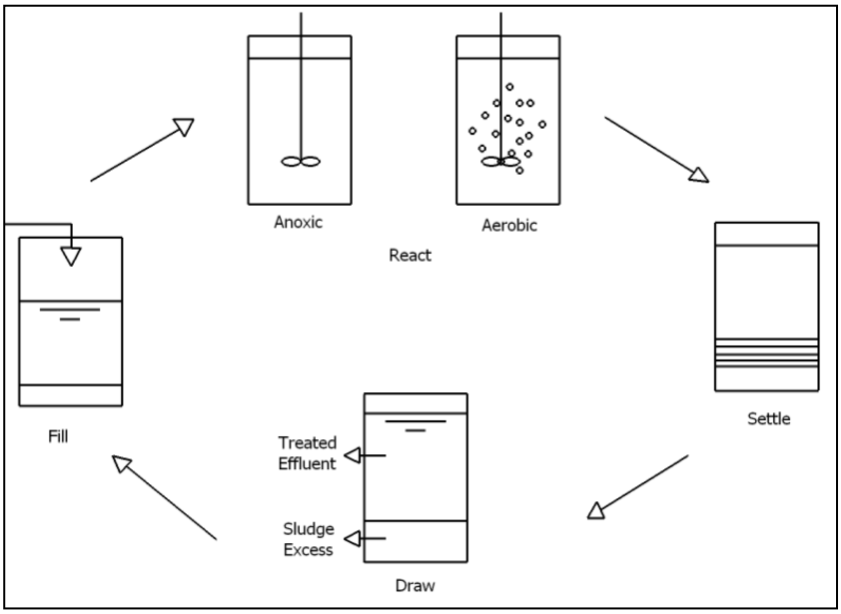

Figure 24: Schematic View of Sequence Batch Reactor

(Source: Onsite Wastewater Treatment Systems Technology Fact)

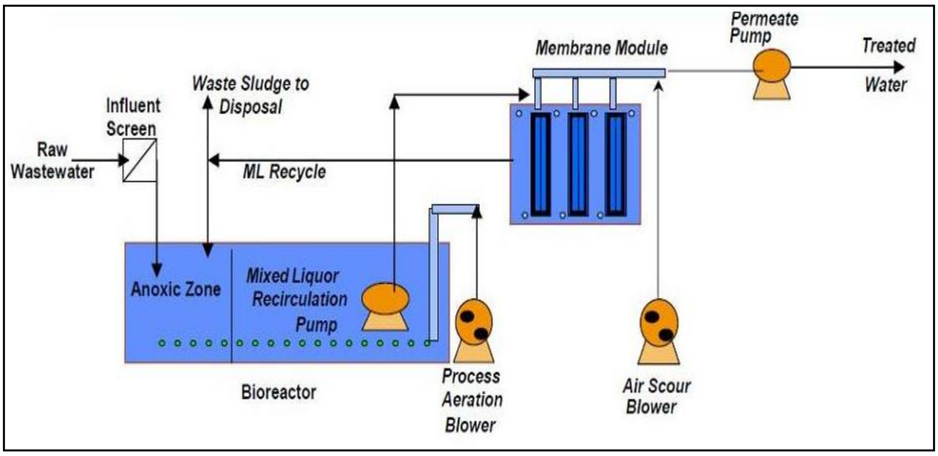

Figure 25: Schematic View of Membrane Bioreactor

(Source: Fitzgerald 2008)

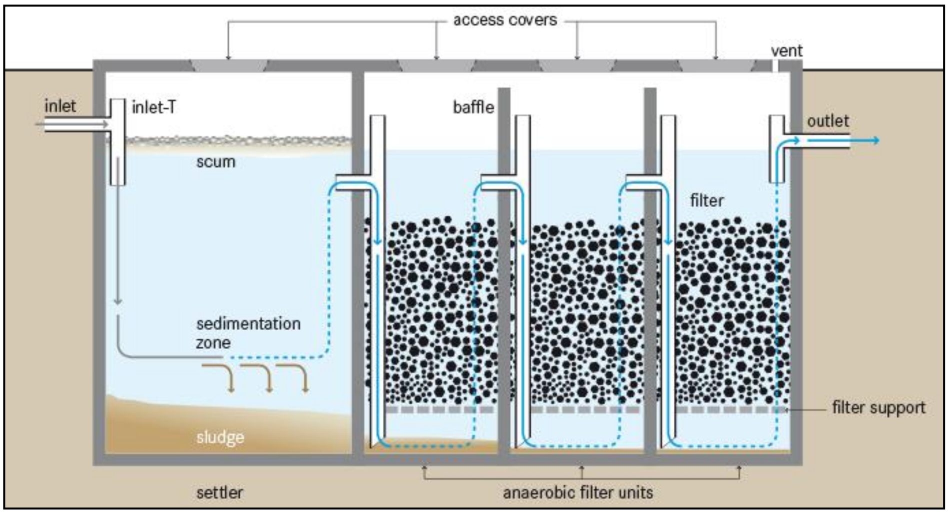

Figure 26: Schematic View of Anaerobic filter

(Source: Tilley et al. 2014)

Decision Matrix for Effluent Treatment

Based on the technological options, a decision matrix was prepared with respect to land availability, energy requirement, skill requirement, CAPEX, OPEX, groundwater depth and discharge standard (Table 13). The matrix ascertains the favourability of a technology in comparison with those of other identified technologies. Green colour symbolises low favourability, yellow moderate favourability and red high favourability.

Table 13: Decision-Making Matrix for Effluent Treatment

Constraint	Legend	WSP	ASP	SBR	MBR	ABR+CW	CW	AF	ASP+RB	UASB	ABR
Land requirement	Low (Green) Medium (Yellow) High (Red)	Red	Green	Green	Green	Red	Red	Green	Red	Green	Yellow
Energy requirement	Low (Green) Medium (Yellow) High (Red)	Green	Red	Red	Red	Green	Green	Green	Red	Green	Green
Groundwater level (shallow/deep)	Shallow (Green) Deep (Red)	Green	Green	Green	Green	Green	Green	Red	Green	Green	Green
CAPEX	Low (Green) Medium (Yellow) High (Red)	Yellow	Red	Red	Red	Red	Red	Yellow	Red	Red	Yellow
OPEX	Low (Green) Medium (Yellow) High (Red)	Green	Red	Red	Red	Green	Green	Green	Red	Yellow	Green
Skill	Low (Green) Medium (Yellow) High (Red)	Yellow	Red	Red	Red	Red	Red	Yellow	Red	Red	Red
Discharge standard	Low (Green) Medium (Yellow) High (Red)	Red	Red	Red	Red	Red	Red	Yellow	Red	Red	Yellow

Step 3: Technology for Post-Effluent Treatment

The technologies used for post-effluent treatment are chlorination and ozonation (Table 14). Post-Effluent Treatment stage is the final treatment of effluent/ liquid which is generated from effluent treatment plant. Post-effluent treatment stage called as tertiary treatment.

Table 14: General Descriptions of Post-Effluent Treatments

Treatment Option	*E. coli* (Removal Efficiency)	CAPEX (Rs./MLD)	OPEX (Rs./MLD/year)	Advantages	Disadvantages
Ozonation	>90%	-	-	1. It rapidly reacts with bacteria, viruses and protozoa over a wide pH range 2. Germicidal properties of ozonation are stronger than those of chlorination 3. For disinfection, chemicals are not added to water 4. This technology is efficient for removal of organics and inorganics 5. More than 90% removal of bacteria and viruses 6. It is cost-effective	1. Large amount of electricity is needed to produce ozone 2. Requires skilled personnel for design and construction
Chlorination	100%	3,00,000	2,000	1. It is a simple, inexpensive and reliable technique 2. kills bacteria and viruses up to 100%; good removal of microbes from treated water 3. Widely available in different countries 4. Cost-effective 5. Easy to handle	1. It cannot deactivate parasites like *Giardia* and cryptosporidium, and worm eggs 2. Chlorine availability may be restricted in rural and remote areas 3. High organic matter in treated water leads to the risk of toxic disinfection by chlorination through by-product formation

Step 4: Technology for Sludge Treatment

A solid part would be produced after primary treatment. This is a partially treated solid, which needs further treatment before disposal. The technologies used for sludge treatment are composting, vermicomposting, deep row entrenchment, shallow trenches, solar drying, solar sludge oven, lime stabilisation and sludge drying bed. This is the final stage of treatment of biosolids before discharge.

A schematic overview of technologies is presented in Figures 27 to Figure 30, while general descriptions of the technologies used for sludge treatment are presented in Table 15.

Figure 27: Schematic View of Composting and Vermicomposting
(Source: Composting: The Right Cover)

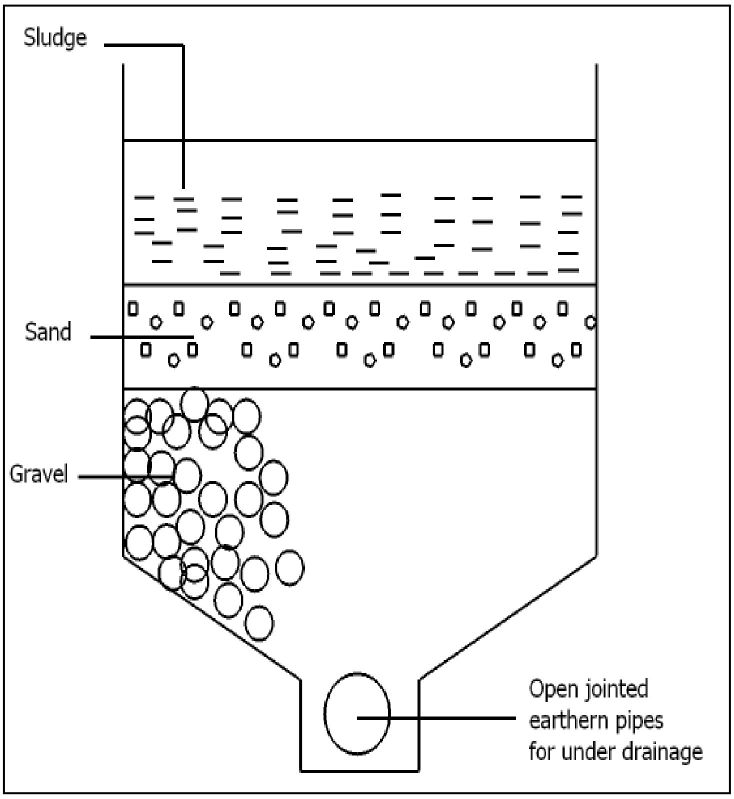

Figure 28: Schematic View of Sludge Drying Bed
(Source: SSWM)

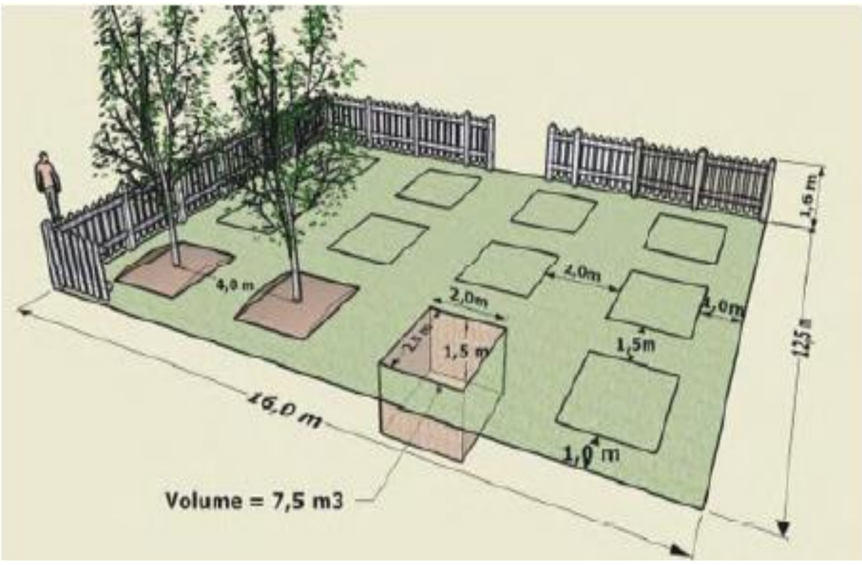

Figure 29: Schematic View of Planted Burying Pits or Trenches
(Source: Low Cost Systems for the Management of Sludge from Toilets and Shower Units)

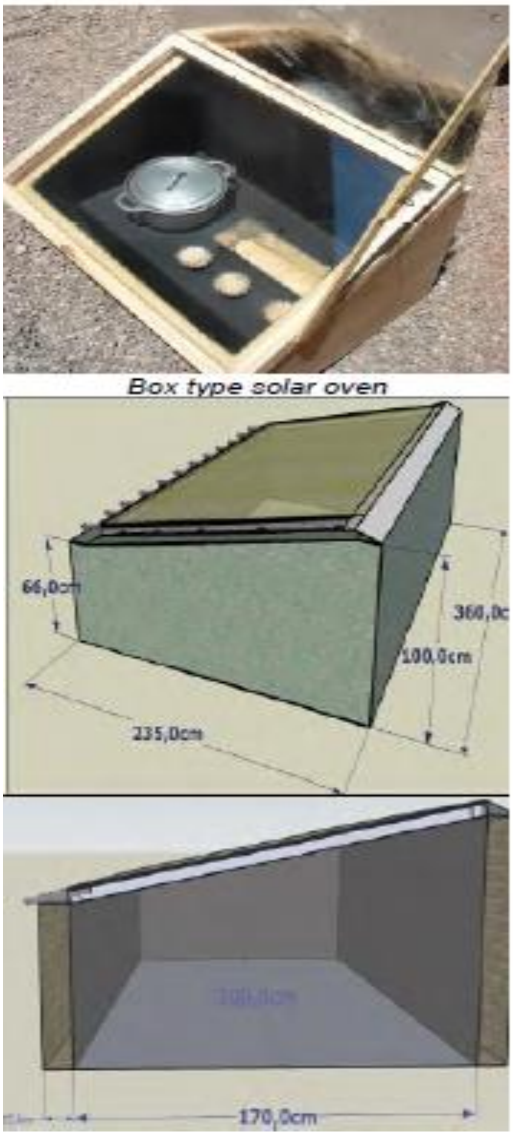

Figure 30: Schematic View of Solar Sludge Oven
(Source: Low Cost Systems for the Management of Sludge from Toilets and Shower Units)

Table 15: General Descriptions of Sludge Treatment Technologies

Treatment Option	Properties	CAPEX (Rs./ MLD)	OPEX (Rs./MLD /year)	Land Required (m^2/MLD)	Advantages	Disadvantages
Co-composting	Co-composting can be applied at the household level/community level/cluster level/ward and city levels	-	-	-	1. High pathogen reduction 2. Output of co-composting is a good soil conditioner	1. Requires technical and managerial skills for operation of the co-composting plant and for generating a safe product with value
Vermicomposting	Vermicomposting can be applied at the household level/community level/cluster level/ward and city levels	3,00,00,000	8,00,00,000	1,000	1. Pathogen inactivation is good 2. End product generated from vermicomposting is a good soil conditioner	1. Requires technical and managerial skills 2. Worms are liable to be affected by toxic components 3. (Cost is higher than co-composting
Sludge drying bed + Co-composting	Sludge drying bed can be applied at the community level/cluster level/ward and city levels	-	-	-	1. Easy to operate 2. Energy is not required 3. End product can be used as a fertiliser 4. Water amount of sludge is reduced	1. Requires stabilised sludge to reduce nuisance and odours 2. High land requirement 3. Blockage of sand bed
Solar Drying	Solar drying can be applied at the community level/cluster level/ward and city levels	-	-	-	1. Low energy requirements 2. Low investment costs 3. High potential dewatering efficiency	1. High space requirements 2. Skilled staff is required
Shallow Trenches	Shallow trenches can be applied at the household level/ community level/cluster level/ward and city levels	-	-	-	1. Simple system 2. Helps in land remediation 3. No nuisance; Flexibility: no restriction on the amount or characteristic of sludge	1. Land area required is high 2. Pests/groundwater pollution 3. Needs regular groundwater monitoring

Treatment Option	Properties	CAPEX (Rs./ MLD)	OPEX (Rs./MLD /year)	Land Required (m^2/MLD)	Advantages	Disadvantages
Lime stabilisation	Lime stabilisation can be applied at the household level/community level/cluster level/ward and city levels	-	-	-	1. $CaCO_3$ addition precipitates metals and phosphorus 2. Reduction of pathogens, odours, degradable organic matter 3. Energy is not required	1. Requirement of consumables (lime) and a dry storage area 2. Pathogen regrowth is also a concern 3. Lime is an alkaline material; it reacts strongly with moisture and poses high risks of hazard to the eyes, skin and respiratory system 4. Skilled staff is required
Deep row entrenchment	Deep row entrenchment can be applied at the household level/community level/cluster level/ward and city levels	-	-	-	1. Inexpensive technique 2. Trees planted on top get many benefits such as extra CO_2 fixation, erosion protection or potential economic benefits	1. It may cause groundwater pollution 2. High land availability 3. Potential nuisance to adjacent areas
Solar Sludge Oven	Solar sludge oven can be applied at the household level/community level/cluster level/ward and city levels	-	-		1. Sludge is hygienic 2. Simple to use 3. The amount of sludge is reduced; low environmental impact 4. The dried sludge can be considered for use	1. Limited processing capacity: (only ≈12 m^3 per 8 months) 2. Cost is higher compared with that of burial pits or trenches 3. May generate a foul smell

Decision Matrix for Sludge Treatment

Table 16 summarises the favourability of the different sludge treatment technologies, with respect to different resource requirements and discharge standards. The matrix ascertains the favourability of a technology in comparison with those of other identified technologies. Green colour symbolises low favourability, yellow moderate favourability and red high favourability.

Table 16: Decision-Making Matrix for Sludge Treatment

Constraint	Legend	Co-Composting	Vermicomposting	Sludge Drying Bed +Co-Composting	Lime Stabilization	Solar Drying	Shallow Trenches	Solar Sludge Oven	Deep Row Entrenchment
Land Requirement	Low (green) Medium (yellow) High (red)	Red	Red	Red	Yellow	Red	Red	Green	Red
Energy Requirement	Low (green) Medium (yellow) High (red)	Green	Green	Green	Green	Green	Green	Green	Green
Ground Water Level (Shallow/Deep)	Shallow (green) Deep (red)	Green	Green	Green	Red	Red	Red	Green	Red
Capex	Low (green) Medium (yellow) High (red)	Red	Red	Red	Green	Yellow	Green	Yellow	Green
Opex	Low (green) Medium (yellow) High (red)	Red	Red	Yellow	Green	Yellow	Green	Green	Green
Skill	Low (green) Medium (yellow) High (red)	Green	Green	Green	Yellow	Yellow	Green	Yellow	Green
Discharge Standard	Low (green) Medium (yellow) High (red)	Red	Red	Red	Red	Red		Red	

Part D: Designed System for Faecal Sludge Management

Basically, there are three types of sanitation system in India, i.e., onsite[12], decentralised[13] and networked[14] are used for FS and wastewater management. In the present study total twelve systems are designed for FSM at the household/cluster/community level.

[12] Onsite technology refers to the treatment of waste at the point of generation either fully or partially, i.e., within the household premises. This technology is dependent on the periodic removal of faecal sludge from vaults, pits and tanks.
[13] In the decentralised technology, the toilets are connected to tank for storage (e.g., septic tank); it requires a provision for transporting wastewater and sludge from the tank to the treatment facility.
[14] A networked system also requires a provision for transporting wastewater from the toilet via a system of sewers to the treatment facility. Sewers consist of a network of buried pipes that carry wastewater from a house to the point of disposal. Sewers remove both excreta and sullage from the households, thereby negating the need for on-site servicing

A brief description of each system is given below:

System 1: Twin-Pit System

Key Features of the Technology

- It is not a complete system.
- It is a non-sewered system.
- There is no water treatment, reuse/recovery in a twin-pit system. FS after being given a settling time can be used for land application.
- It should be used at the household level. In other cases, the volume of pit should be large.
- Time taken for installation: less than 1 month.
- System lifetime: porous pits have a lifetime of 10 years.
- Frequency of complete system cleaning/maintenance (years): three years is acceptable under good conditions of low ground water and porous soil.

Land requirement: 5 m^2/HH (household) land is required for the construction of the toilet and for storage of products that are generated from the user interface.

Energy requirement: energy is not required for this treatment.

Environmental regulation: low, due to missing water treatment/recovery in a twin-pit system.

Health regulation: low, because of lower reduction of pathogens.

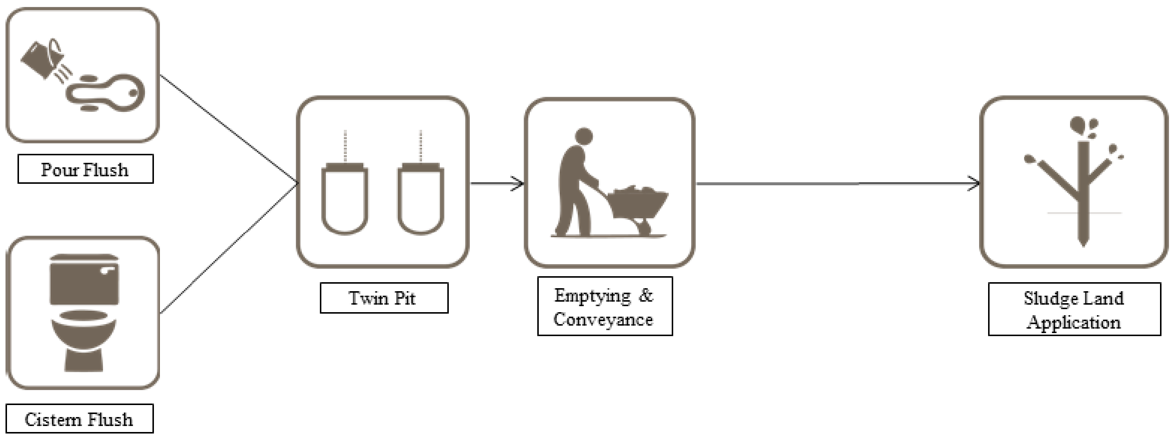

Figure 31: Twin-Pit System for FSM

System 2A: Septic Tank + UDB + WSP + Co-composting + Chlorination

Key Features of the Technology

- It is a complete system.
- It is a non-sewered system.
- Septic tank could be designed for the household level, whereas the drying bed/WSP for the community level.
- Time taken for the installation of this system is up to 6 months.

System lifetime (years): soak pit, 3–5 years; septic tank lifetime, 50 years. UDB/WSP: 50 years.

facilities. This technology is appropriate for urban areas with higher population density where water consumption is relatively high and soil permeability is low.

Frequency of complete system cleaning/maintenance (years): soak pit, 3–5 years; septic tank to be emptied once in 1–3 years. The unplanted drying bed needs to be cleaned depending on the filling frequency.

Performance of the system: waste stabilisation ponds remove BOD up to 75–85%; COD to 74–78%; TSS, 75–80%; TN, 70–90%; TP, 30–45% and coliform to 60–99.9%.

Land requirement: 7 m^2/HH land is required for the construction of the toilet and for storage of products that are generated from the user interface. 6,000 m^2/MLD land is required for the WSP treatment.

Energy requirement: the power requirement of the WSP is 5.7 kWh/day/MLD.

Environmental regulation: high

Health regulation: high

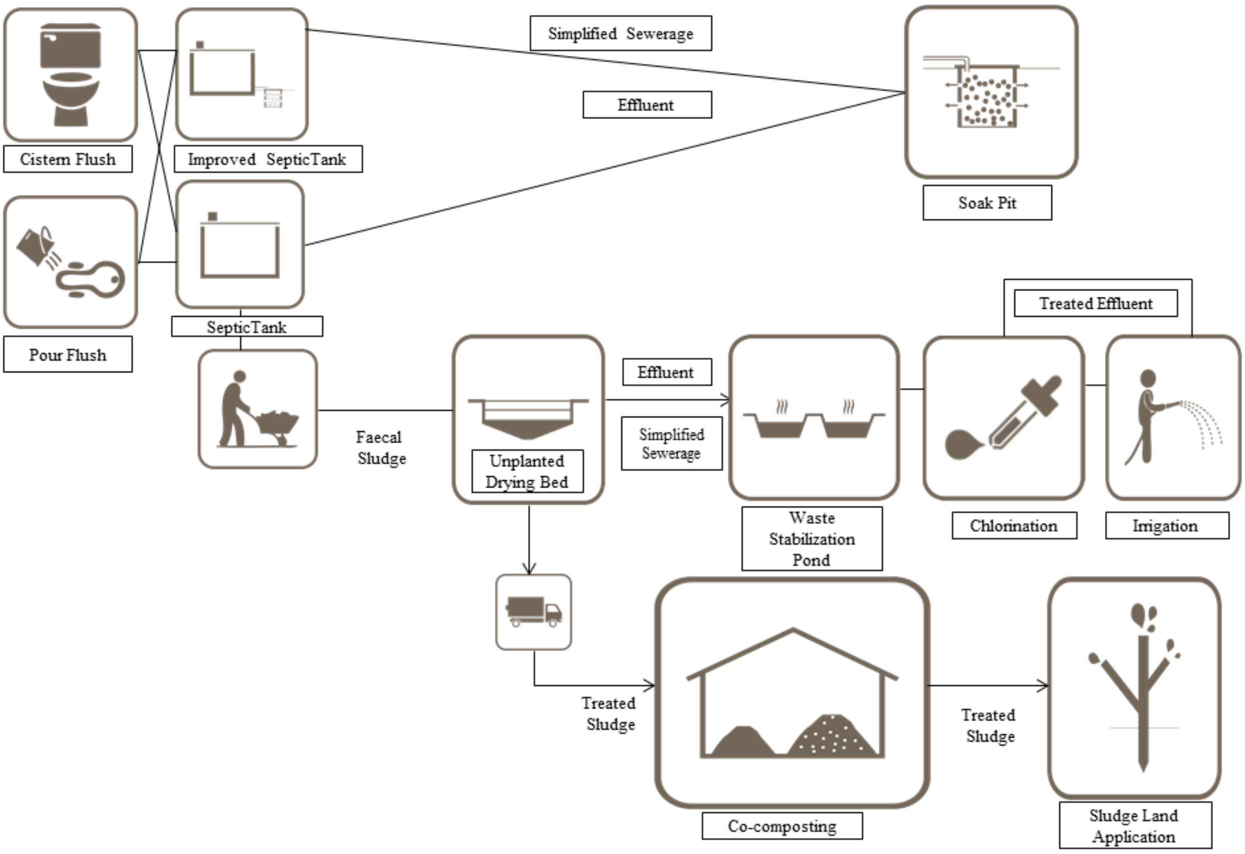

Figure 32: Decentralised System for FSM (Septic tank + UDB + WSP + Co-composting)

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank/conventional septic tank for storage of black water. Manual/motorised emptying and a truck are used for sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into four parts (Figure 32):

(1) Primary treatment: an unplanted drying bed (UDB) is used for the solid–liquid separation.

(2) After the solid–liquid separation, the liquid part is transferred to an effluent treatment plant; i.e., a waste stabilisation pond (WSP) is used for the effluent treatment.

(3) The treated liquid generated from the effluent treatment plant undergoes post-effluent treatment for better quality; the chlorination technology is, hence, chosen for the final treatment of the liquid.

(4) The solid part that is generated from the unplanted drying bed is transferred to the sludge treatment plant for further treatment (i.e., co-composting technology for better quality of sludge).

System 2B: Septic Tank + AD + Co-composting + Chlorination

Key Features of the Technology

- It is a complete system.
- It is a non-sewered system.
- Septic tank could be designed for the household level, whereas AD for the community level.
- Time taken for installation of this system is up to 1 year.

System lifetime (years): septic tank life time, 50 years; AD lifetime, 50 years if well designed and constructed.

Frequency of complete system cleaning/maintenance (years): soak pit, 3–5 years; septic tank to be emptied once in 1–3 years.

Performance of the system: anaerobic digester removes BOD up to 60–90%, COD to 60–80% and TSS to 60–85%.

Land requirement: 7 m^2/HH land is required for the construction of the toilet and for the storage of products that are generated from the user interface. 600 m^2/MLD land is required for the AD treatment.

Energy requirement: the power requirement of the AD is 60 kWh/day/MLD.

Environmental regulation: high

Health regulation: high

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank/conventional septic tank for storage of black water. Manual/motorised emptying and a truck are used for sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into four parts (Figure 33):

(1) Primary treatment: an anaerobic digester (AD) is used for the solid–liquid separation as well as treatment.

(2) After the solid–liquid separation, the liquid part is transferred to an effluent treatment plant; i.e., constructed wetland (CW) is used for the effluent treatment.

(3) The treated liquid generated from the effluent treatment plant undergoes post-effluent treatment for better quality; the chlorination technology is, hence, chosen for the final treatment of the liquid.

(4) Solid part that is generated from the anaerobic digester (AD) is transferred to the sludge treatment plant. The sludge treatment plant uses two components, i.e., centrifugation and co-composting.

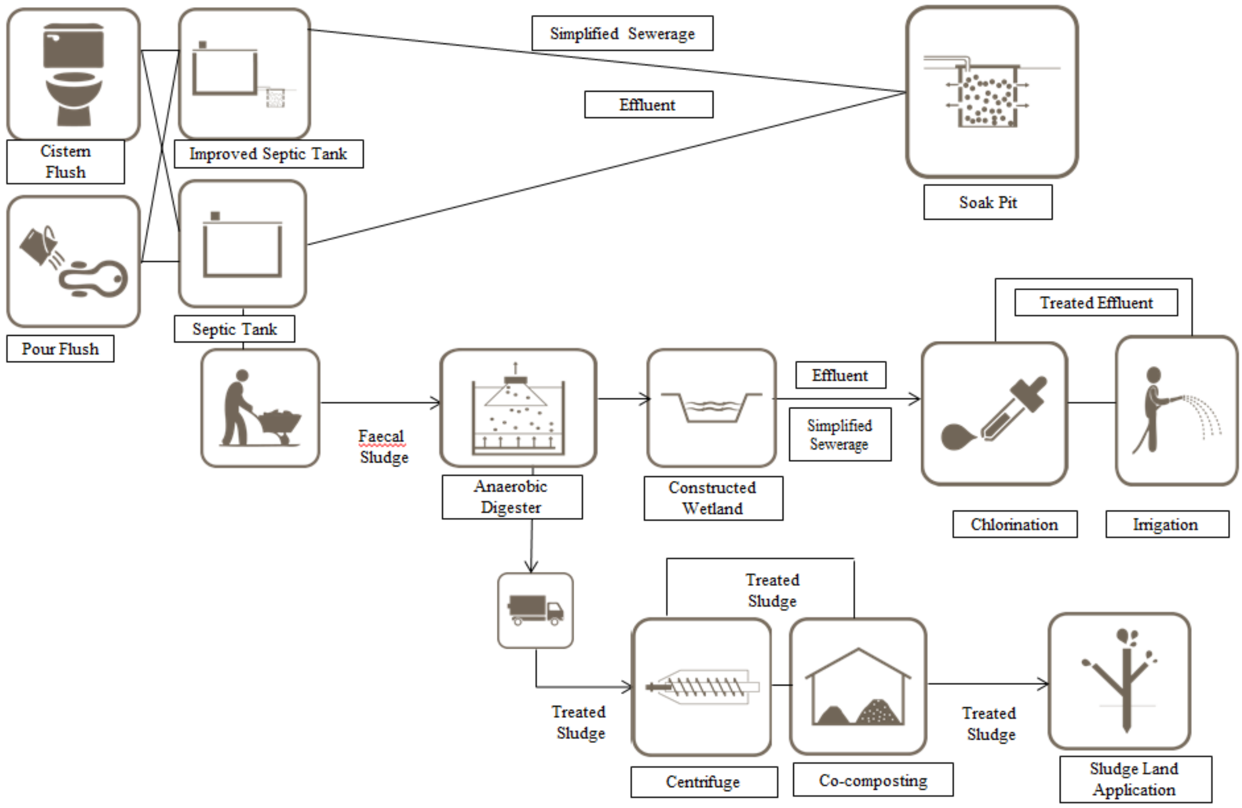

Figure 33: Decentralised System for FSM (AD + Co-composting + Chlorination)

System 2C: Septic Tank+ Centrifugation + ASP + Vermicomposting + Ozonation

Key Features of the Technology

- It is a complete system.
- It is a non-sewered system.
- Septic tank could be designed for the household level, whereas the ASP for the community level.
- The time taken for the installation of this system is up to 1 year.

System lifetime (years): septic tank lifetime, 50 years; ASP treatment plant lifetime, 50 years if well designed and constructed.

Frequency of complete system cleaning/maintenance (years): Soak pit, 3–5 years; septic tank to be emptied once in 1–3 years.

Performance of the system: ASP removes BOD up to 85–92%; COD to 93–94%, TSS to 75–80%, TN to >90%, TP to >90% and coliform to 60–90%.

Land requirement: 7 m^2/HH land is required for the construction of the toilet and for the storage of products that are generated from the user interface. 900 m^2/MLD land is required for the ASP treatment.

Energy requirement: the power requirement of the ASP is 185.7 kWh/day/MLD.

Environmental regulation: high

Health regulation: high

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank/conventional septic tank for storage of black water. Manual/motorised emptying and a truck are used for sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into four parts (Figure 34):

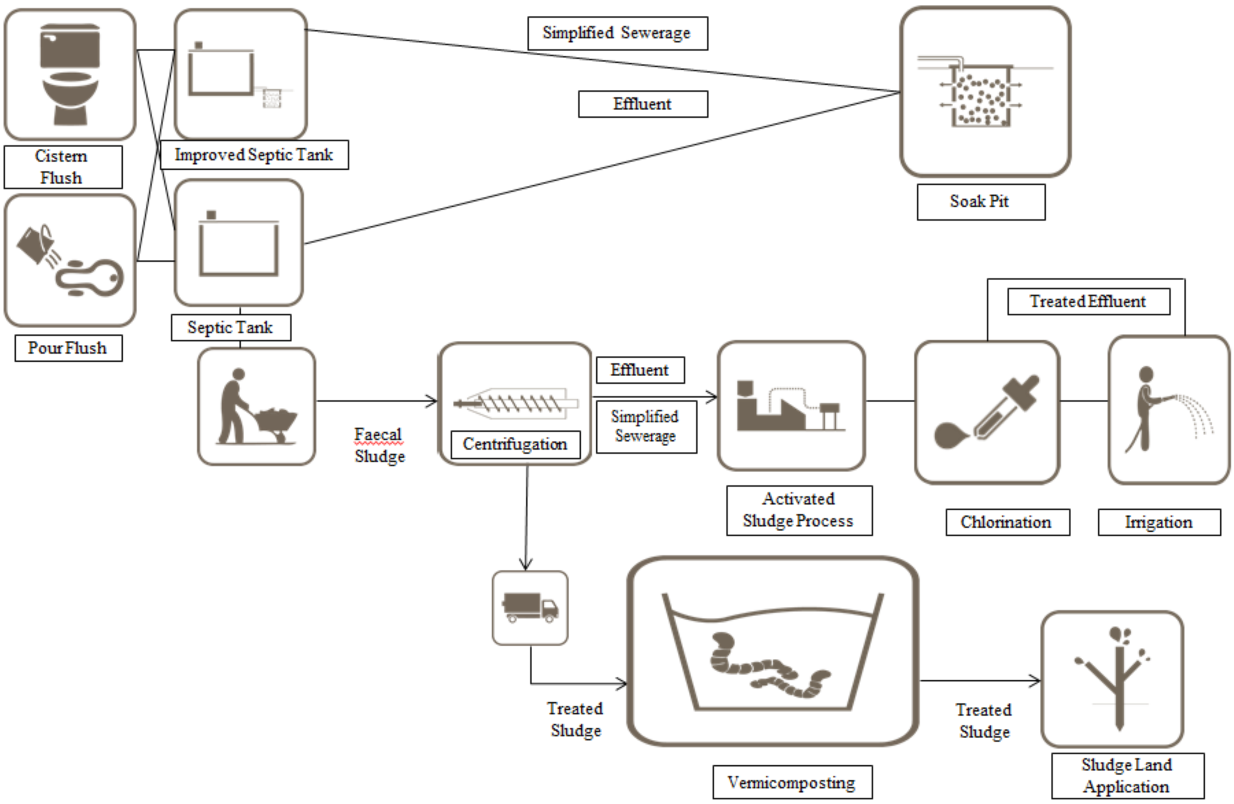

Figure 34: Decentralised System for FSM (Centrifugation + ASP + Vermicomposting + Ozonation)

(1) Primary treatment: Centrifugation is used for solid–liquid separation.

(2) After the solid–liquid separation, the liquid part is transferred to an effluent treatment plant, i.e., the activated sludge process (ASP) is used for the effluent treatment.

(3) The treated liquid generated from the effluent treatment plant undergoes post-effluent treatment for better quality; the chlorination technology is, hence, chosen for the final treatment of the liquid.

(4) The solid part that is generated from centrifugation is transferred to the sludge treatment plant. The vermicomposting technology is chosen for better quality of sludge.

System 2D: Septic Tank + Centrifugation + SBR + Co-composting + Chlorination

Key Features of the Technology

- It is a complete system.
- It is a non-sewered system.
- Septic tank could be designed for the household level, whereas the SBR for the community level.
- Time taken for the installation of this system is up to 1 year.

System lifetime (years): septic tank lifetime, 50 years; SBR treatment plant lifetime, 50 years if well designed and constructed.

Frequency of complete system cleaning/maintenance (years): soak pit, 3–5 years; septic tank to be emptied once in 1–3 years.

Performance of the system: SBR removes BOD up to 95%, COD to 90%, TSS to 95% and TN to 70–80%.

Land requirement: 7 m^2/HH land is required for the construction of the toilet and for the storage of products that are generated from the user interface. 450 m^2/MLD land is required for the SBR treatment.

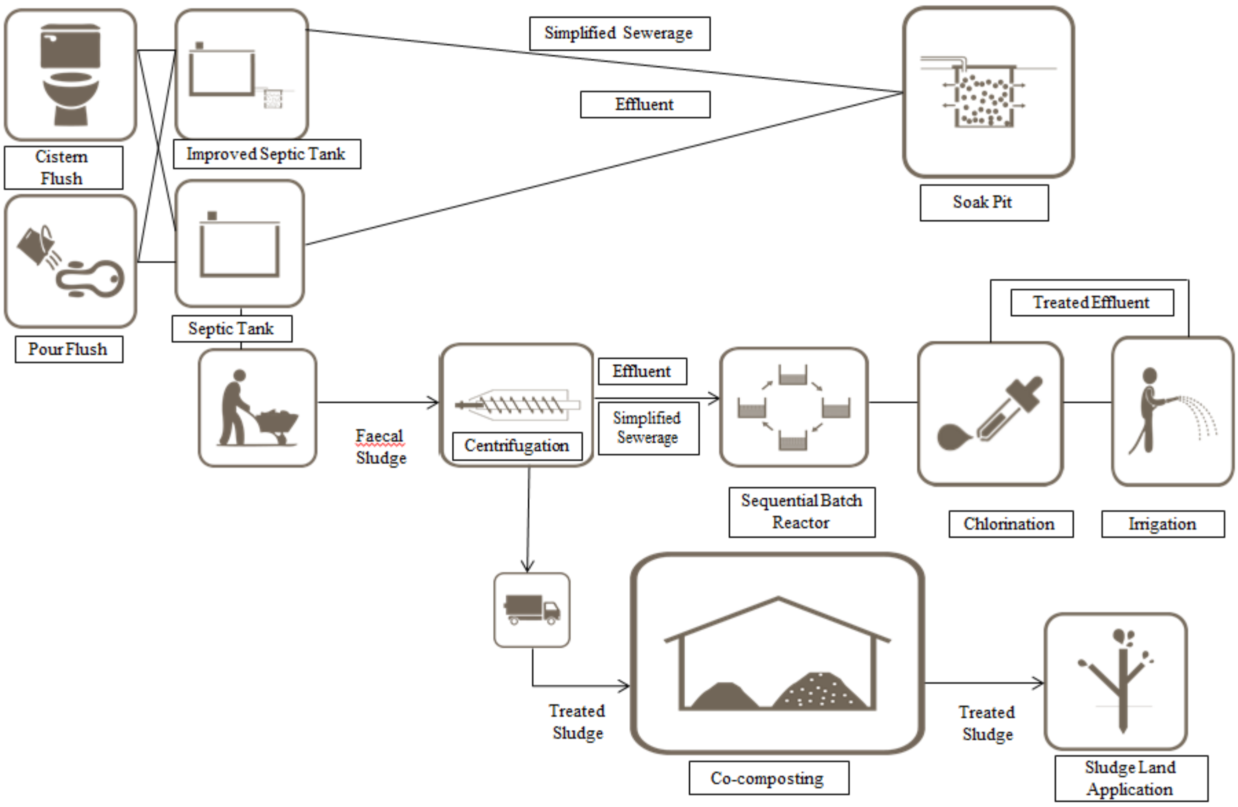

Figure 35: Decentralised System for FSM (Centrifugation + SBR + Co-composting + Chlorination)

Energy requirement: the power requirement of the SBR is 153.7 kWh/day/MLD

Environmental regulation: high

Health regulation: high

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank/conventional septic tank for storage of black water. Manual/ motorised emptying and a truck are used for the sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into four parts (Figure 35):

(1) Primary treatment: Centrifugation is used for the solid–liquid separation.

(2) After solid liquid separation, the liquid part is transferred to the effluent treatment plant, i.e., a sequential batch reactor (SBR) is used for the effluent treatment.

(3) The treated liquid generated from the effluent treatment plant undergoes post-effluent treatment for better quality; the chlorination technology is, hence, chosen for the final treatment of the liquid.

(4) The solid part that is generated from centrifugation is transferred to the sludge treatment plant. Co-composting technology is chosen for better quality of sludge.

System 2E: Septic Tank + Centrifugation + MBR + Co-composting + Ozonation

Key Features of the Technology

- It is a complete system.
- It is a non-sewered system.
- Septic tank could be designed for the household level, whereas the MBR for the community level.
- Time taken for the installation of this system is up to 1 year.

System lifetime (years): septic tank lifetime, 50 years; MBR treatment plant lifetime, 50 years if well designed and constructed.

Frequency of complete system cleaning/maintenance (years): soak pit, 3–5 years; septic tank to be emptied once in 1–3 years.

Performance of the system: MBR removes BOD up to 95%, COD to >90%, TSS to >90%, TN to >90% and TP to >90%.

Land requirement: 7 m^2/HH land is required for the construction of the toilet and for the storage of products that are generated from the user interface. 450 m^2/MLD land is required for the MBR treatment.

Energy requirement: the power requirement of the MBR is 302.5 kWh/day/MLD.

Environmental regulation: high

Health regulation: high

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank/conventional septic tank for storage of black water. Manual/ motorised emptying and a truck are used for sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into four parts (Figure 36):

(1) Primary treatment: Centrifugation is used for solid–liquid separation.

(2) After the solid–liquid separation, the liquid part is transferred to an effluent treatment plant, i.e., a membrane bioreactor (MBR) is used for the effluent treatment.

(3) The treated liquid generated from the effluent treatment plant undergoes post-effluent treatment for better quality; the chlorination technology is, hence, chosen for the final treatment of the liquid.

(4) The solid part that is generated from centrifugation is transferred to the sludge treatment plant, i.e., co-composting for better quality of sludge.

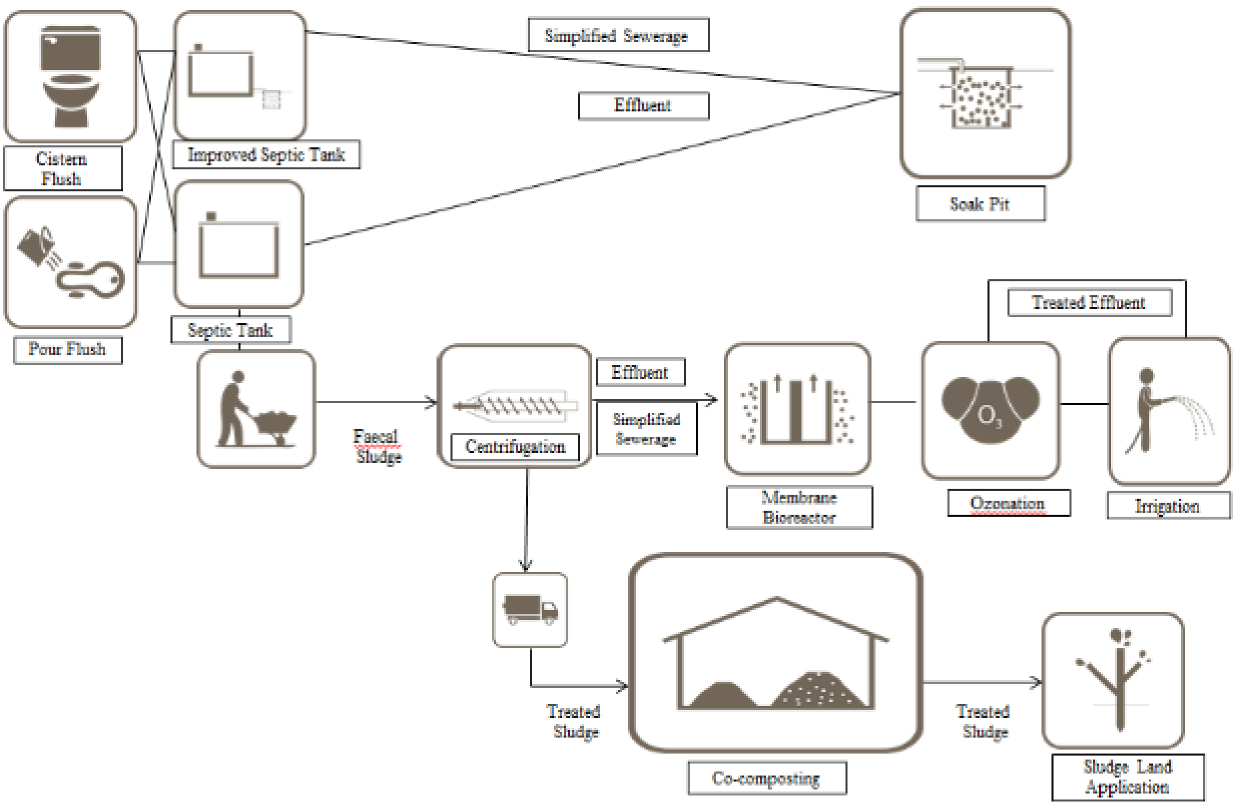

Figure 36: Decentralised System for FSM (Centrifugation + MBR + Co-composting + Ozonation)

System 3A: Septic Tank/BD + MD+ AF + CW + Co-composting

Key Features of the Technology

- It is a complete system.
- It is a modified sewered system.
- This system can be applied for the shared/community level.
- Time taken for installation of this system is up to 1 year or more.

System lifetime (years): treatment plant lifetime is 50 years if well designed and constructed.

Frequency of complete system cleaning/maintenance (years): the biogas settler needs regular attention, and sludge needs to be emptied on schedule. The AF treatment plant and wetland would require daily maintenance/attention.

Performance of the system: the anaerobic filter with the constructed wetland removes BOD up to 50–90% and TSS up to 50–80%.

Land requirement: 7 m^2/HH land is required for the construction of the toilet and for the storage of products that are generated from the user interface.

Energy requirement: the power requirement of the AF is 34 kWh/day/MLD.

Environmental regulation: high

Health regulation: high

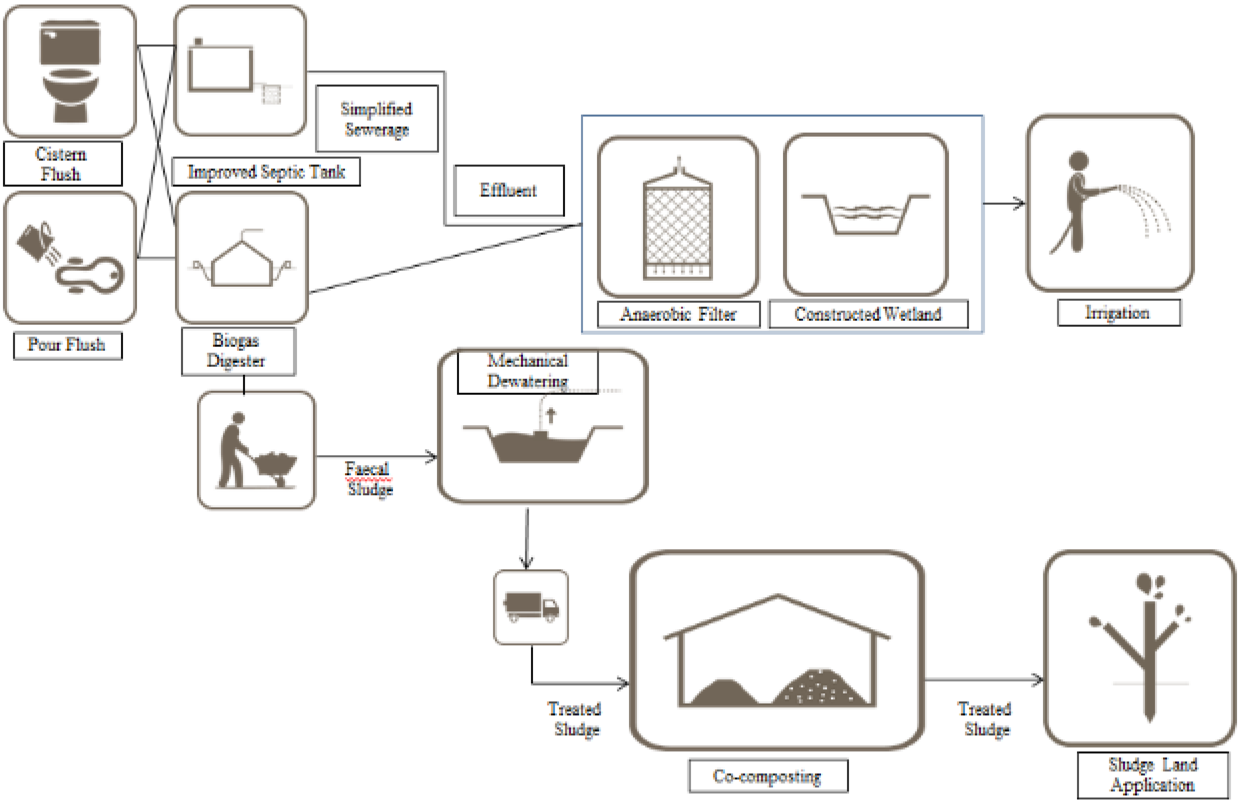

Figure 37: Decentralised System for FSM (MD+ AF + CW + Co-composting)

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank/biogas for storage of black water. Manual/ motorised emptying and a truck are used for sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into three parts (Figure 37):

(1) Primary treatment: Mechanical dewatering (MD) is used for solid–liquid separation.

(2) After the solid–liquid separation, the liquid part is transferred to an effluent treatment plant. An anaerobic filter (AF) and the constructed wetland (CW) technology are used for the effluent treatment.

(3) The solid part that is generated from mechanical dewatering is transferred to the sludge treatment plant. The co-composting technology is chosen for the better quality of sludge.

System 3B: Septic Tank/BD+ MD + WSP + Co-composting

Key Features of the Technology

- It is a complete system.
- It is a small-bore sewered system.
- This system can be used at the community level.
- Time taken for installation of this system is up to 1 year or more.

System lifetime (years): septic tank lifetime, 50 years; treatment plant lifetime, 50 years if well designed and constructed.

Frequency of complete system cleaning/maintenance (years): septic tank to be emptied once in 2–3 years. The sludge drying bed is to be cleaned depending on the filling frequency. The WSP would require daily maintenance/attention.

Performance of the system: the waste stabilisation pond removes BOD up to 75–85%, COD to 74–78%, TSS to 75–80%, TN to 70–90%, TP to 30–45% and coliform to 60–99.9%.

Land requirement: 7 m^2/HH land is required for the construction of the toilet and for the storage of products that are generated from the user interface.

Energy requirement: the power requirement of this system is 5.7 kWh/day/MLD.

Environmental regulation: high

Health regulation: high

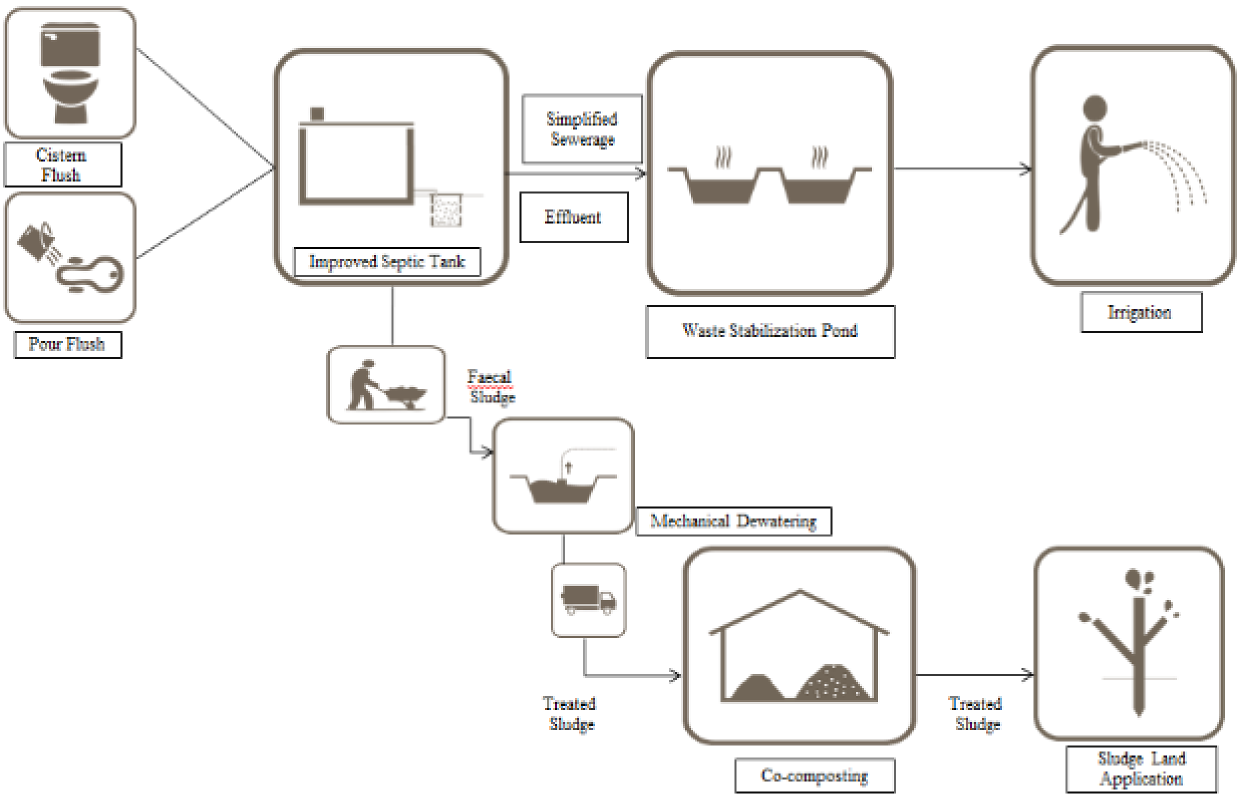

Figure 38: Decentralised System for FSM (MD + WSP + Co-composting)

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank for storage of black water. Manual/ motorised emptying and a truck are used for sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into three parts (Figure 38):

(1) Primary treatment: Mechanical dewatering (MD) is used for solid–liquid separation.

(2) After the solid–liquid separation, the liquid part is transferred to an effluent treatment plant. The waste stabilisation pond (WSP) technology is used for the effluent treatment.

(3) The solid part that is generated from mechanical dewatering is transferred to the sludge treatment plant. The co-composting technology is chosen for better quality of sludge.

System 4: ASP + Reed Bed + Sludge Drying Bed + Co-composting

Key Features of the Technology

- It is a complete system.
- It is a sewered system.
- This system can be applied at the community/ward/city level.
- Time taken for the installation of this system is up to 1 year.

System lifetime (years): sewer lifetime, 50 years; treatment plant lifetime, 50 years if well designed and constructed.

Frequency of complete system cleaning/maintenance (years): the sewer would require regular maintenance. The treatment plant would require daily maintenance/attention.

Performance of the system: ASP +Reed Bed removes BOD up to 90–95%, COD to 85–90%, TSS to >90%, TN to >60% and coliform to 90–99.9%.

Land requirement: 900 m^2/MLD land is required for the ASP treatment.

Energy requirement: the power requirement of the ASP is 185.7 kWh/day/MLD.

Environmental regulation: high

Health regulation: high

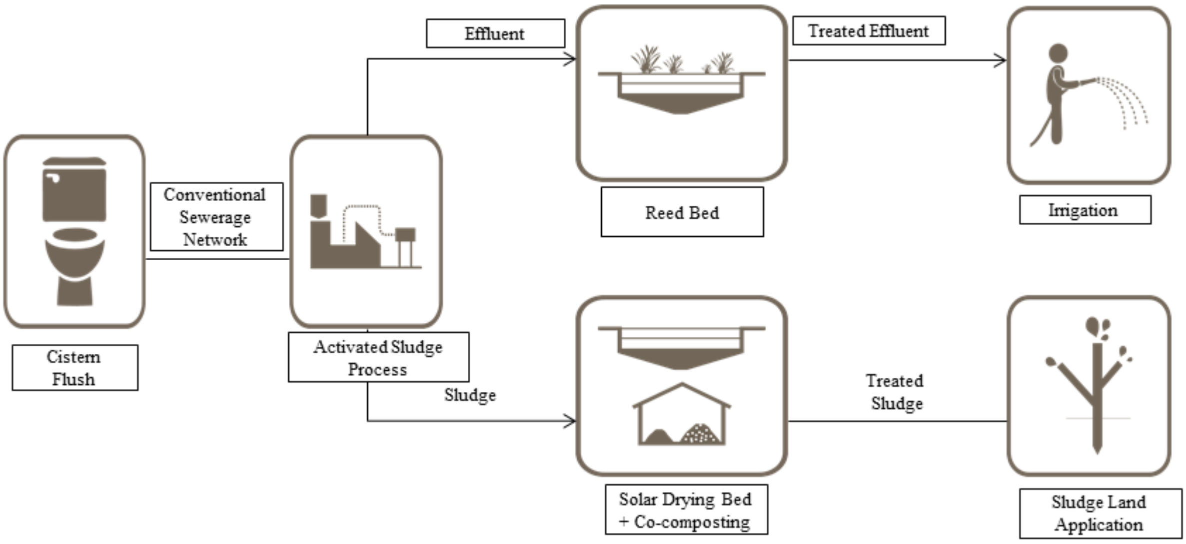

Figure 39: Networked System for FSM (ASP + Reed Bed + Sludge Drying Bed + Co-composting)

Components of the system: This is a networked system. In this system, waste water is transported from a cistern flush toilet via a system of sewers to the treatment facility. Treatment is divided into three parts (Figure 39):

(1) Primary treatment: Activated sludge process (ASP) is used for solid–liquid separation as well as treatment.

(2) Effluent treatment: After primary treatment, the liquid part is transferred to an effluent treatment plant, i.e., reed bed (RB) for further treatment.

(3) Sludge treatment: The solid part that is generated from primary treatment is transferred to the sludge treatment plant. The solar drying bed (SDB) + co-composting technology are chosen for better quality of the sludge.

System 5: Septic Tank + IT + CW + Sludge Drying Bed + Co-composting

Key Features of the Technology

- It is a complete system.
- It is a non-sewered system.
- Septic tank could be designed for the household level, whereas the sludge and effluent treatment designed for the community level.
- Time taken for the installation of this system is 6 months to1 year for small systems.

System lifetime (years): septic tank lifetime, 50 years; drying bed/Imhoff tank lifetime, 50 years if well designed and constructed.

Frequency of complete system cleaning/maintenance (years): septic tank to be emptied once in 2–3 years. The sludge-drying bed is to be cleaned depending on the filling frequency. The CW would require daily maintenance/attention.

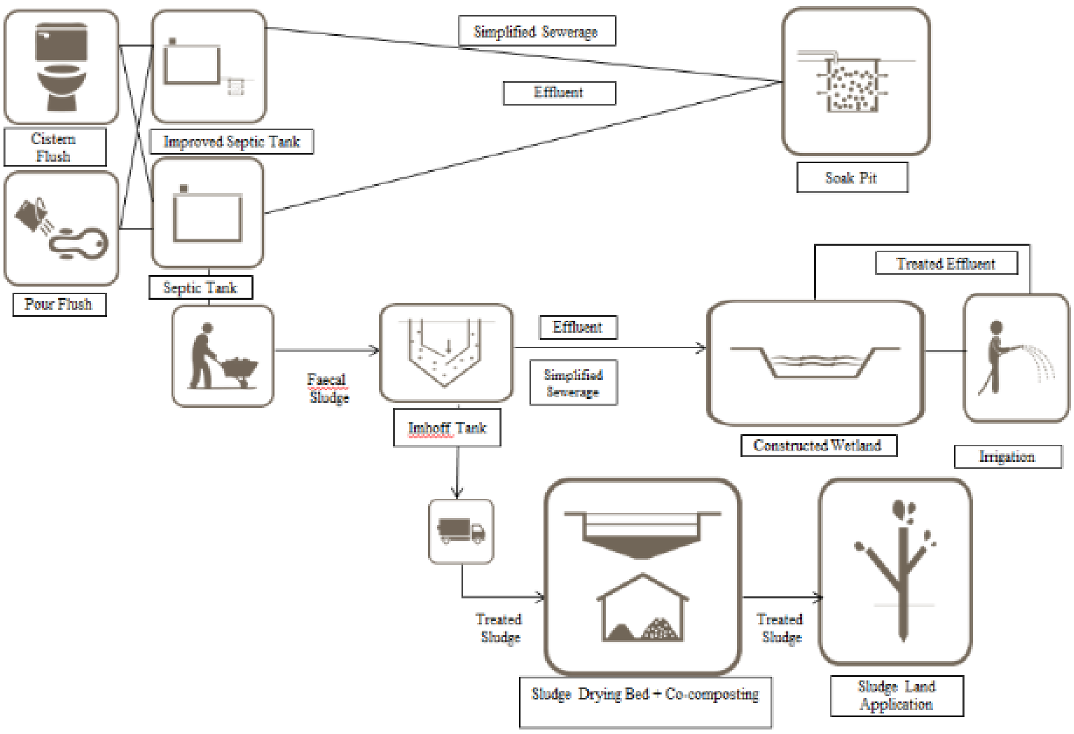

Figure 40: Decentralised System for FSM (IT + CW + Sludge Drying Bed + Co-composting)

Performance of the system: the Imhoff tank removes BOD up to 30–50% and TSS up to 50–70%.

Land requirement: 450 m^2/MLD land is required for the Imhoff tank treatment.

Energy requirement: the power requirement of the IT is 45 kWh/day/MLD.

Environmental regulation: medium, due to less degradation of organic matter compared with that in other systems.

Health regulation: low, due to lower reduction of pathogens.

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank/conventional septic tank for storage of black water. Manual/ motorised emptying and a truck are used for sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into three parts (Figure 40):

(1) Primary treatment: Imhoff tank (IT) is used for solid–liquid separation as well as treatment.

(2) After the solid–liquid separation, the liquid part is transferred to an effluent treatment plant, i.e., a constructed wetland (CW) is used for the effluent treatment.

(3) The solid part that is generated from Imhoff tank is transferred to the sludge treatment plant, i.e., sludge drying bed (SDB) + co-composting is used for better quality of the sludge.

System 6A: ABR+ Sludge Drying Bed + Co-composting

Key Features of the Technology

- It is a complete system.
- It is a sewered system.
- This system can be applied at the community/ward/city level.
- Time taken for the installation of this system is 6 months to one year for small systems.

System lifetime (years): more than 50 years for this system.

Frequency of complete system cleaning/maintenance (years): the sewer would require regular maintenance. The treatment plant would require daily maintenance/attention.

Performance of the system: the ABR removes BOD up to 70–95%, TSS to 80–90% and coliform to 20–30%.

Land requirement: 1,000 m^2/MLD land is required for the ABR treatment.

Energy requirement: the power requirement of the ABR is 34 kWh/day/MLD.

Environmental regulation: high

Health regulation: medium

Components of the system: This is a networked system. In this system, waste water is transported from a cistern flush toilet via a system of sewers to the treatment facility. Treatment is divided into two parts (Figure 41):

(1) Primary treatment: An anaerobic baffled reactor (ABR) process is used for solid–liquid separation as well as for treatment of solid and liquid.

(2) Sludge treatment: The solid part that is generated from primary treatment is transferred to the sludge treatment plant, i.e., solar drying bed (SDB) + co-composting is used for the better quality of sludge.

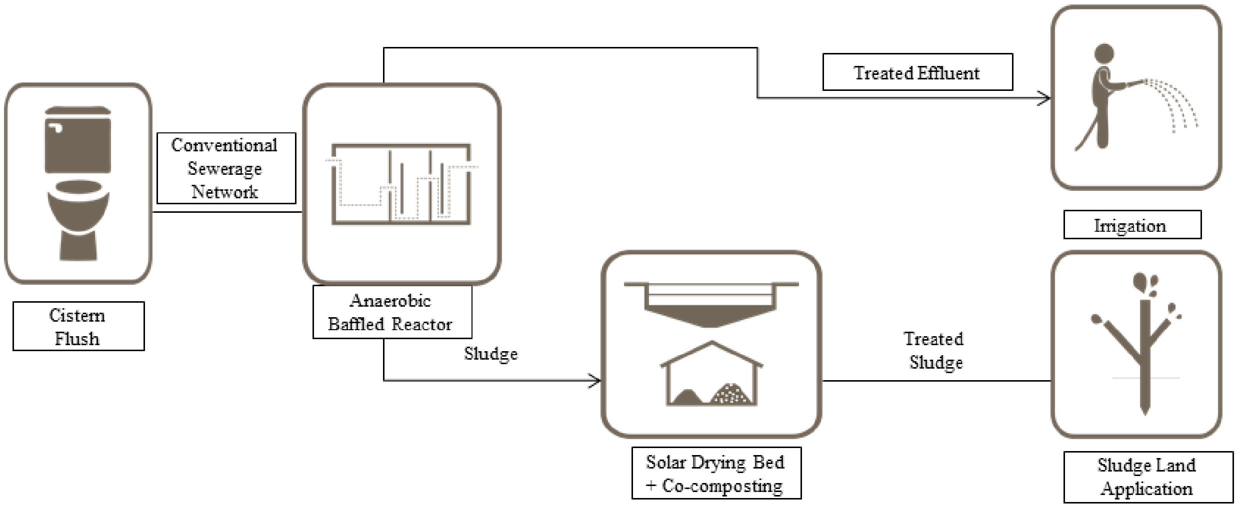

Figure 41: Networked System for FSM (ABR+ Sludge-Drying Bed + Co-composting)

System 6B: AF+ Sludge Drying Bed + Co-composting

Key Features of the Technology

- It is a complete system.
- It is a sewered system.
- This system can be applied at the community/ward/city level.
- Time taken for the installation of this system is 6 months to 1 year for small systems.

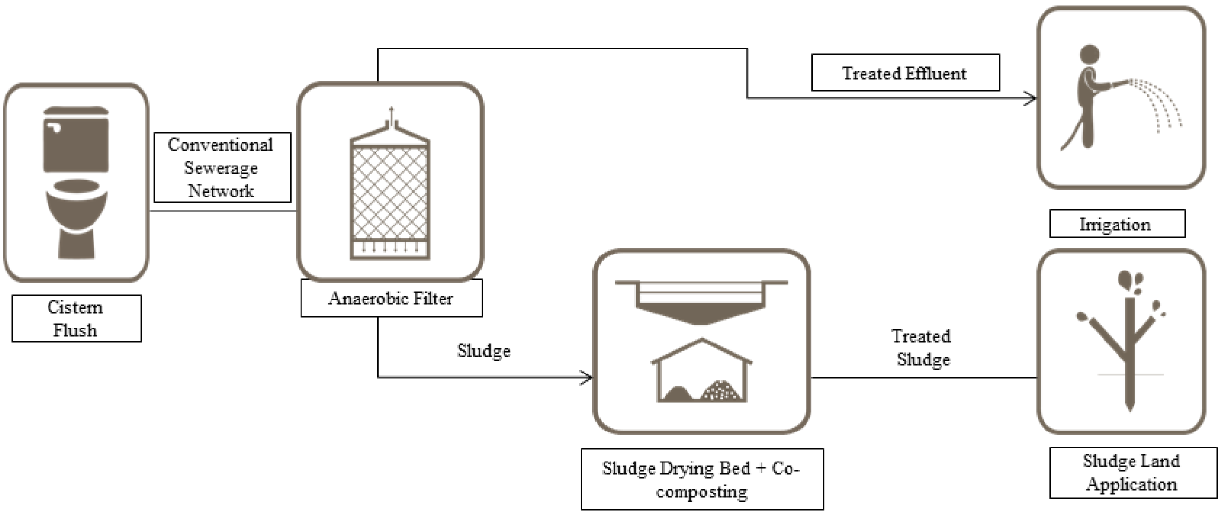

Figure 42: Networked System for FSM (AF+ Sludge Drying Bed + Co-composting)

System lifetime (years): more than 50 years for this system.

Frequency of complete system cleaning/maintenance (years): the sewer would require regular maintenance. The treatment plant would require daily maintenance/attention.

Performance of the system: the anaerobic filter removes BOD up to 50–90% and TSS up to 50–80%.

Energy requirement: the power requirement of the AF is 34 kWh/day/MLD.

Environmental regulation: high

Health regulation: medium

Components of the system: This is a networked system. In this system, waste water is transported from a cistern flush toilet via a system of sewers to the treatment facility. Treatment is divided into two parts (Figure 42):

(1) Primary treatment: An anaerobic filter (AF) process is used for solid–liquid separation as well as for treatment of solid and liquid.

(2) Sludge treatment: The solid part that is generated from primary treatment is transferred to the sludge treatment plant, i.e., solar drying bed (SDB) + co-composting is used for better quality of the sludge.

System 7: Septic Tank + Belt Filter Press + CW + Lime Stabilisation + Ozonation

Key Features of the Technology

- It is not a complete system (the components of FSM are missing).
- It is a non-sewered system.
- Septic tank could be designed for the household level, whereas the sludge and effluent treatment can be designed for the community level.
- Time taken for the construction of this system is less than 2 weeks.

System lifetime (years): septic tank lifetime, 50 years.

Frequency of complete system cleaning/maintenance (years): septic tank to be emptied once in 2–3 years once. The CW would require frequent maintenance/attention.

Energy requirement: the power requirement of this system is 22 kWh/day/MLD.

Environmental regulation: medium, due to missing components for FSM.

Health regulation: low, due to lower reduction of pathogens.

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank/conventional septic tank for storage of black water. Manual/ motorised emptying and truck is used for the sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into four parts (Figure 43):

(1) Primary treatment: Belt filter press (BFP) is used for the solid–liquid separation.

(2) After the solid–liquid separation, the liquid part is transferred to an effluent treatment plant, i.e., constructed wetland (CW) is used for the effluent treatment.

(3) The treated liquid generated from the effluent treatment plant undergoes post-effluent treatment for better quality; the ozonation technology is, hence, chosen for the final treatment of the liquid.

(4) The solid part that is generated from belt filter press is transferred to the sludge treatment plant. Lime stabilisation technology is chosen for better quality of sludge.

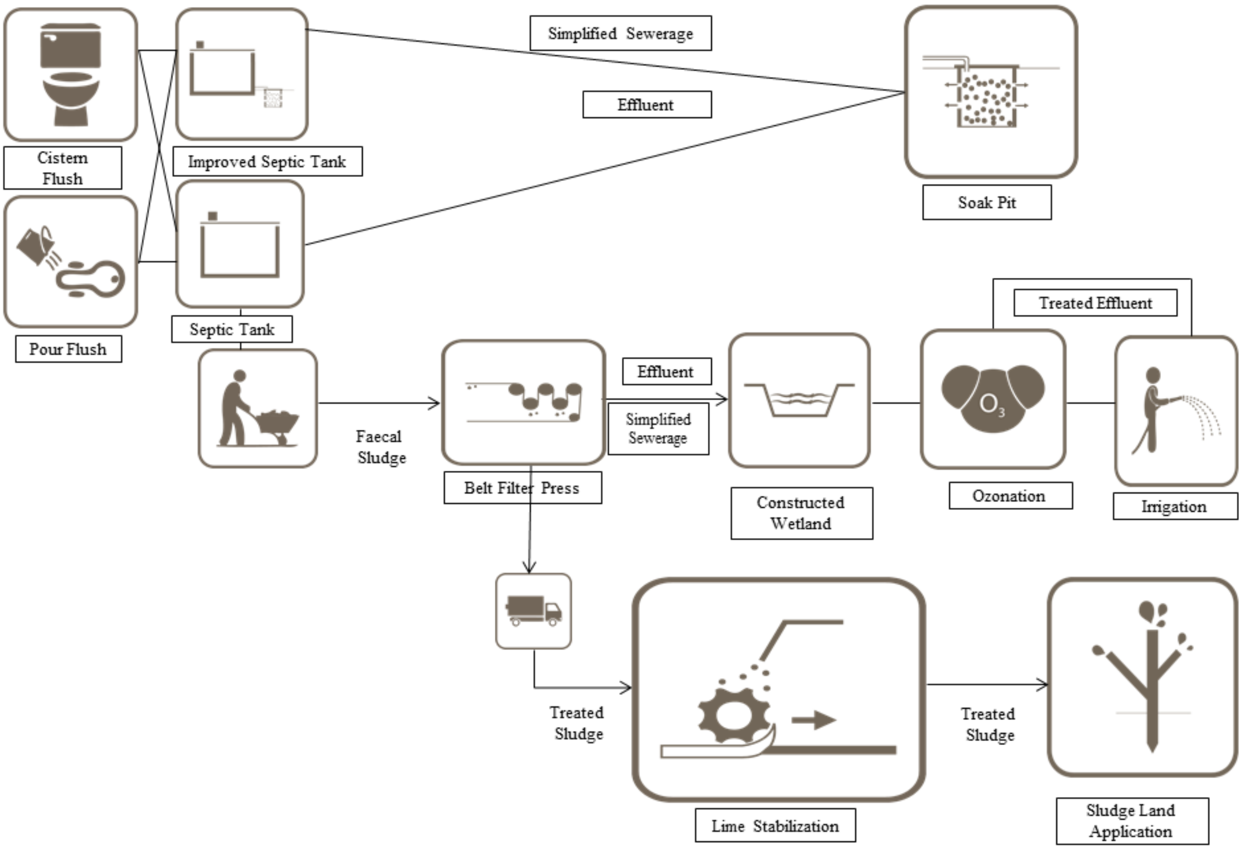

Figure 43: Decentralised System for FSM (Belt Filter Press + CW + Lime Stabilisation)

System 8: UASB+ Sludge Drying Bed + Co-composting

Key Features of the Technology

- It is a complete system.
- It is a sewered system.
- This system can be applied at the community/ward/city level.
- Time taken for the installation of this system is about 1 year.

System lifetime (years): more than 50 years for this system.

Frequency of complete system cleaning/maintenance (years): the sewer would require regular maintenance. The treatment plant would require daily maintenance/attention.

Performance of the system: the UASB removes BOD up to 75–85%, COD to 60–80%, TSS to 75–80% and TN to 10–20%.

Land requirement: 1,000 m^2/MLD land is required for the UASB treatment.

Energy requirement: the power requirement of the UASB is 34 kWh/day/MLD.

Environmental regulation: high

Health regulation: high

Components of the system: This is a networked system. In this system, waste water is transported from a cistern flush toilet via a system of sewers to the treatment facility. Treatment is divided into two parts (Figure 44):

(1) Primary treatment: up-flow anaerobic sludge blanket (UASB) process is used for solid–liquid separation as well as for treatment of solid and liquid.

(2) Sludge treatment: the solid part that is generated from primary treatment is transferred to the sludge treatment plant, i.e., sludge drying bed (SDB) + co-composting is used for better quality of the sludge.

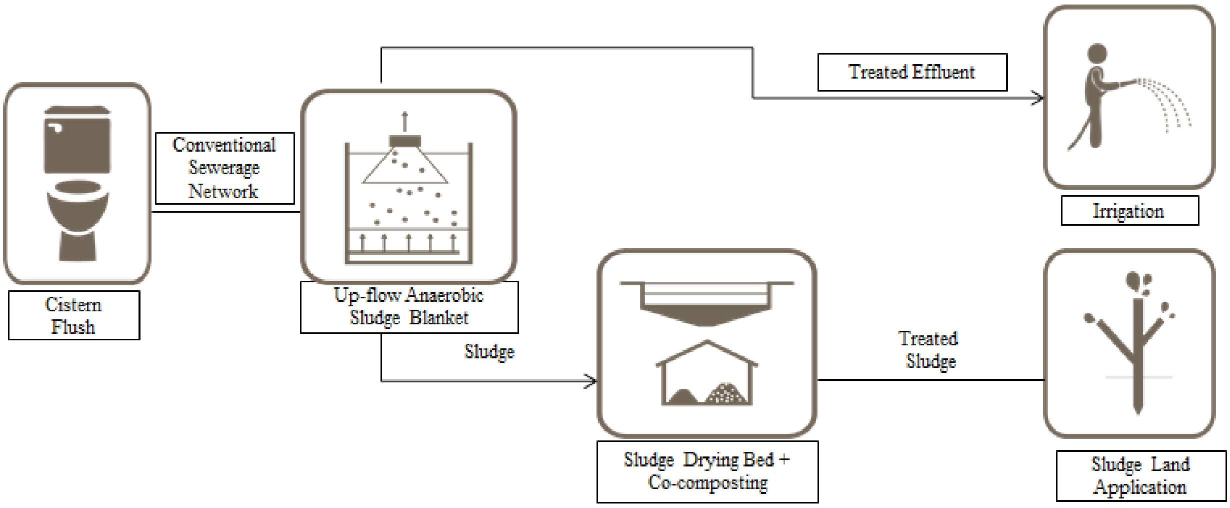

Figure 44: Networked System for FSM (UASB+ Sludge Drying Bed + Co-composting)

System 9: Septic Tank + MD + WSP + Solar Drying

Key Features of the Technology

- It is a complete system.
- It is a non-sewered system.
- Community-level public toilet and sludge-drying bed, and community-level WSP treatment.
- Time taken for the installation of the system: construction, 3–6 months for a public latrine; 3–6 months for a drying bed and for filtrate treatment.

System lifetime (years): septic tank lifetime, 50 years. WSP, 50 years if well designed and constructed.

Frequency of complete system cleaning/maintenance (years): septic tank to be emptied once in 2–3 years once. The WSP would require frequent maintenance/attention.

Performance of the system: the waste stabilisation pond removes BOD up to 75–85%, COD to 74–78%, TSS to 75–80%, TN to 70–90%, TP to 30–45% and coliform to 60–99.9%.

Land requirement: 7 m^2/HH land is required for the construction of the toilet and for the storage of products that are generated from the user interface. 6,000 m^2/MLD land is required for the WSP treatment.

Energy requirement: the power requirement of the WSP is 5.7 kWh/day/MLD.

Environmental regulation: high

Health regulation: high

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank/conventional septic tank for storage of black water. Manual/ motorised emptying and a truck are used for the sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into three parts (Figure 45):

(1) Primary treatment: Mechanical dewatering (MD) is used for solid–liquid separation.

(2) After the solid–liquid separation, the liquid part is transferred to an effluent treatment plant, i.e., a waste stabilisation pond (WSP) is used for the effluent treatment.

(3) The solid part that is generated from the mechanical dewatering is transferred to the sludge treatment plant, i.e., solar drying (SD) is used for the better quality of sludge.

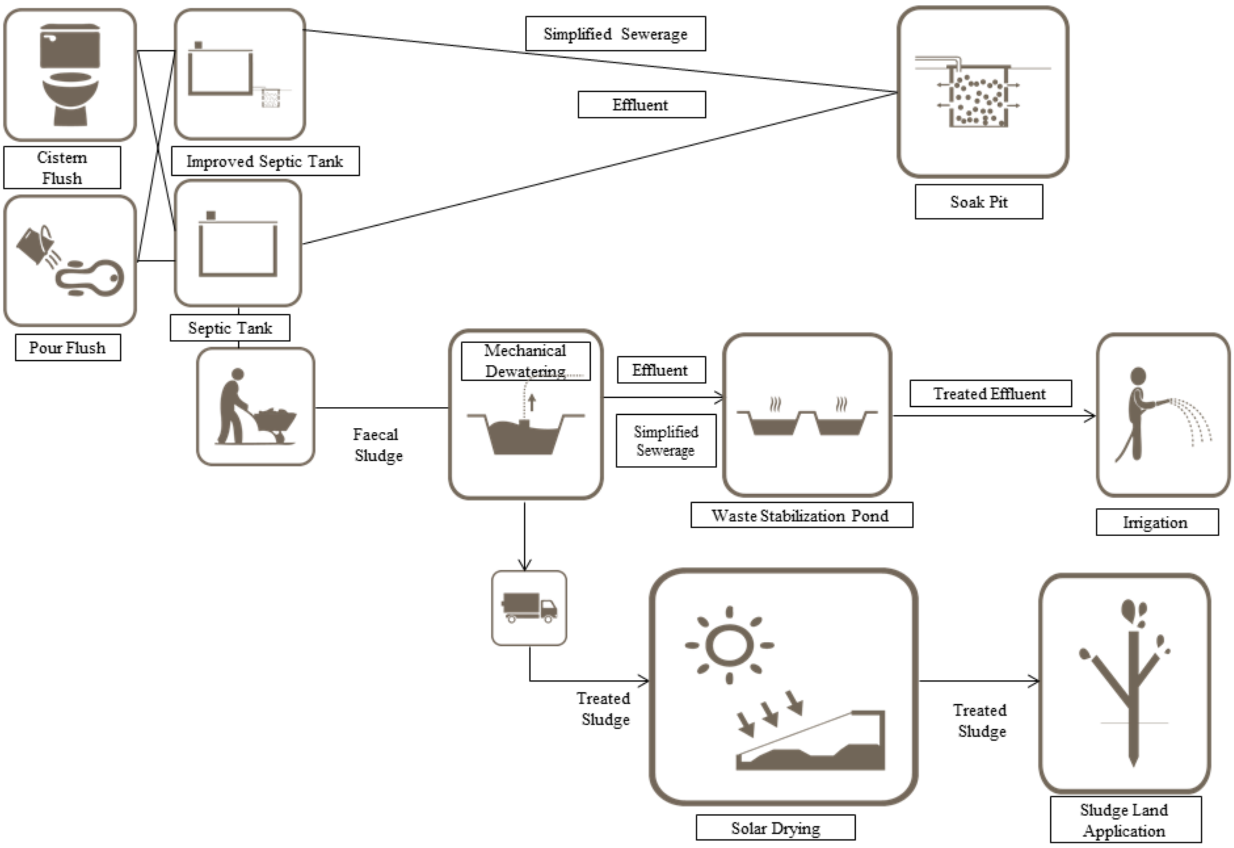

Figure 45: Decentralised System for FSM (MD + WSP + Solar Drying)

System 10: Septic Tank + PDB + CW + Shallow Trenches

Key Features of the Technology

- It is a complete system.
- It is a non-sewered system.
- Septic tank could be designed for the household and community levels for trenching.

- Time taken for the installation of the system: construction < 1 month for septic tank, 2–3 months for the trenching site.

System lifetime (years): septic tank, 50 years; trenching site, 5–10 years.

Frequency of complete system cleaning/maintenance (years): Septic tank, de-sludging every 2–3 years; trenching site, cover soil, maintenance of trees, etc.,—daily attention.

Land requirement: 7 m^2/HH land is required for the construction of the toilet and for the storage of products that are generated from the user interface.

Environmental regulation: medium

Health regulation: medium

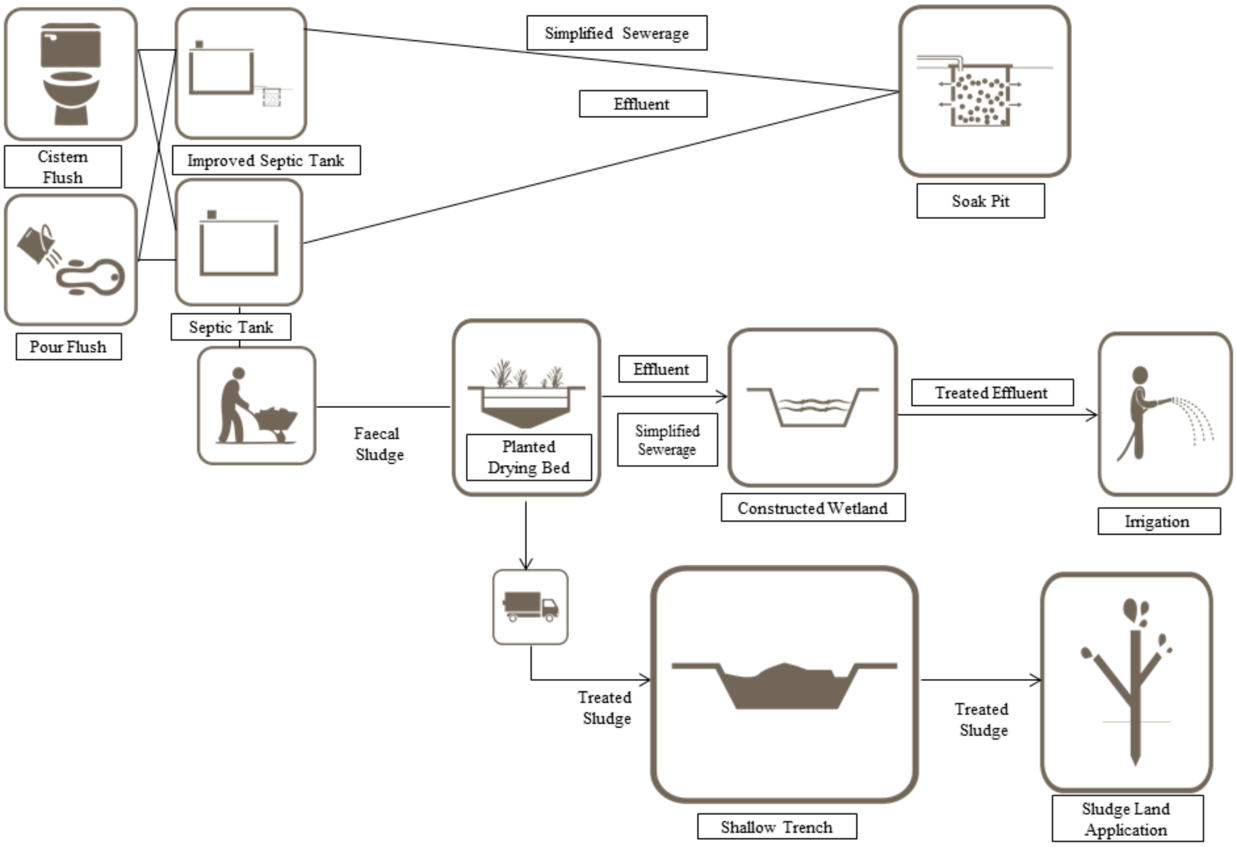

Figure 46: Decentralised system for FSM (PDB + CW + Shallow Trenches + Chlorination)

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank/conventional septic tank for storage of black water. Manual/ motorised emptying and a truck are used for sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into three parts (Figure 46):

(1) Primary treatment: A planted drying bed (PDB) is used for solid–liquid separation.

(2) After the solid–liquid separation, the liquid part is transferred to an effluent treatment plant, i.e., a constructed wetland (CW) is used for the effluent treatment.

(3) The solid part that is generated from the planted drying bed is transferred to the sludge treatment plant, i.e., a shallow trench is used for better quality of the sludge.

System 11: Geobags + WSP+ Co-composting

Key Features of the Technology

- It is a complete system.
- It is a non-sewered system.
- Septic tank could be designed for the household level and geo-bags for the community level.
- Time taken for the installation of the system: construction <1 month for septic tank, 2–3 months for geo-bag and filtrate treatment.

System lifetime (years): septic tank, 50 years; geo-bag, 6–12 months.

Frequency of complete system cleaning/maintenance (years): septic tank, de-sludging every 2–3 years; geo-bag and filtrate treatment, intermittent attention.

Performance of the system: the waste stabilisation pond removes BOD up to 75–85%, COD to 74–78%, TSS to 75–80%, TN to 70–90%, TP to 30–45% and coliform to 60–99.9%.

Land requirement: 7 m^2/HH land is required for the construction of the toilet and for the storage of products that are generated from the user interface. 6,000 m^2/MLD land is required for the WSP treatment.

Energy requirement: the power requirement of the WSP is 5.7 kWh/day/MLD.

Environmental regulation: high

Health regulation: high

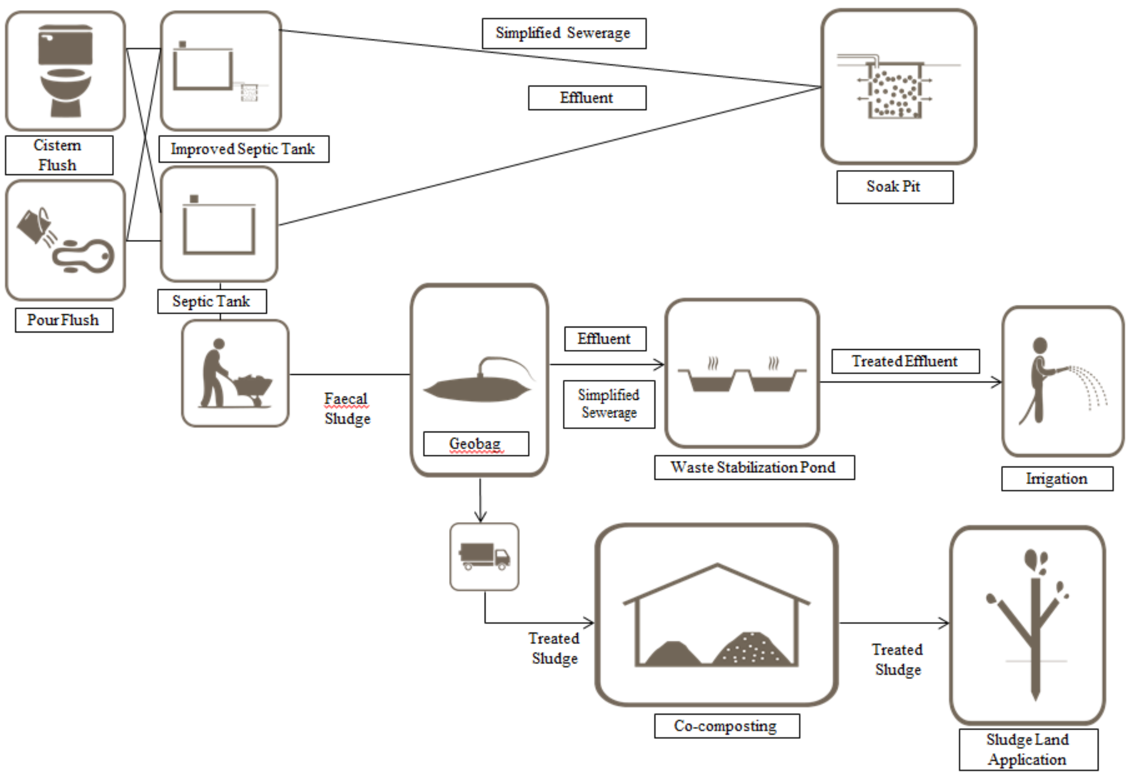

Figure 47: Decentralised System for FSM (Geobags + WSP+ Co-composting)

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank/conventional septic tank for storage of black water. Manual/ motorised emptying and a truck are used for sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into three parts (Figure 47):

(1) Primary treatment: Geobags are used for solid–liquid separation.

(2) After the solid–liquid separation, the liquid part is transferred to the effluent treatment plant, i.e., a waste stabilisation pond (WSP) is used for the effluent treatment.

(3) The solid part that is generated from the geobags is transferred to the sludge treatment plant, i.e., co-composting is used for better quality of the sludge.

System 12: Septic Tank + ABR + CW + Sludge Drying Bed + Co-composting

Key Features of the Technology

- It is a complete system.
- It is a non-sewered system.
- Septic tank could be designed for the household level and the effluent and sludge treatment for the community level.
- Time taken for the installation of this system is 6 months to 1 year for small systems.

System lifetime (years): more than 50 years for this system.

Frequency of complete system cleaning/maintenance (years): the treatment plant would require daily maintenance/attention.

Performance of the system: ABR removes BOD up to 70–95%, TSS to 80–90% and coliform to 20–30%.

Land requirement: 1,000 m^2/MLD land is required for the ABR treatment.

Energy requirement: the power requirement of the ABR is 34 kWh/day/MLD.

Environmental regulation: high

Health regulation: high

The estimated cost of an ABR ranges from US$425 to US$650 per cu.m for a treatment capacity of 10cu.m if used in combination with other treatment modules.

Components of the system: This is a decentralised system. In this system, a pour flush/cistern flush toilet is connected to an improved septic tank/conventional septic tank for storage of black water. Manual/ motorised emptying and a truck are used for sludge collection and transport. After collection from the septic tank, the sludge is transferred to the treatment facility. Treatment is divided into three parts (Figure 48):

(1) Primary treatment: An anaerobic baffled reactor (ABR) is used for solid–liquid separation.

(2) After the solid–liquid separation, the liquid part is transferred to an effluent treatment plant, i.e., a constructed wetland (CW) is used for the effluent treatment.

(3) The solid part that is generated from the anaerobic baffled reactor is transferred to the sludge treatment plant, i.e., solar drying bed (SDB) + co-composting is used for better quality of the sludge.

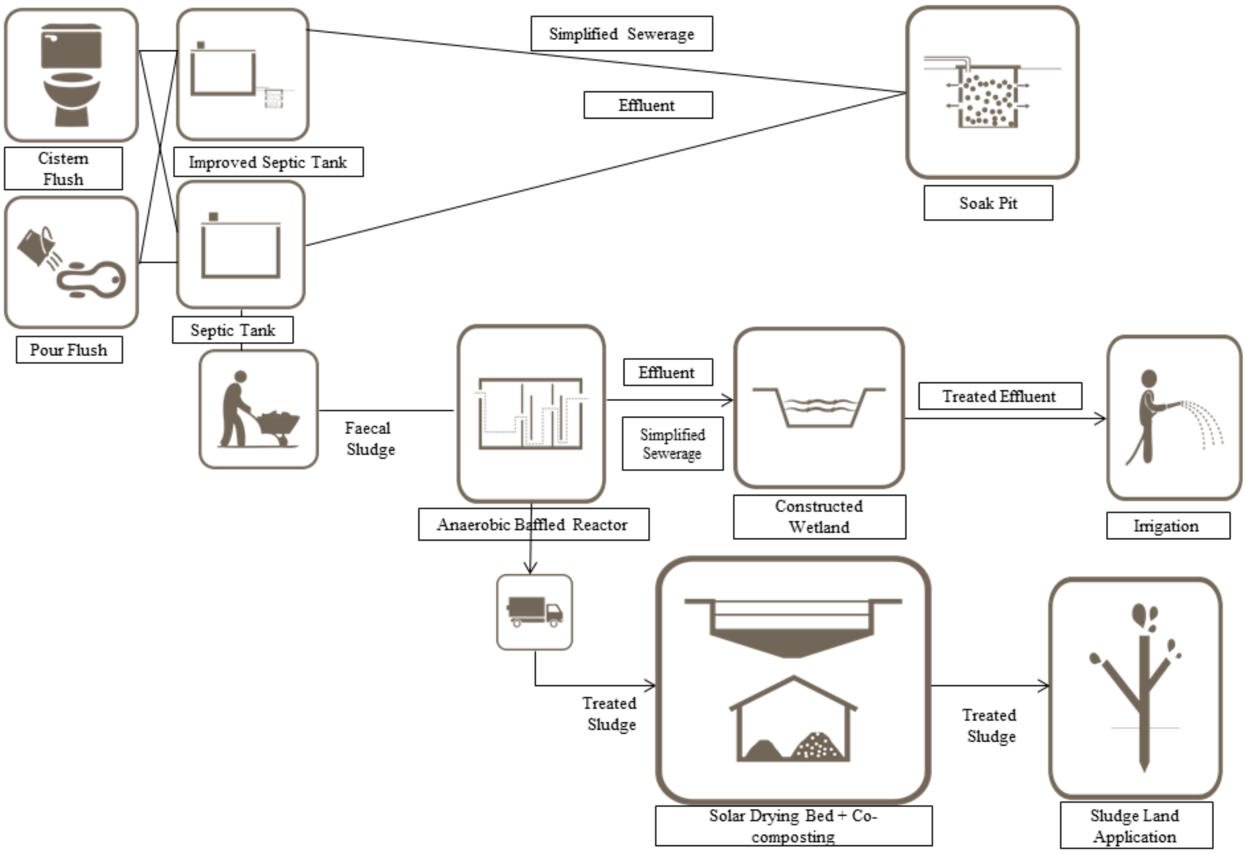

Figure 48: Decentralised System for FSM (ABR + CW + Sludge Drying Bed + Co-composting)

Comparison of Systems

Table 17 provides a comparison of the 12 systems.

Table 17: Comparison of 12 Systems w.r.t. Land, Energy, Performance & Cost

System Number	System Name	Type of System	System Lifetime	Applicability of System	Land Availability	Performance of the System	Energy Requirement	CAPEX	OPEX
System 1	Twin-pit system	Onsite system	Twin pit, 10 years	Household level	5 m^2/HH for Pit + Toilet	-	Not required	INR 4,500 /HH for pit	INR 400/HH/year
System 2A	UDB + WSP + Co-composting + Chlorination	Decentralised system	ST, 50 years; soak pit, 3–5 years, UDB/WSP, 50 years	Ward/city/cluster level	7 m^2/HH for Storage + Toilet; WSP, 6,000 m^2/MLD	BOD, 75–85%; COD, 74–78%; TSS, 75–80%; TN, 70–90%; TP, 30–45%; coliform, 60–99.9%	WSP, 5.7 kWh/d/MLD	IST, INR 75,000/HH; WSP: INR 23,00,000/MLD; UDB: 3,00,00,000/MLD	IST, INR 1,500/HH/year; UDB, INR 50,00,000/MLD/year; WSP, INR 2,00,000/MLD/year
System 2B	AD + Co-composting + Chlorination	Decentralised system	ST, 50 years; soak pit, 3–5 years, AD, 50 years	Ward/city/cluster level	7 m^2/HH for Storage + Toilet; AD, 600 m^2/MLD	BOD, 60–90%; COD, 60–80%; TSS, 60–85%	AD, 60 kWh/d/MLD	IST, INR 75,000/HH; AD, INR 5,00,00,000/MLD	IST, INR 1,500/HH/year; AD, INR 30,00,000/MLD/year
System 2C	Centrifugation + ASP + Vermicomposting + Ozonation	Decentralised system	ST, 50 years; soak pit, 3–5 years, ASP, 50 years	Ward/city/cluster level	7 m^2/HH for Storage + Toilet; ASP, 900 m^2/MLD	BOD, 85–92%; COD, 93–94%; TSS, 75–80%; TN, >90%; TP, >90%; coliform, 60–90%	ASP, 185.7 kWh/d/MLD; Centrifugation: 20–300 kWh per metric tonne of solid	IST, INR 75,000/HH; ASP, 68,00,000/MLD	IST, INR 1,500/HH/year; ASP, INR 7,00,000/MLD/year
System 2D	Centrifugation + SBR + Co-composting + Chlorination	Decentralised system	ST, 50 years; soak pit, 3–5 years, SBR, 50 years	Ward/city/cluster level	7 m^2/HH for Storage + Toilet; SBR, 450 m^2/MLD	BOD, 95%; COD, 90%; TSS, 95%; TN, 70–80%	SBR, 153.7 kWh/d/ MLD; Centrifugation: 20–300 kWh per metric tonne of solid	IST, INR 75,000/HH; SBR, INR 75,00,000/MLD	IST, INR 1,500/HH/year; SBR, INR 6,00,000/MLD/year
System 2E	Centrifugation + MBR + Co-composting + Ozonation	Decentralised system	ST, 50 years; soak pit, 3–5 years, MBR, 50 years	Ward/city/cluster level	7 m^2/HH for Storage + Toilet; MBR, 450 m^2/MLD	BOD, 95%; COD, >90%; TSS, >90%; TN, >90%; TP, >90%	MBR, 302.5 kWh/d/ MLD; Centrifugation: 20–300 kWh per metric tonne of solid	IST, INR 75,000/HH; MBR, INR 30,000,000 /MLD	IST, INR 1,500/HH/year; MBR, INR 9,00,000 /MLD/year

System Number	System Name	Type of System	System Lifetime	Applicability of System	Land Availability	Performance of the System	Energy Requirement	CAPEX	OPEX
System 3A	MD+ AF + CW + Co-composting + Chlorination	Decentralised system	Treatment plant life, 50 years	Ward/city/cluster level	7 m²/HH for Storage + Toilet	BOD, 50–90%; TSS, 50–80%	AF, 34 kWh/d/MLD	BD, INR 60,000/HH	BD, INR 1,400/HH/year
System 3B	MD + WSP + Co-composting + Chlorination	Decentralised system	Treatment plant life, 50 years	Ward/city/cluster level	7 m²/HH for Storage + Toilet	BOD, 75–85%; COD, 74–78%; TSS, 75–80%; TN, 70–90%; TP, 30–45%; coliform, 60–99.9%	WSP, 5.7 kWh/d/MLD	IST, INR 75,000/HH; WSP, INR 23,00,000/MLD	IST, INR 1,500/HH/year; WSP, INR 2,00,000/MLD/year
System 4	ASP + reed bed + Sludge Drying Bed + Co-composting	Networked system	Sewer and treatment plant life, 50 years	Ward/city/cluster level	ASP, 900 m²/MLD	BOD, 90–95%; COD, 85–90%; TSS, >90%; TN, >60%; coliform, 90–99.9%	ASP: 185.7 kWh/d/MLD	ASP, INR 68,00,000/MLD	ASP, INR 7,00,000/MLD/year
System 5	IT + CW + Sludge Drying Bed + Co-composting + Chlorination	Decentralised system	ST, 50 years; IT, 50 years	Ward/city/cluster level	7 m²/HH for Storage + Toilet; IT, 900 m²/MLD	BOD, 30–50%; TSS, 50–70%.	IT, 45 kWh/d/MLD	IST, INR 75,000/HH; IT, INR 5,00,00,000/MLD	IST, INR 1,500/HH/year; IT, INR 30,00,000/MLD/year
System 6A	ABR+ Sludge Drying Bed + Co-composting	Networked system	Treatment plant life, 50 years	Ward/city/cluster level	ABR, 1,000 m²/MLD	BOD, 70–95%; TSS, 80–90%; coliform, 20–30%	ABR, 34 kWh/d/MLD	ABR, INR 5,00,00,000 INR/MLD	ABR, INR 30,00,000/MLD/year
System 6B	AF+ Sludge Drying Bed + Co-composting	Networked system	Treatment plant life, 50 years	Ward/city/cluster level	-	BOD, 50–90%; TSS, 50–80%	AF, 34 kWh/d/MLD	AF, US$350 to US$500 per cu.m for a treatment capacity of 10 cu.m, if the AF is used in combination with other treatment modules (e.g., in DEWATS) [39]	-
System 7	Belt Filter Press + CW + Lime Stabilisation + chlorination	Decentralised system	ST, 50 years	Ward/city/cluster level	7 m²/HH for Storage + Toilet	-	22 kWh/d/MLD	-	-
System	System Name	Type of	System	Applicability	Land	Performance	Energy	CAPEX	OPEX

Number		System	Lifetime	of System	Availability	of the System	Requirement		
System 8	UASB+ Sludge Drying Bed + Co-composting	Networked system	>50 years	Ward/city/cluster level	UASB, 1,000 m²/MLD	BOD, 75–85%; COD, 60–80%; TSS, 75–80%; TN, 10–20%.	UASB, 34 kWh/d/MLD	UASB, INR 68,00,000 /MLD;	UASB, INR 6,00,000/MLD/year
System 9	MD + WSP + Solar Drying + Chlorination	Decentralised system	ST, 50 years; WSP, 50 years	Ward/city/cluster level	7 m²/HH for Storage + Toilet; WSP, 6,000 m²/MLD	BOD, 75–85%; COD, 74–78%; TSS, 75–80%; TN, 70–90%; TP, 30–45%; coliform, 60–99.9%	WSP, 5.7 kWh/d/MLD	IST, INR 75,000/HH; WSP, INR 23,00,000MLD	IST, INR 1,500/HH/year; WSP, INR 2,00,000/MLD/year
System 10	PDB + CW + Shallow Trenches + Chlorination	Decentralised system	ST, 50 years; trenching site, 5–10 years	Ward/city/cluster level	7 m²/HH for Storage + Toilet	-	-	IST, INR 75,000/HH	IST, INR 1,500/HH/year
System 11	Geo-bags + WSP+ Chlorination	Decentralised system	ST, 50 years; geo-bag, 6–12 months	Ward/city/cluster level	7 m²/HH for Storage + Toilet; WSP: 6,000 m²/MLD	BOD, 75–85%; COD, 74–78%; TSS, 75–80%; TN, 70–90%; TP, 30–45%; coliform, 60–99.9%	WSP, 5.7 kWh/d/MLD	IST, INR 75,000/HH; WSP, INR 23,00,000/MLD	IST, INR 1,500/HH/year; WSP, INR 2,00,000/MLD/year
System 12	ABR + CW + Sludge Drying Bed + Co-composting + Chlorination	Decentralised system	>50 years	Ward/city/cluster level	ABR, 1,000 m²/MLD	BOD, 70–95%; TSS, 80–90%; coliform, 20–30%	ABR, 34 kWh/d/MLD	IST, INR 75,000/HH; ABR, INR 5,00,00,000 /MLD;	IST, INR 1,500/HH/year; ABR, INR 30,00,000/MLD/year

TP: Twin Pit; IST: Improved Septic Tank; ST: Septic Tank; BD: Biogas Digester; UDB: Unplanted Drying Bed; PDB: Planted Drying Bed/Reed Bed; AD: Anaerobic Digester; MD: Mechanical Dewatering; IT: Imhoff Tank; ABR: Anaerobic Baffled Reactor; BFP: Belt Filter Press; WSP: Waste Stabilisation Pond; ASP: Activated Sludge Process; SBR: Sequence Batch Reactor; MBR: Membrane Bioreactor; CW: Constructed Wetland; AF: Anaerobic Filter; UASB: Upflow Anaerobic Sludge Blanket.

Part E: Benefits of Treated Sludge

After the final stage of sludge treatment, “treated sludge” would be produced. Treated sludge, which is fully stabilised sludge, can serve in different reuse options such as in combustion as fuel [48], in biochar production [49], in building materials [50] [51] and as a soil conditioner [52] [53] [54] [55]. The most common reuse option for treated sludge is as a soil conditioner and fertiliser in developing countries. Human excreta is rich in plant nutrients; the nitrogen, phosphorus and potassium contained in human excreta are suitable as fertiliser. However, treated sludge and effluent might still contain pathogens, and so it is recommended that before use of wastewater and sludge for agricultural purposes, the applied material be characterised.

Part F: Compatibility Matrix

Compatibility matrix

Compatibility matrix defines the components (Table 18) that are compatible with each other.

Example of compatibility relation: if x and y are two options of two different sub processes, then C(x,y) is defined as follows:

C(x,y) = 1, if the two options are fully compatible.

C(x,y) = 0.5, if the two options are neither fully compatible nor fully incompatible.

C(x,y) = 0, if the two options are fully incompatible.

C(x,y) = NA, if the sub-processes to which the second option belongs is not applicable to the first option.

Table 18: Components of the Sanitation Value Chain

Sanitation value chain	Components	Components code
User Interface	Pour flush toilet	U1
	Cistern flush	U2
	UDDT (Urine Diverting Dry Toilet)	U3
	Dry Toilet (composting toilet)	U4
	UDT	U5
	Community – Pour Flush	U6
	Public – pour flush	U7
	Community – Cistern	U8
	Public – Cistern	U9
Storage/Collection/Treatment	Twin pit	S1
	Septic Tank with soak pit , water tight (single/twin)	S2
	Conventional septic tank	S3
	Biogas digester	S4
	Septic Tank with soak pit – (Community and Public)	S5
	Biogas Digester – (Community and Public)	S6
	Composting Chamber+Urine Tank	S7
	VIP	S8
	Composting Chamber	S9
Emptying and Conveyance	Gulper + Trucks	E1
	Manual Diaphragm Pump + Trucks	E2
	MAPET (Manual Pit Emptying	E3

Sanitation value chain	Components	Components code
	Technology) + Trucks	
	Motorised Diaphragm Pump + Trucks	E4
	Trash Pump + Trucks	E5
	Pit Screw Auger + Trucks	E6
	Gobbler + Trucks	E7
	Small Bore	E8
	Simplified Sewerage	E9
Primary Treatment	Unplanted Drying Bed	SE1
	Planted Drying Bed/Reed Bed	SE2
	AD/UASB Reactor	SE3
	Centrifugation	SE4
	Thickening And Dewatering (Mechanical Dewatering)	SE5
	Settling And Thickening Tank	SE6
	Imhoff Tank	SE7
	Anaerobic Baffled Reactor	SE8
	Belt Filter Press	SE9
	Geobags	SE10
	Horizontal Gravel Filter	SE11
Effluent Treatment	WSP	ET1
	ASP	ET2
	SBR	ET3
	MBR	ET4
	ABR+CW	ET5
	CW	ET6
	AF	ET7
	ASP+reed bed	ET8
	UASB	ET9
	ABR	ET10
Sludge Treatment	Co-Composting	ST1
	Vermicomposting	ST2
	Deep Row Entrenchment	ST3
	Sludge Drying Bed +Co-Composting	ST4
	Lime Stabilisation	ST5
	Solar Drying	ST6
	Shallow Trenches	ST7
	Geobag	ST8
	Solar Sludge Oven	ST9
Disinfection	Chlorination – Disinfection	DI1
	Ozone – Disinfection	DI2
Disposal	Irrigation; Aquaculture; Macrophyte; Disposal/ Recharge	D1
	Sludge: Land Application; Surface Disposal	D2
	Soak Pit / Leach Field & Dispose To HH Garden	D3

Part G: Sanitech Tool

The "Sanitech tool" has been developed by the Center for Study of Science, Technology and Policy (CSTEP). This tool can be accessed at http://darpan.cstep.in/sanitation.

Objective

The objective is to develop a decision-support tool that will help cities in India to provide cost-effective and sustainable sanitation options for all, especially the urban poor, through an integrated framework for assessment of different sanitation options. It is well recognised by sanitation researchers and strategic policy makers that there is a need for portfolio approaches to sanitation. However, there is a need to build a broader framework for decision makers whose understanding of the approach can influence how sanitation investments are prioritised. There is a need to develop a broad resource base for decision makers, which will enable them to understand the sanitation needs of a city as well as provide them information about a range of sanitation system options that can serve these needs.

This platform will allow for a rational process for demonstrating the trade-offs between different stakeholders preferences and views for addressing different key questions. All urban local bodies need to have a sanitation plan, and this tool can help in this process of planning where the decision of right systems (information from different sources mentioned above has been collated) is of ultimate importance.

The Tool

In this context, the decision-support tool has been developed to facilitate an integrated approach to the sanitation investment planning process for urban local bodies in India. The tool is envisioned to provide stakeholders information and knowledge of existing and new technologies in a manner that allows them to compare options, assess cost/benefits and make informed decisions. This will also help decision makers to understand the relative value for money associated with decentralised options, and to support an enabling policy and market environment for providers of sanitation products and services. It can also be used as a capacity-building tool. The design of the tool will be generic such that it can be used for any area provided certain data are available. Field data from a city in India are being collected to demonstrate the potential of the tool. Sustainable access to sanitation would mean not only access to sanitation, but also addressing the whole value chain. The tool has a GIS-enabled user interactive interface, and allows users to create and compare scenarios; it also allows the assessment of the impact of various sanitation options. It will provide a framework for analysis, visualisation and self-learning where modification of system/technology inputs based on new information, addition of new parameters for a system, and addition/deletion/modification of systems can be done easily, enabling iterative action plans to get the best solution by comparing scenarios. It will also help facilitate collaboration and consultation with the partners, stakeholders, and decision makers within this sector. The information and research outputs of the non-government organisations and knowledge partners working in the sanitation domain can be integrated into this platform, enhancing the robustness of the tool, instead of re-inventing the work done by them.

In short, this tool will aid decision-making by sharing data; creating, storing, and sharing scenarios; comparing scenarios and identifying trade-offs; identifying avenues for improvement of models; and identifying the need for new models and more sophisticated models. The tool will be sufficiently robust to add new innovative sanitation systems for assessment as data from field studies become available.

Target Audience

The target audience for this tool could be elected officials and policymakers influencing sanitation infrastructure decisions; utilities and government agencies responsible for sanitation provision; technocrats and consultants; decision makers in Urban Local Bodies (ULBs); the Ministry of Urban Development (MoUD), the Government of India (GoI), and its technical/capacity-building departments; and also technology developers.

When to Use

SANITECH will be used at the Pre-Feasibility stage of the project cycle. It will give an idea of the different systems that are suitable to the city/ward context. The user at this point can select a range of suitable technologies (scenarios) and compare them against certain key parameters like environmental compliance, costs, resource needs, etc.

Data Needs

The data required for the city/ward or any other spatial unit are shown in Table 19 and 20.

Table 19: City/Ward/Any Spatial Unit – Population and Sanitation Data

Data Required	Non slum	Slum	Type of Unit
Population	_	_	
No. of households	_	_	Numerical Value
No. of commercial institutions	_	_	Numerical Value
% of homes having toilets and septic tank	_	_	Percentage
% of homes having toilets (but no storage/collection)	_	_	Percentage
% of homes has sewerage system	_	_	Percentage
% of homes having a decentralised system	_	_	Percentage
% of homes having no toilets	_	_	Percentage

Table 20: Constraints Data for City/Ward/Any Spatial Unit

Part of Sanitation Value Chain	Constraints	Please indicate:
User Interface	Water Availability	(High/Medium/Low)
	Land Availability	(Yes/No)
	Anal Cleansing Method	(Water/Soft Paper/Hard or Bulky)
	Water Supply	(None/ Fetched/Hand Pump/Standpipe/Tanker Connection)
Containment/Storage	Groundwater Level	(Shallow/Deep)
	Soil Type	(Clayey/ Silty/ Sandy/Rocky)
Emptying and Conveyance	(Vehicular Accessibility)	(Yes/No)
For Treatment Facility	Land Availability	(Low/Medium/High)
	Soil Type	(Clayey/ Silty/ Sandy/ Rocky)
	Groundwater Level	(Shallow/Deep)
	Flood-Prone	(Not Affected/ Frequent (Low-Lying Area)/ Not Frequent)
	Terrain/Topography/Slope	(Flat/ Slope)
Treatment Type	Mechanised/Ecological–Biological	Mechanised Ecological–Biological No Preference

Decision Flow

SANITECH has two repositories of information that are used to carry out analyses on the sanitation situation of any area. These repositories contain information on the spatial unit (city or ward or similar) and on the technologies (across the sanitation value chain). Figure 49 shows the decision flow of the tool.

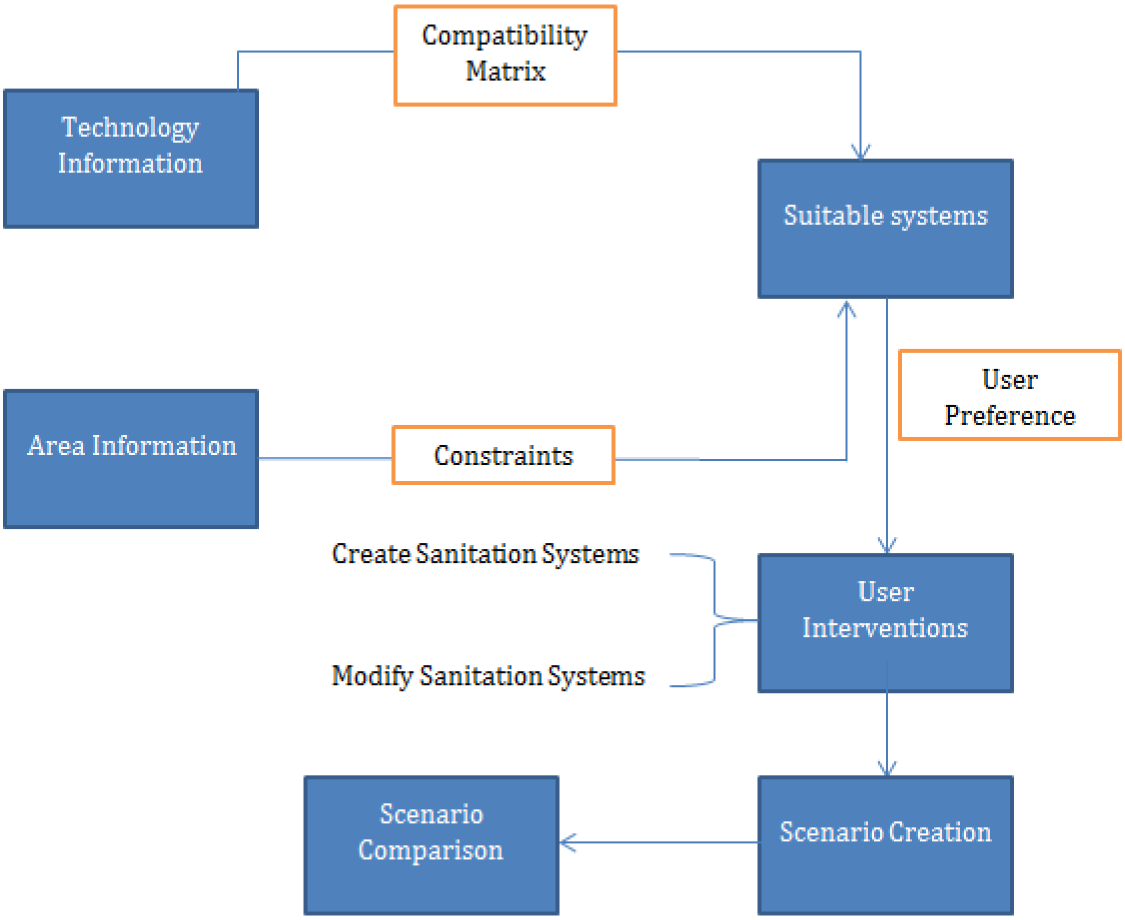

Figure 49: Decision Flow of the Tool

The compatibility matrix and constraints are crucial in determining what technologies under each component are compatible with the technologies in the subsequent component, and which technologies are compatible with the area under consideration.

What are constraints?

While considering the different sanitation options for an area, certain factors may have a limiting impact on the choices available. For example, a lack of space at a household would take away the possibility of providing individual household toilets. These factors are collectively called constraints. These are applicable at every part of the Sanitation value chain, although the exact constraint would vary from component to component.

Which constraints have been considered?

SANITECH takes into account 11 constraints, which are distributed over five components of the sanitation chain. They are as follows:

1. Constraints on User Interface:

Water Availability: A limitation in water availability would raise problems if water-intensive technologies are used (such as cistern flush toilets, which traditionally are more water-intensive than manually pouring water for flushing). Water availability is categorised into low [less than 25 lpcd (Litres per Capita per Day)], medium (25–60 lpcd) and high (more than 25 lpcd).

Land Availability: In order to build a toilet within a dwelling, a minimum about of space (3 m^2) is required. If this area is not available, the users would need to consider building public or community toilets instead.

2. Constraints on Storage:

Groundwater Level: While choosing a sanitation system, it is important to keep the groundwater level of the area in mind. Aquifers are often a source of freshwater for household use, especially drinking and bathing. It is therefore important to ensure that aquifers do not get contaminated by wastewater. The risk of contamination is higher if the aquifer is closer to the surface as any leachate from a sanitation system could flow into it. Further, storage technologies are generally underground; therefore, the distance between the bottom of the storage unit and the aquifer is lowered. The risk of groundwater contamination can be lowered by watertight storage units or lining them with impermeable material. Here, the distance to the groundwater is measured from the surface. Deep groundwater would be 5 m or more below the ground surface (bgs), whereas shallow groundwater would be less than 5 m bgs.

Soil Type: The performance and suitability of onsite systems and storage components depends heavily on the local geography. Like groundwater, the type of soil is an important factor as it will influence the soil permeability – a feature of soil that is often used in the design of sanitation technologies. Soak pits, for example, perform best in soil with good absorptive properties, and, thus, clayey soil would not be the ideal choice. SANITECH allows users to choose the soil type in a region (silty, sandy, and clayey). In case of mixed soil, users should choose the predominant soil type.

3. Constraints on Emptying and Conveyance:

Vehicular Accessibility: Most onsite and decentralised systems require removal or movement of FS that is collected by some form of storage technology. For this purpose, vehicles (big or small trucks) need to be able to move across the spatial unit. Users can choose whether the area under consideration can be accessed by FS transport vehicles. The possible conveyance options will be highlighted accordingly.

Slope: In case of a sewerage network, the presence of a natural gradient will allow the wastewater to flow simply by the force of gravity. If the surface is flat, then additional digging work and/or pipes adapted to flat areas might be needed. In the constraints, "high" denotes slopes greater than 1% (1m/100m) and "low" denotes slopes less than 1%.

Soil Type: A rocky layer near the surface would make it difficult to lay pipes for a sewerage network. For this constraint, users can define the spatial unit as either "rocky" or "not rocky".

4. Constraints on Treatment:

Groundwater Level: Similar to the constraint for storage.

Energy Availability: This constraint relates the energy intensiveness of the technologies to the availability of energy in the spatial unit. Some technologies (membrane bioreactor), especially the highly mechanised ones, will be highly dependent on a constant source of energy for operation, whereas others will have little to no dependence on energy.

Land Availability: This constraint relates the land-use intensiveness of the technologies to the availability of land in the spatial unit. Many technologies require a large area to perform effectively. In regions where space available is limited, it will be difficult (and expensive) to implement such technologies.

Technical Skill Availability: Depending on the type of technology, the skill level needed will differ. Technical skill availability is associated to the depth of technical knowledge required for the operation of any technology. Generally, the required know-how is initially more available for "Old" techniques like composting or drying, which are easy to understand. For energy-intensive technology, the maintenance–repair, especially, will be more challenging.

What should be kept in mind while using constraints?

It is important to remember that many technologies can be improved in order to overcome the limitations set by the constraints. The tool, however, assumes that the technologies being used are not improved and/or adapted to local needs. If users feel that a pre-existing constraint for the spatial unit can be overcome, then they can change the constraints through the list available on the left-hand side of the tool. Any additional expense that may occur due to the improvement of the technology design will not be taken into account by the tool.

ANNEXURE-I

Compatibility Matrix of User Interface to Storage

	S1	S2	S3	S4	S5	S6	S7	S8	S9
U1	1	1	1	1	1	1	0	0	0
U2	1	1	1	1	1	1	0	0	0
U3	0	0	0	0	0	0	1	0	0
U4	0	0	0	0	0	0	0	1	1
U5	0	0.5	0.5	0.5	0	0	1	0	0
U6	0	0	0	0	1	1	0	0	0
U7	0	0	0	0	1	1	0	0	0
U8	0	0	0	0	1	1	0	0	0
U9	0	0	0	0	1	1	0	0	0

Compatibility Matrix of Storage to Emptying and Conveyance

	E1	E2	E3	E4	E5	E6	E7	E8	E9
S1	1	1	1	1	1	1	1	0	0
S2	1	1	1	1	1	1	1	1	0
S3	1	1	1	1	1	1	1	1	0
S4	1	1	1	1	1	1	1	1	0
S5	1	1	1	1	1	1	1	1	0
S6	1	1	1	1	1	1	1	1	0
S7	1	1	1	1	1	1	1	1	0
S8	1	1	1	1	1	1	1	0	0
S9	1	1	1	1	1	1	1	0	0

Compatibility Matrix of Emptying and Conveyance to Primary Treatment

	SE1	SE2	SE3	SE4	SE5	SE6	SE7	SE8	SE9	SE10	SE11
E1	1	1	1	1	1	1	1	1	1	1	1
E2	1	1	1	1	1	1	1	1	1	1	1
E3	1	1	1	1	1	1	1	1	1	1	1
E4	1	1	1	1	1	1	1	1	1	1	1
E5	1	1	1	1	1	1	1	1	1	1	1

E6	1	1	1	1	1	1	1	1	1	1	1
E7	1	1	1	1	1	1	1	1	1	1	1
E8	0	0	0	0	0	0	0	0	0	0	0
E9	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

Compatibility Matrix of Primary Treatment (Sludge Effluent Separation) to Effluent Treatment

	ET1	ET2	ET3	ET4	ET5	ET6	ET7	ET8	ET9	ET10
SE1	1	1	1	1	1	1	1	1	1	1
SE2	1	1	1	1	1	1	1	1	1	1
SE3	0	0	0	0	0	0	0	0	0	0
SE4	1	1	1	1	1	1	1	1	1	1
SE5	1	1	1	1	1	1	1	1	1	1
SE6	1	1	1	1	1	1	1	1	1	1
SE7	1	1	1	1	1	1	1	1	1	1
SE8	1	1	1	1	1	1	1	1	1	1
SE9	1	1	1	1	1	1	1	1	1	1
SE10	1	1	1	1	1	1	1	1	1	1

Compatibility Matrix of Primary treatment (Sludge Effluent Separation) to Sludge Treatment

	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9
SE1	1	1	1	1	1	1	1	1	1
SE2	1	1	1	1	1	1	1	1	1
SE3	1	1	1	1	1	1	1	1	1
SE4	1	1	1	1	1	1	1	1	1
SE5	1	1	1	1	1	1	1	1	1
SE6	1	1	1	1	1	1	1	1	1
SE7	1	1	1	1	1	1	1	1	1
SE8	1	1	1	1	1	1	1	1	1
SE9	1	1	1	1	1	1	1	1	1
SE10	1	1	1	1	1	1	1	1	1

Compatibility Matrix of Effluent Treatment to Disinfection

	DI1	DI1
ET1	1	1
ET2	1	1

ET3	1	1
ET4	1	1
ET5	1	1
ET6	1	1
ET7	1	1
ET8	1	1
ET9	1	1
ET10	1	1

Compatibility Matrix of Effluent Disinfection to Disposal

	D1	D2	D3
DI1	1	0	0
DI2	1	0	0

Compatibility Matrix of Sludge Treatment to Disposal

	D1	D2	D3
ST1	0	1	0
ST2	0	1	0
ST3	0	1	0
ST4	0	1	0
ST5	0	1	0
ST6	0	1	0
ST7	0	1	0
ST8	0	1	0
ST9	0	1	0

If an Onsite System: Compatibility Matrix of Emptying and Conveyance to Disposal

	D1	D2	D3
E1	0	0.5	0
E2	0	0.5	0
E3	0	1	0
E4	0	0.5	0
E5	0	0.5	0
E6	0	1	0
E7	0	1	0
E8	N.A.	N.A.	N.A.

E9	N.A.	N.A.	N.A.

If a Networked System: Compatibility Matrix of User Interface to Emptying and Conveyance

	E1	E2	E3	E4	E5	E6	E7	E8	E9
U1	0	0	0	0	0	0	0	0	1
U2	0	0	0	0	0	0	0	0	1
U3	NA	NA	NA	NA	NA	NA	NA	NA	NA
U4	NA	NA	NA	NA	NA	NA	NA	NA	NA
U5	NA	NA	NA	NA	NA	NA	NA	NA	NA
U6	0	0	0	0	0	0	0	0	1
U7	0	0	0	0	0	0	0	0	1
U8	0	0	0	0	0	0	0	0	1
U9	0	0	0	0	0	0	0	0	1

If a Networked System: Compatibility Matrix of Emptying and Conveyance to Effluent Treatment

	ET1	ET2	ET3	ET4	ET5	ET6	ET7	ET8	ET9	ET10
E1	0	0	0	0	0	0	0	0	0	0
E2	0	0	0	0	0	0	0	0	0	0
E3	0	0	0	0	0	0	0	0	0	0
E4	0	0	0	0	0	0	0	0	0	0
E5	0	0	0	0	0	0	0	0	0	0
E6	0	0	0	0	0	0	0	0	0	0
E7	0	0	0	0	0	0	0	0	0	0
E8	0	0	0	0	0	0	0	0	0	0
E9	0	0	0	0	0	0	1	1	1	1

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