EFFECTIVE SEPTIC MANAGEMENT FOR CONDOMINIUMS AND APARTMENTS IN SRI LANKA

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Degree of Master of Science

Department of Mechanical Engineering

University of Moratuwa
Sri Lanka

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Thesis submitted in partial fulfilment of the requirements for the degree Master of Science in Building Services Engineering

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DECLARATION

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Dr. Inoka Manthilake	**Department of Mechanical Engineering, University of Moratuwa**	

Date:

ABSTRACT

Sri Lanka is a developing country, where wastewater and septic disposal are not managed at its optimum level. 76% percent of the households equip with their own water sealed latrines for sanitation facilities and discharged septic mixture is collected to a septic tank. Periodical septic removal from the household storages are required at a cost. Limited space availability in urban dwellings, apartments and condominiums caused practical issues to the current practice of the septate removal. Management of variated amounts of septate is a challenging function because the capacities of the offsite treatment plants are inadequate in highly populated urban areas, effectiveness of the treatment facilities is not consistent due to lack of technical knowledge and improper maintenance. Poor handling of human waste is caused by contamination of faecal sludge in water reservoirs, disposal of human excreta and urine without converting them into usable or commercialized end products and huge burden to municipalities to handle septic in terms of economical and practical. Currently effective human waste management becomes a national level discussion. It is planned to conduct national level survey and review the techniques and technological status locally, regionally and globally and make recommendations for practical technology transfer. Other than that enhance the quality of the composting can be obtained from the human excreta to a fertilizer through nutrient addition and facilitate the adoption of new composting technologies to enhance the yield and quality and implement household and institutional level conversion of septic into compost are key concerns.

As per the world health organization prevention of spreading of water borne diseases such as typhoid or cholera is difficult due to the faecal contamination of drinking water sources. More than two million of child deaths annually occur due to the pneumonia and diarrhoea globally. Most of the children living in poor or remote communities are facing this risk and to the facts that preventable diseases are not mitigated by effective interventions which are not provided equally to all communities.

Managing human septic from domestic and commercial sources and urban run-off is largely a matter of proper treatment and disposal. In Sri Lanka 97% of the community is relying on water sealed latrines and septic tanks for sanitation while about 3% use sewerage connection. Large part of the country does not have treatment plants to disposal of faecal sludge safely. Further treatment processes to sanitized night soil is required before disposal or delivering as a fertilizer. Local authorities are simply collecting the content in the septic tanks and dump it into the available treatment plants where poor end product management. Current situation with septic disposal is grown adversely with the increasing the number of multi-storey buildings in the urban areas due to 90% of urban dwellers equip with onsite sanitation systems with water sealed latrines directed to the septic collection tanks or cesspits.

This thesis conducted to find out ancient and latest techniques and technologies of septic management applicable to current practice in the Sri Lankan context. Data were collected from three distinct multi-storey buildings located within the Colombo municipal council and analysed the discharged volumes of the septic and way of disposal. Possibility of adaptation or implementation of ancient and latest technologies are discussed extensively based on the results on the results of the analysis.

Properly treated faecal sludge with organic fractions of municipal solid waste has higher possibility to be used as an agricultural resource for farmers in the country. Currently use of faecal sludge as fertilizers and possibility of replacing the mineral fertilizers are not popular in Sri Lanka. Sustainable and appealing solutions are required to dispose human waste with the increasing population country. Research works and experiments in the relevant areas are required to extend and develop further to ensure the sustainable management of faecal sludge.

ACKNOWLADGEMENT

Most importantly I would like to express our deepest gratitude for the Faculty of Engineering of University of Moratuwa offering a Research project for M.Sc. in Building Services Engineering postgraduates in giving me the opportunity to improve knowledge and skills in performing Research projects. I would also like to convey my gratitude to my supervisor, Dr. Inoka Manthilake and all staff members of Department of Mechanical Engineering for enabling me to complete the research.

C. M. Samarakoon

Thank You,

Department of Mechanical Engineering,

University of Moratuwa.

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1. INTRODUCTION

This chapter gives an introduction of the research, which includes the background, motivation for carrying out the project, aim and objectives, a brief methodology and expected contribution to knowledge.

1.1 Background

Human generated waste management has led to serious environmental issues with the increasing population. Food waste and human faces are the main wastes to be discharged daily. Amount of human faces produced daily is greatly varied with the diet composition and quantity. Generally, it is averaging between 350 to 400 g wet weights per person [1]. Based on that it clearly states that over one billion wet tonnes of food waste and human faces are produced per year worldwide and this production levels are increased gradually [1]. Population of Sri Lanka is about 21.9 million and 18.4% of it is in Urban areas [2]. The sustainable management of human generated waste is turning into a severe issue with the growth population and an environmentally friendly sustainable economically viable solution is required urgently.

Currently, most of the black water collected in developing countries are directly discharged into the water reservoirs or open lands [3]. This creates adverse environmental impacts because when untreated waste is directly discharged into the environment there are considerable negative health effects for both human and wildlife [4]. It is required to enhance current technologies and management to ensure the proper treatment and disposal. Application or introduction of most sophisticated and advanced technologies can be unsuccessful because of factors such as extreme environmental conditions or lack of user ability to manage the system thus robust and cheap options are preferred [5].

Cost effectiveness and proven benefits in uncomplicated technological solutions for composting of black water are causing such solutions attractive for rural areas [6]. Various black water treatment and composting techniques have been introduced and developed in recent years namely improved composting toilets, black water solid composting in source separation systems with vacuum toilets, combined thermophilic composting with lactic acid fermentation in dry toilets and vermicomposting toilets [3]. However, those techniques have pros and cons in various aspects such as toxicity, infections, loss of nutrients and maintenance requirements [7].

Septage management in Sri Lanka requires development to a further extent from the present conditions. In rural municipalities the collected faecal sludge is disposed without prior treatment, recycling or converting into fertilizer [8]. Capacities of the existing septate treatment plants are not adequate to manage the collected septate volumes daily in urban areas. At present the sanitation system's agricultural resources are contaminated from human excreta due to disposing. The aquatic environment is also caused to contaminate from the groundwater with human pathogenic organisms [9]. Open cycles of disposal could be considered as a one potential reason for soil degradation and loss of soil fertility since long term cropping in subjected areas are not able to continue due to loss of essential plant nutrients [10]. Declining water and nutrient retention capacity and lowering the yields are further adverse effects.

1.2 Human Waste Management Problems of Sri Lanka

Over 90% of buildings in Sri Lanka consist onsite sanitation systems such as water sealed latrines. Offsite sanitation systems are not widely used in the country due to lack of knowledge and low governmental involvement. Disposal of accumulations on latrines are majorly released into the environment without proper treatment which initiate and spread adverse health effects on humans, animals and plants.

Co-composting of faecal sludge and municipal solid waste could be a feasible option with low cost techniques to enhancing the sanitation and waste disposal in low income countries [11]. This is commonly applicable in rural areas where faecal sludge is kept onsite and adequate treatment of faecal sludge is lacking [12]. Higher nitrogen content in the human waste may add value as a possible usage as a fertilizer.

1.3 Aim

To make recommendations and develop guidelines for an effective septate management system for condominiums and apartments.

1.4 Objectives

- To obtain knowledge on state of the art of human waste disposal techniques
- To explore the context of the Sri Lankan human waste problem
- To identify areas of improvement in handling, disposal and decomposing process
- To identify potential technologies applicable for Sri Lanka
- To evaluate different options for achieving most suitable solutions, prepare recommendations and develop guidelines for effective septate management systems in buildings.

1.5 Methodology

- Firstly, a literature survey was performed to identify different techniques and technologies used to manage the human waste (Septage) around the world. While understanding the state of art of human waste disposal, anciently used and recently developed human waste disposal techniques were studied. Separation of Urine and faeces were used in ancient Sri Lankan lavatories since it was helpful to less harmful disposal of remaining to the environment. Various techniques of human waste management can be used to convert the faecal and urine into usable outcomes.
- The current techniques of human waste collection, treatment and disposal in Sri Lankan was understood. Also, the impact of existing human waste dumping was clarified. It was seen that above 90% of human waste is collected by water sealed latrines and directed to the onsite septic collection tank for treatment or connected to the sewer network which is only available in the Colombo MC and Kandy MC.
- Identification of areas of improvement in handling and disposal process of septate is carried out by closely examining the present procedures in the municipalities of Sri Lanka. Case studies are carried by selecting a municipality and 3 buildings with nature of apartment complexes and offices, then collect data by means of structured questionnaires on quantity of production, method of disposal, the technologies used for conversion, available data on the environmental impacts due to disposal of human waste or remains of treated septic into environment.

- Analysis of the collected data by questionnaires to identify potential areas of improvements. Among potential technologies of human waste management discussed extensively in the literature survey and filtered they based on the possibility of applying in the Sri Lankan context.
- Combination of existing techniques with the new improvements is considered to evaluate different options for achieving most optimised solutions. Then set of recommendations and future research for developing guidelines on effective human waste management systems in buildings.

2. LITERATURE REVIEW

The second chapter consists of the literature review of relevant fields. This includes a review on ancient septic management systems, new concepts and new technologies implemented on septic management around the word. Further, latest technologies used for designing, modelling, and testing of these systems prior to implementation along with opportunities for reducing water usage are also reviewed.

2.1 Worldwide Ancient Septage Management Systems

There were different techniques used around the world subjecting to design changes over time based on the geographical and climate conditions, disposal handling, water consumption and social attitudes to private and communal latrines. Such examples were found from ancient archaeological sites such as ancient Mesopotamia, Minoan Civilization, Japanese and Chinese.

2.1.1 Ancient Systems in Sri Lanka

Evidence for such systems can be found in the ruins of ancient lavatory systems of Anuradhapura, Sigiriya and Polonnaruwa in Sri Lanka. There was onsite treatment facility for disposed urines by letting them to pass through series bottomless clay pots were equipped with sand, lime and charcoal ensuring purified dispose to the earth. Urine, septate and water separately collected into three pits in the "Baddhasima Prasada" at Polonnaruwa exhibits attention paid on handling of human waste after discharge.

The ancient Buddhist monasteries appear to have paid high concern to sanitation systems [13]. The remains of the urinals and lavatories provide best evidence by equipped with cesspits, underground clay pots, wash stones with footsteps and curtain stones.

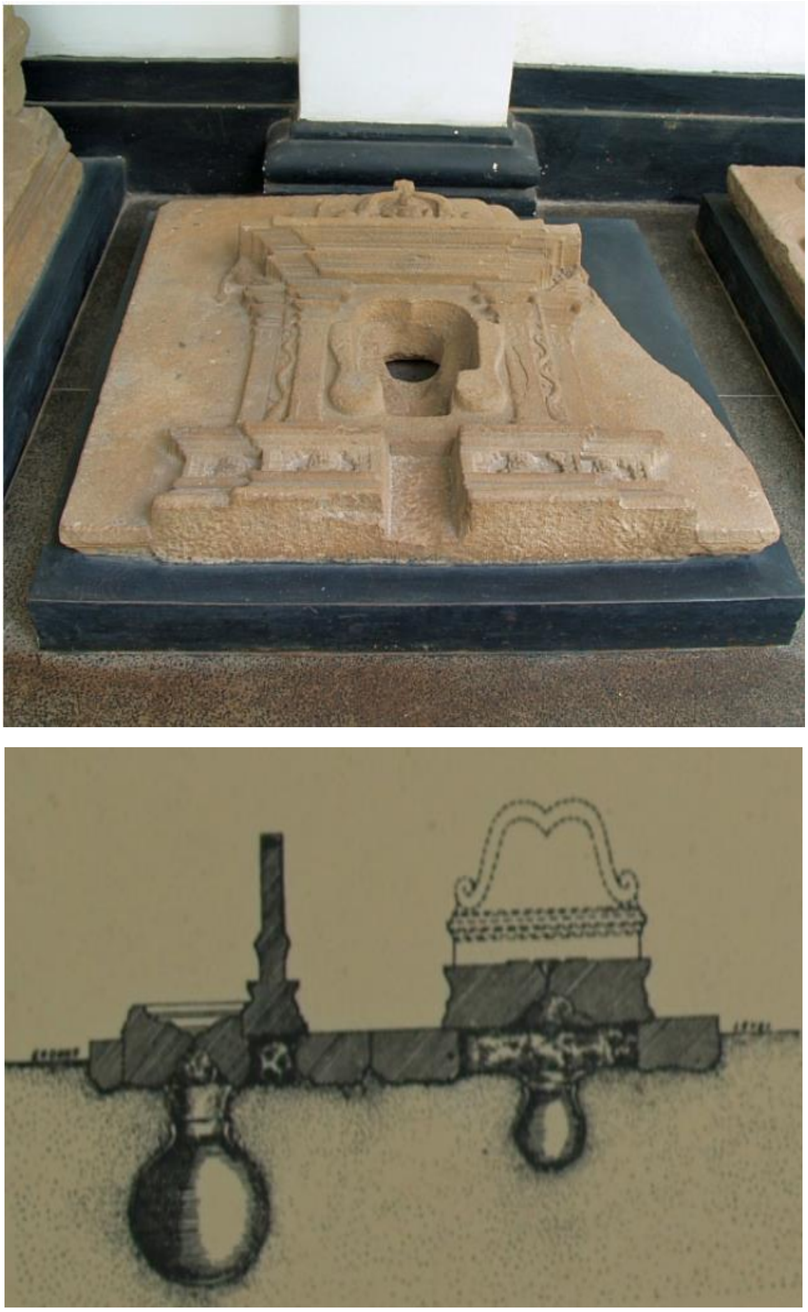


Figure 1: Ancient Lavatory Slab from Anuradhapura [14]

The techniques of the construction of toilets and lavatories have developed in certain stages as per the remaining in the ancient cities of Anuradhapura, Sigiriya and Polonnaruwa [13]. Evidence for the most developed stage in this process identifies in the present remaining of constructions of the “Abhayagiri” complex located in Anuradhapura and at the “Baddasima passada” and the hospital complex of “Alaahana Pirivena” in Polonnaruwa [13] [14]. Safe distance was maintained between the toilets and residence of the monks during the construction at Abhayagiri. However, construction of the "Baddhasima passada" and the Alahana Pirivena hospital complex had closure distance to the residential quarters provided for monks. Extra toilets with ring shapely arranged well pits were constructed in the periphery of the hospital for the staff and visitors.

Monasteries' liquid discharging into urinals has been directed into pits with use of terracotta pipes. In the remaining urinary pits at "Abhayagiri", there is arrangement of large bottomless pots made of clay of decreasing size have been positioned one above the other. As per the past data these pots were filled with sand, lime and charcoal to filter urine when pass through down to the earth in a purified condition. Seven pots were common in certain pits and number of pots had been reduced in other locations. Cement clay was used to vertically fix the pots together [14].

Septic water and urine have been separated in the toilets of "Baddhsima Praasada" at Polonnaruwa by separate terracotta pipes arrangement into urine collection pit while excreta were diverted to different septic pit [13]. Unfortunately this practice of separating in ancient time is not employed today and in contrast to these ancient systems, where the waste is allowed to decompose at the premises of its source, the methods practiced today are explained in the next section.

Lavatory slabs mostly found in the remaining of the Buddhist temples in ancient buildings of Anuradhapura. Ancient Sri Lankans had developed sanitary facilities accordingly to the remaining of used systems.

An interesting location of Biso Pokuna or Princess pond situated at Galebadda village between Moneragala and Siyabalanduwa road has Archaeological remains of the foundation of a building was also noticed on the side of the pond together with an interesting archaeological remains of an attractively carved toilet. The pond has been used by a local princess in 12^{th} century A.D. It is made from solid rock and has 4 water inlets shaped as dragon mouths. These inlets are presumed to be fed by a system of tunnels. The remaining of urinals and lavatories at Colombo Museum also provide evidence of sanitary and health care facilities that time with cesspits, underground clay pots, wash stones with footsteps and curtain stones.

Figure 2: Remaining of Urinals and Lavatories at Colombo Museum [14]

2.1.2 Ancient Septic Management Systems in Other Countries

Accordingly, to the examples and remaining found in the other countries in ancient times, there is clear evidence on reuse of treated/converted human waste without direct disposal into the earth soil. There were sewers found with similar functionality to the modern sewers system with extending to 12 – 15 m depth via pipes. Cesspool lavatories found in the Egypt is a great example to reuse of human excreta as fertilizer. Chinese were used human excreta to feed into pigs and fertilizer.

Water consumption in ancient lavatories paid much attention. Toilet flushing were combined with collected rainwater in Mesopotamia. Japanese example found which uses continuous flow of water for flushing and separation of human excreta from water for the reuse.

Different kind of facilities were use in different time periods, how designs were changed with time, common aspects of sanitation facilities and different social attitudes to use private and communal latrine are discussed in this section.

It is observed that there is first evidence of use of flushing lavatories attached to a high degree of complexity design sewage system were found in the ancient habitations of Harappa and Mohenjo Daro in Indus Valley belongs to period of mid-3rd millennium BC [15] [16]. House units of Harappa, Mohenjo – Daro and Lothal was facilitated with a private bath toilet space connected to drainage system to carry dirty water to a larger drain that connected to public sewage and drainage system [15]. Same types of technologies were used in Minoan Crete and other Greek island during the same time period [17].

There were cesspool lavatories constructed in interiors in wealthy community houses, temples and exteriors in other dwellings in ancient Egypt. Excavations in Egypt lavatories found that underneath has a wooden or stone slab seat with a main hole to a cesspool, that was filled with sand or released into nearby fields in intervals of every few days to use human waste as fertilizer [15]. The remaining at the temple of King Suhura at Abusir provide evidence of stone basins attached to the walls were common niches used as lavatories. Beaten copper pipes used to emptying of waste.

Ancient Mesopotamia

Human waste management in ancient Mesopotamia was done in two ways. Direct disposal into the open ground or cesspits and by move it far from the place it was generated with use of canals or pipes. There is enough evidence to prove that ancient Mesopotamians used the technology and capable to construct sewerage pipes to transport the waste from the buildings. Figure 3 below shows the pipes from backed clay used to take the waste outside of city walls from large sewage collectors.

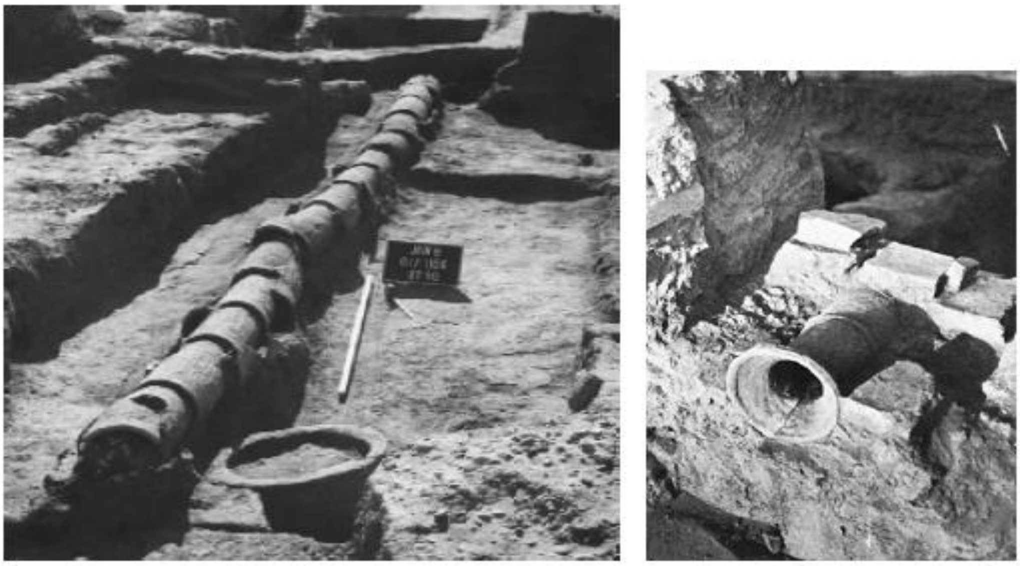


Figure 3: Pipes from Baked Clay [15]

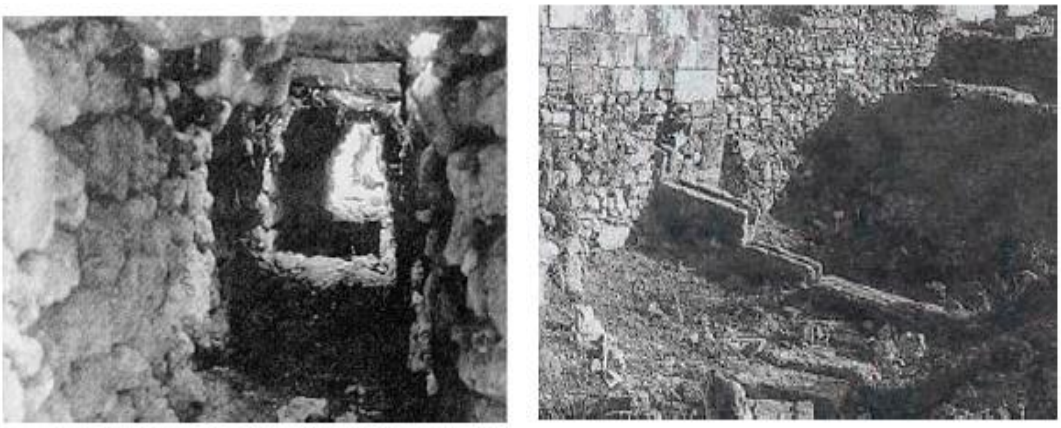


Figure 4: Underground sewer system - Interior b) Canals build through the walls of buildings constructed to discharge wastewater [15]

Hence, disposal of sewage could be managed by three different ways of directly discharge to the gutter or canalization of street, with aid of the pits built in the city if the house is situated closure to the pit, sprightly move out of the city by means of canalizations for the houses being next to the city walls. Those canals were regularly spaced along the ramparts [15] [18].

Latterly, Margueron has argued the idea of having of large scale sewage collectors in ancient Mesopotamian cities [15] [19]. Margueron declares that flow of solid waste needs conduit slopes and water discharges are larger than existence in Mesopotamia. Net of water conduits expose in Mesopotamian cities were used separate collection of wastewaters. Hence, solid waste was managed by cesspits that have been found greater extent across Mesopotamia. Collected rainwater and discharges of wastewater were not allowed to mix and they were transported in distinct conduits other than in cities where wastewater was discharged to permeable streets. In buildings with multiple stories, rainwater collected in the terrace was directed with pipes or canalizations to the water well and discharged wastewater was collected from the upper stories to the cesspit. Figure 5 below shows a simple sketch of these parallel canalization build in multi-story building in Ugarit.

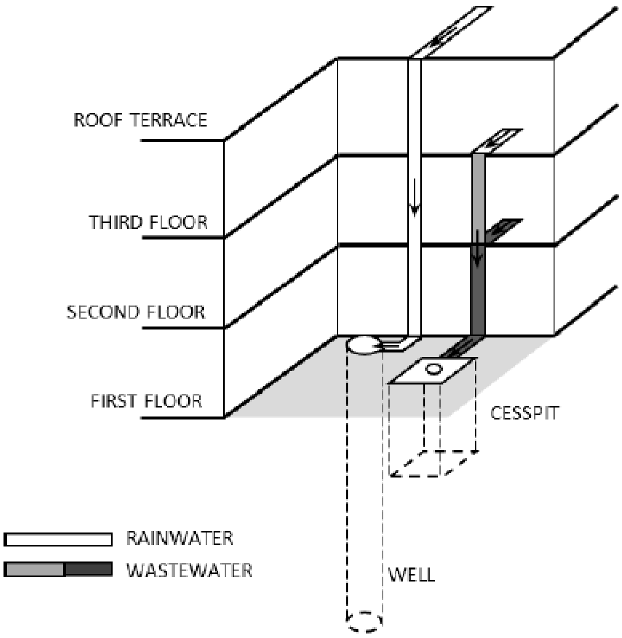


Figure 5: Parallel Canalization of Multi-Story Building [15]

Arrangement of the black water pits found during the excavation, arranged with pipes made of baked clay in the shape of a cylinder. Arrangement of pipes were heaped on top of each other, end with a bell-shaped design on the top that attaches to the toilet. The pipes have small hole for drainage and the permeability of the surrounding soil was improved by the ceramics, which frequently broke. The pipe sections were approximately 60 cm long and 48 cm in diameter with very thin walls as shown in Figure 6. Depth of pipes reached to about 12 to 15 m until they reach into the desert sand and served every purpose of modern sewer [20].

Figure 6: Clay Backed Pipes [15]

Two types of toilets were found in ancient Mesopotamia. A squat toilet and the seated toilet. There were different formations for the disposal of waste. The squat type had built a deep pit out of cylindrical ceramic clay pots. The other method of disposal method was outward sloping drain from the building.

Figure 7: Squat Type Toilet and Seat Type Toilet [15]

Figure 7 above shows a toilet from the palace of Mari. These toilets have an orifice at the floor, linked to a conduit, canal or towards to the cesspit. Impermeable white bitumen was applied to the base of the toilet and room floor. Wastes are directed to the cesspit that's normally positioned beneath the evacuation orifice and short length pipe connection with steep slope was there when the pit orientation is not located directly under the toilet.

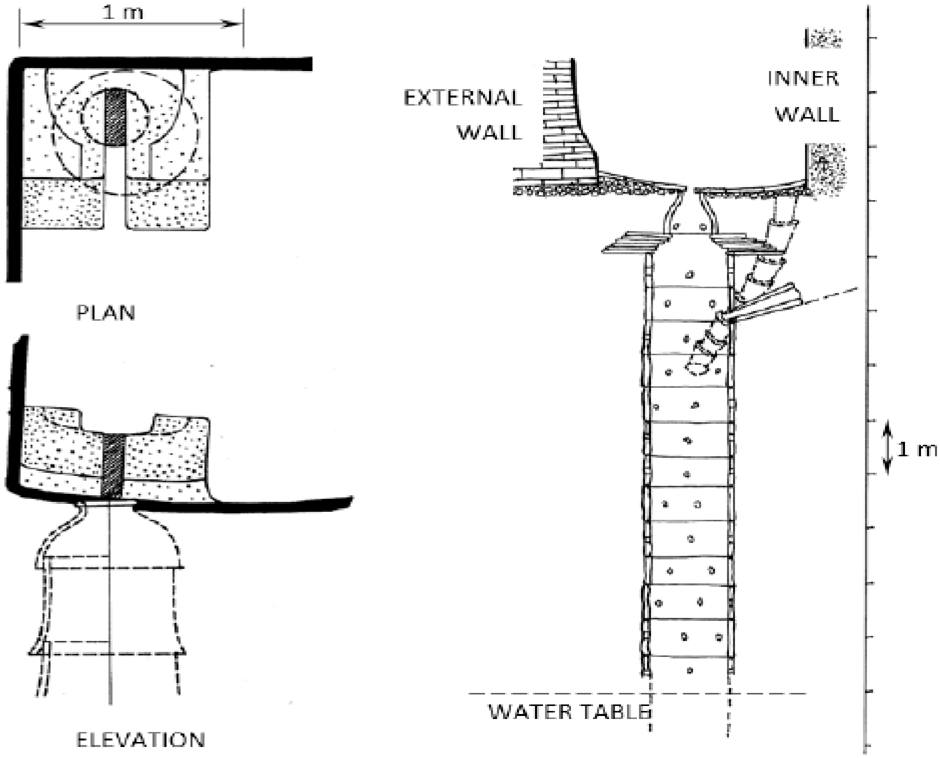


Figure 8: Cesspits Used for Disposal of Wastewater [15]

The Minoan Civilization (3200 – 1100 B.C.)

The Minoan civilization thrived mostly on the island of Crete, Greece. The plumbing and drainage systems of the Minoans were extremely advanced [21]. Aside from that, the Minoans had a sophisticated waste management scheme. The dispose of organic wastes, they used sophisticated plumbing and strategically placed sites. Figure 8 depicts a well-planned system of stone drains for sewage and storm water. There were huge stone sewers, some of which were large enough for people to pass through [22].

Figure 9: Remains of Minoan Engineering [15]

In Minoan Crete, public toilets were uncommon: instead, the lavatory was located in the private living rooms of many homes. The presence of a sewer at the floor level breaching the exterior wall and communicating with the outside central sewerage and drainage system was evidence for the existence of a toilet in most places. Moreover, traces of some kind of provision for a stone or wooden seat were discovered in some houses. [23].

The toilet located in the residential quarter of Minos Knossos Palace may be the world's first flush toilet. Roof top reservoir of rainy water collection was used as the water source. However, system was designed with ability to flush during the rainless summer by means of user or external attendant. Figure 10 depicts the flushed style toilet's configuration. The toilet's seat is made of wood.

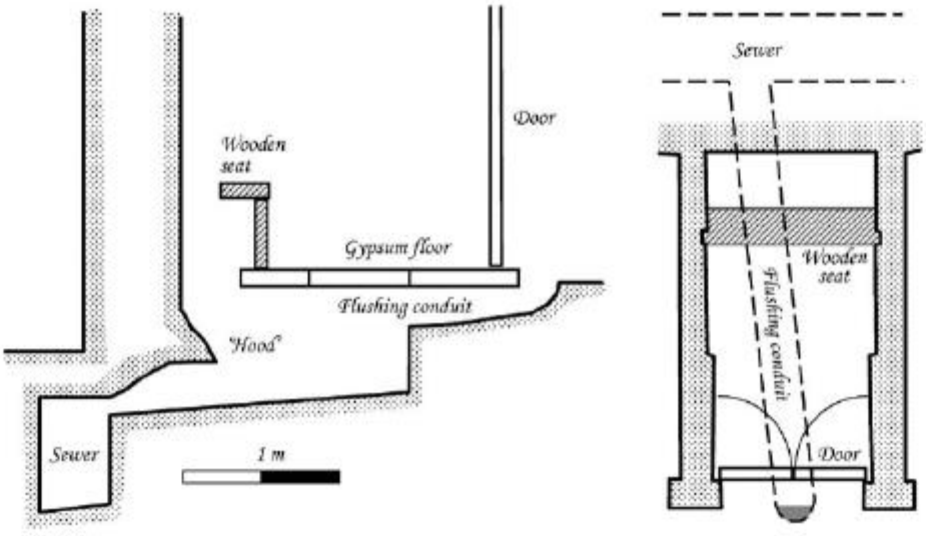


Figure 10: Flush Type Toilet Arrangement in Palace of Minos Knossos [15]

Drains in Minos are flushed by rainfall that falls into the light wells at most times of the year. In general, however, water was needed to be poured into the toilets for flushing.

Civilization of the Indus Valley (ca. 3200-1900 B.C.)

The Indus valley civilization is a great example of well-planned cities, well paved streets, separate quarters, and an efficient and successful drainage system with ventilation and toilets. Mohenjo – Daro was one of the Indus Valley's cultural capitals. Every resident of this urban area had their own bathroom, complete with lavatory, and was connected to the sewerage and drainage system [24]. Bathrooms, lavatories, and the sewage and drainage system are the three primary components of a domestic wastewater treatment system. The public toilet system used in many countries had long history and most of them managed by the municipalities. However, most of them were disgust with minor maintenance and lack of basic facilities [15].

The third millennium of BC was known as the Cleanliness age. In various parts of the world, including Mahenjo-Daro, various types of toilets and sewer systems were developed. Some of the most advanced lavatories were built into the outer walls of houses in 2800 BC. There were primitive toilets in the Western style, made of bricks with wooden seats on top. They had vertical chutes, which enabled waste to fall into street drains or cesspits [15].

The only people who use the toilets in Mohenjo – Daro were the rich. The rest of the group squatted over old pots buried in the ground or utilized open pots as seen in Figure 11.

Figure 11: Public, Open, and Household Toilet in Indus Valley [15]

Early Chinese Dynasties (Approximately 770 BC – 220AD)

According to the earliest record available, toilet construction began during the Warring States period (475-221BC). To ensure privacy, toilets were constructed with high walls at the time. Toilet construction was very common during the Han dynasty (ca. 202 BC-220 AD). Building toilets other than pigsties was more common at that time. It is most likely due to the use of human dross as pig feed or the mixing of human and pig ordure as a fertilizer [15].

Figure 12: Pigsty Toilet Model [15]

Examples from Japanese

There were variety of lavatories used in the past. Squat type toilet is the more popular in past Japan and it is the simplest formation found. There was a pit underneath to collect human faeces. With a combination of easy and joined technological solutions, continuous flow is used as a flushing system. The toilet with continuous flow found at Heijo-Kyo as shows in the Figure 14 how a water duct bypass is used to provide the required flushing. After that, the waste was directed into the main duct. This arrangement was a form of method for re use wastewater flow for toilet flushing.

As a result of the current examples, the Japanese toilets had either minimal or adequate privacy.

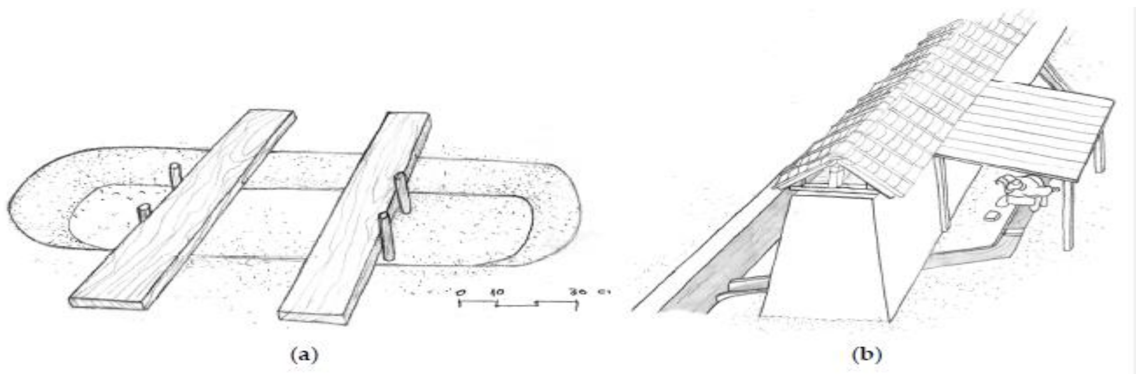


Figure 13: (a.) Squat Type Toilet (b.) Open Air Toilet [15]

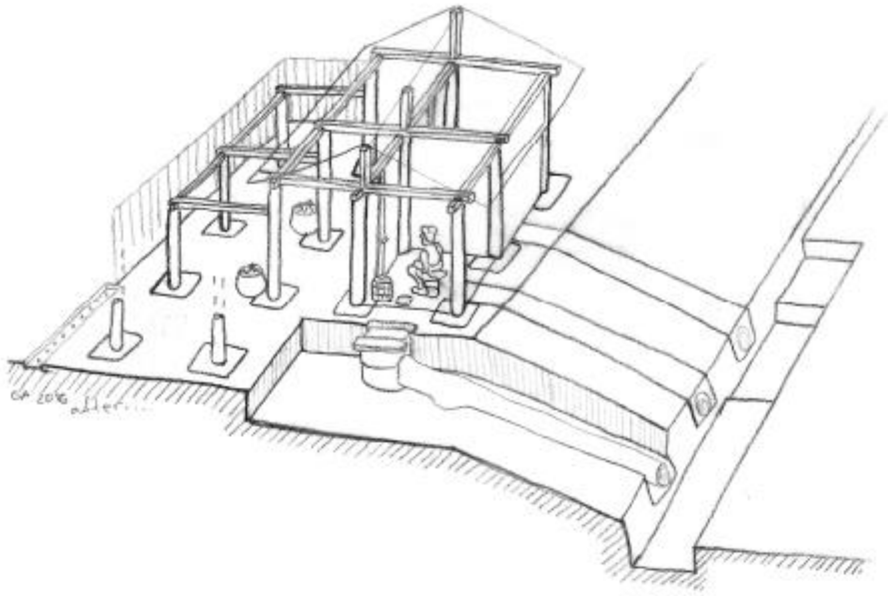


Figure 14: (c) Toilet Complex at Akila Castle [15]

2.2 Recent Septic Management Technologies

According to 2015 figures, one-third of the world's population (2.4 billion) still uses unimproved sanitation systems, including 946 million of people who use open defecation [25]. About 2 billion people use toilets that are attached to septic tanks and are unable to safely empty or discharge raw waste into open water bodies or drains. Today, over 880 million people live in slum-like conditions, with about half of those living in rural areas without access to sanitation. Increased disease incidence and contamination of the environment are linked to poor sanitation around the world. [26] [27]. This section of the report discusses about how latest technologies and improvements of existing toilet and septate treatment systems around the world.

2.2.1 Six Different Harmless Lavatory Systems

"Toilet Revolution" became hot word in the China in 2015 with aim of improve sanitation, hygiene and attach diseases [25] [28]. Under this china has used sixed different harmless sanitary toilets with goal of reach to 85% popularizing rate of sanitary toilets by 2020 and 100% by 2030 [29] [30]. The scenarios of six separate safe sanitary toilets are discussed in below.

Type 1 - Three Septic Tank type

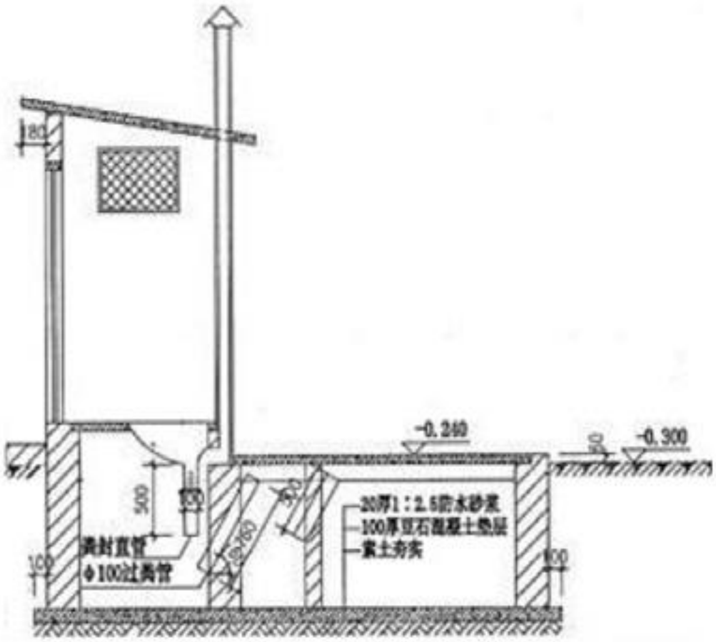


Figure 15: Three Septic Tank Type [25]

Three septic tanks are used in this setup, and wastewater is pumped out one by one. The first chamber serves as a settler, while the second serves as a post settler and scum separator, and the third serves as a storage tank. The size of the storage tank is determined by the sessional reuse pattern or the emptying services capability Suitable to use in rural areas with availability of vacuum trucks and the centralized treating is available.

Type 2 - Double Vault Funnel Type

This system applicable in areas with short of rainfall. Ceramic, cements or composite are used to prefabricated vault. It is essential to compost liquid before using it as a fertilizer or for soil enhancement prior to planting.

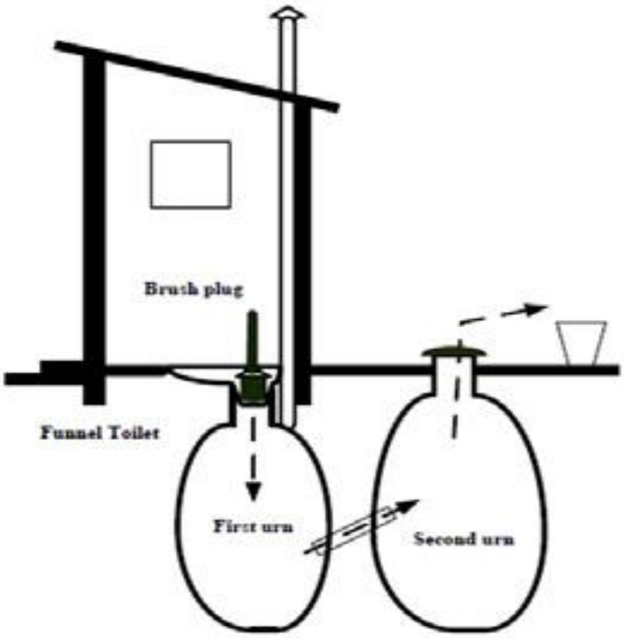


Figure 16: Double Vault Funnel Type [25]

Type 3 - Double Pit Alternative Type

There are two pits of function alternatively. One pit is for the use while keeping the other one for stored for composting to correcting the carbon to nitrogen ratio. This arrangement is preferred in area with short rainfall.

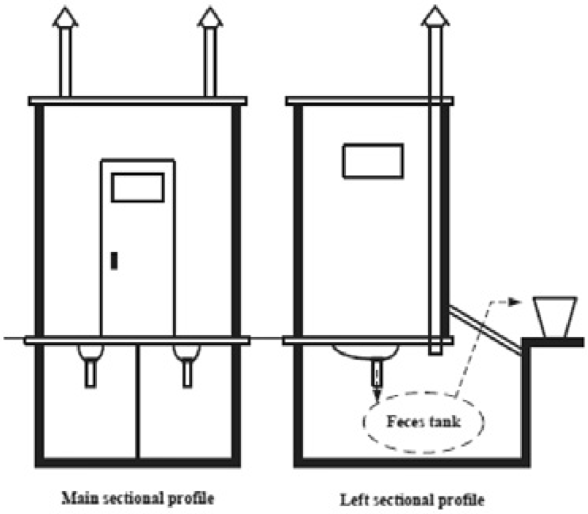


Figure 17: Double Pit Alternative Type [25]

Type 4 - Biogas linked Toilet

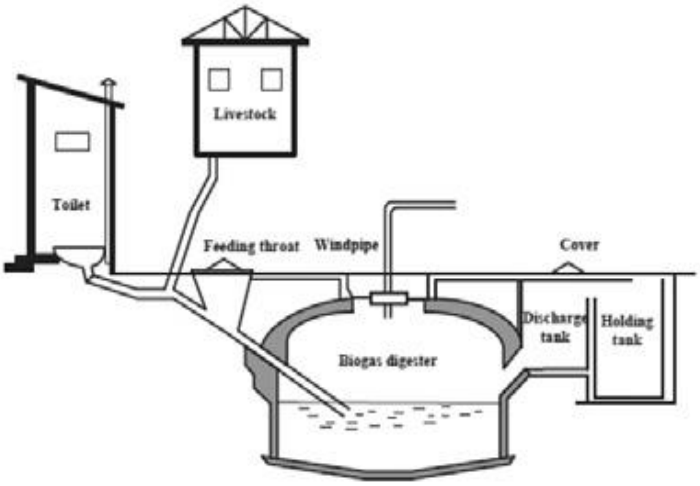


Figure 18: Biogas Linked Toilet [25]

This toilet is built near to livestock shed. Human waste and animal waste are both usable for biogas production which can be used for cooking and lighting. More suitable to use under warm climate areas.

Type 5 – Toilet with Urine and Faeces Division

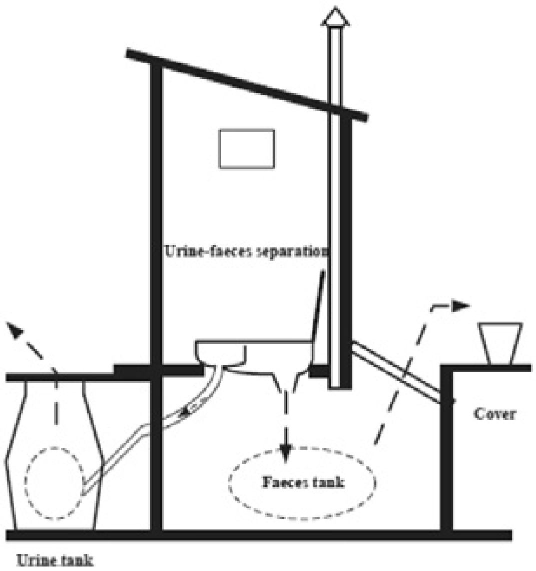


Figure 19: Urine and Feces Division Toilet [25]

Separate collection of urine and faeces. Diluted urine with water is directly used as fertilizer and faeces are dehydrated for harmless treatment. Especially useful in areas of arid and water deficient.

Type 6 - Integrated Flushing Toilet

Figure 20: Integrated Flushing Toilet [25]

This toilet is connected with fresh water supply and complete drainage is connected to sewage treatment. Treatment facility and building sewage pipeline is required. Cost involvement is higher. Useful in rich rural areas, dwellings, apartments, or suburbs which are connected to sewer pipeline network and combined with the central or decentralized sanitation.

2.2.2 Faecal Sludge Management in Japan

The approximate population of Japan is about 120 million. Centralized wastewater treatment plants are used to treat 72% of population's excreta is transported in sewers [31]. Sewer system is used to transport black water (from toilets) and greywater from (wastewater from household except black water) through pipes to wastewater treatment plants. Packaged Onsite treatment system uses in suburbs and rural villages and urban areas like Tokyo Metropolis. Package onsite treatment unit of johkasou systems installed at each house unit. This percentage is about 21% [31]. The johkasou systems collect and accumulate faecal sludge, which is then emptied and transported by vacuum trucks. Processing to be carried out in faecal sludge treatment plants. The rest of the 7% of excreta is managed by onsite treatment technologies such as night-soil treatment in Japan. Fully lined tanks use for accumulation without treatment which collects the excreta from toilet drains. Faecal sludge is transported by vacuum trucks to night soil treatment plants.

Convert Faecal Sludge to Fertilizer in Saitama City

Saitama has a population of about 1.27 million people and a relatively high population density [32]. The city makes use of both off-site and on-site sanitation services. Most of the population (about 92%) is connected to the sewerage grid, while the remaining 8% uses a bundled onsite treatment system. Because of the scarcity of land, it is impossible to maintain separate sanitary landfills for sludge created by wastewater treatment plants and sludge treatment plants. Sludge produced by packaged onsite treatment systems is transported to two sludge treatment plants in Saitama. Phosphate, an important fertilizer ingredient for agriculture, is found in faeces sludge. Sludge recycling is a more attractive option than the sludge disposal. Safe recycling and composting of sludge use as a fertilizer in Japan which came out from Omiya Purification Centre.

Wastewater Reuse in Saitama Shintoshin

Land subsidence caused to restrict use of groundwater in Saitama. About 70% of the water is taken from the rivers and increasing demand for water is a challenge to find a reliable supply of water. Aiming of environmentally friendly development of the city, main developers considered rainwater and wastewater as water source.

At the Saitama Sewage Treatment Centre, wastewater collected from housing units and industrial locations is treated with traditional activated sludge as a secondary treatment. The treated water is further treated at the Shintoshin Purification plant using a combination of bio filtration and ozonisation processes to ensure that the wastewater is of reusable quality.

Due to the reuse of treated wastewater accounts for saving of freshwater about 250,000 cubic meters yearly. Monetary value of above saving is about $ 939,000 [32].

Tadotsu Wastewater Treatment for Water Resource Management

Tadotsu is a town on Japan's Shikoku Island, on the Seto Inland Coast. This town receives little rain and has previously experienced water shortages and droughts. Wastewater reuse is encouraged to ensure a reliable water source for drinking and irrigation, reduce the risk of drought, and keep river and groundwater levels safe. River rehabilitation, agriculture drainage, parks and gardens, ground water recharge, and augmentation of the streams and brooklets that flow through the town are all examples of uses for treated wastewater.

Wastewater is reused to store in ecological habitats and enhance the town's natural ecosystem. It allowed the construction of new water features and the revitalization of parks. Those locations caused to increase the town attractiveness and enhancing tourism.

2.2.3 Forward Osmosis Toilet Systems with Resource Orientation

Human waste is high nutrients, and resource focused toilets with forward osmosis (FO) technology can recover clean water, nitrogen, phosphorus, potassium, biogas, and heat from urine and faces [33]. An adult produces 1.5 kilo grams of urine and 140 g of faces per day on average. Content of the human faces and urine are summarized in the table 1 below.

To handle 1 cubic meter of wastewater every day, a standard secondary sewage treatment plant uses 0.3-0.6 kWh of electricity [34]. In additionally energy is consumed for conveyance and collection will finally results in use of massive energy consumption which has a negative impact on the environment due to resource waste and construction and operating [35] [36]. Both the environment and the economy bear a heavy burden by current sewage treatment process/ plants due to excess use of energy and chemicals for the treatment. To address these problems, Human waste is being used to recycle resources and electricity, and this is becoming a global consensus [37] [38].

Wet human faeces contains 75% of water and remaining solid portion is 88 – 97% of organic compounds [39]. About 91 – 96% percent of urine is consisted with water.

Total solids from the dry urine per person per day is about 59 g on average. It consists organic matter about 65 – 85 % [39].

Table 1:Human Feces and Urine Contamination

Type	Human Faces	Urine
Organic Compounds	88-97%	65-85%
Nitrogen (N)	5 – 7%	15 – 19%
Phosphorous (As P_2O_5)	3 – 5.4%	2.5 – 5%
Potassium (As K_2O)	1 – 2.5%	3 – 4.5%
Carbon (C)	40 – 55%	11 – 17%
Ca (As CaO)	4 – 5%	4.5 – 6%

Source: ([33] [40])

Following new treatment processes are have been developed to recover resource and energy from the human faces and urine.

- Struvite precipitation to recover nitrogen and phosphorous [41] [42].
- The electrochemical treatment to recovering nitrogen and disinfection [43] [44] [45].
- Combustion may use to convert human waste into a fuel source [46].
- Hydrothermal carbonization procedure can be used to safely reuse human bio wastes while also recovering nutrients [47].
- Dehydration can be used for volume reduction in urine and adsorption technology can used to convert recovered products with safety aspects [48].
- Hybrid processes of membrane-based pre concentration and ion exchange for recovering clean water and nitrogen, as well as hybrid flocculation and nutrient precipitation for recovering nutrients in urine, are both applicable hybrid technologies [49].

Forward Osmosis is a sustainable membrane technology with significant advantages of use for nutrient rich wastewater. FO membrane systems have many advantages over other membrane technologies, such as reverse osmosis (RO) and electro dialysis (ED) [33].

a) Low membrane strength is required and there is no requirement for external pressure
b) When polluted, fouling is poor and can be retrieved easily
c) A higher iron rejection rate

Seven different types of toilet systems were evaluated with FO units, considering the various water supply and drainage infrastructure conditions in various regions.

Scenario - A

This is a traditional public toilet system with two operating modules that are used in both urban and rural areas. In urban areas use tap water for flushing and rural areas use clean water to flush. Urban areas discharge wastewater into the sewage treatment plants and in rural areas wastewater is collected in septic tanks and eventually transports wastewater to STP. Figure 22 below shows the arrangement of the Scenario A.

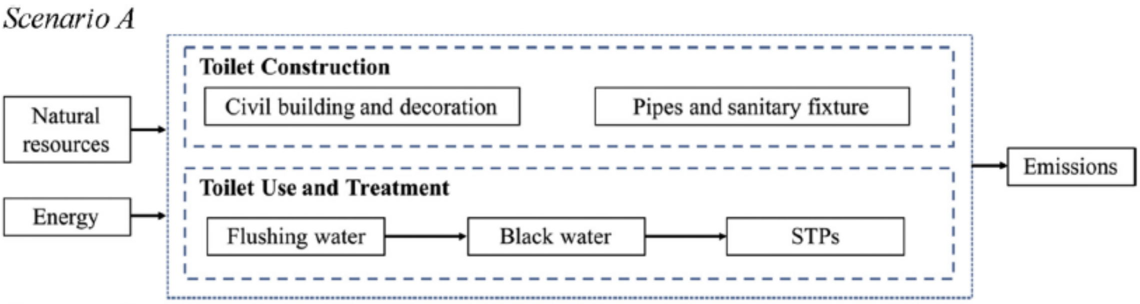


Figure 21: Scenario A Type Toilet [40]

Scenario B1 and B2

As shown in Figure 23, these are two partial resource recovery toilet systems. Urine (Yellow Water) and faces (Brown Water) are isolated in this setup by vacuum urine diversion. Then liquid fertilized is obtained by concentrating the yellow water via FO system. A reverse osmosis (RO) is used at the same time to recycle the draw solution used in the FO system and recover flushing water

Brown water is kept in a vacuum valve for a few days to allow for settlement, after which the upper liquid is discharged into the sewer and the sediment is transported by trucks. Scenario B1 is work on photovoltaic cells and scenario B2 is used electricity. Areas with drainage facilities are best match for these systems.

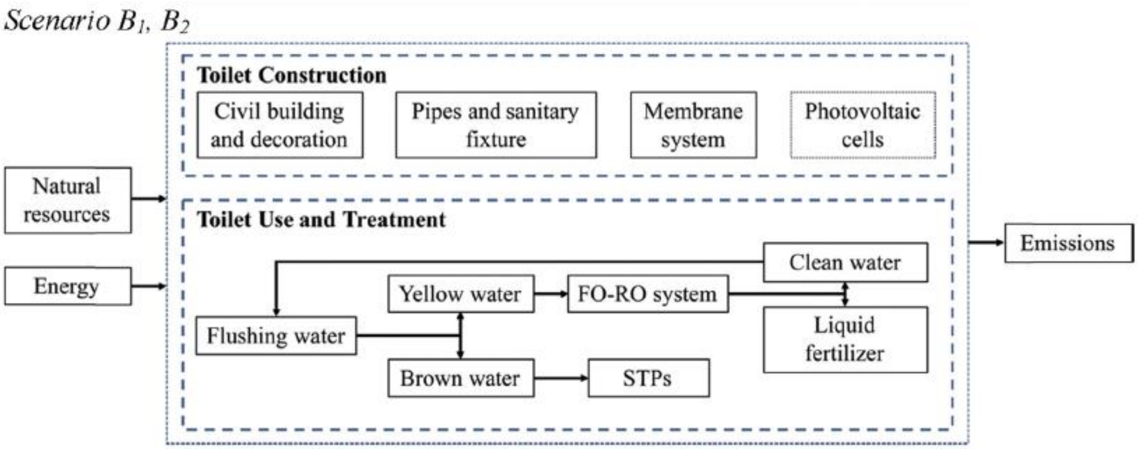


Figure 22: Scenario B1 and B2 Type Toilets [33]

Scenario C1, C2, C3 and C4

These scenarios are a complete resource recovery toilet system. In these non-sewer systems based on scenario B, anaerobic digestion is used to treat brown water. When sufficiently filtered surface water is provided for flushing by the RO method, separation from the public water supply system is possible. Scenario C is further categorized depending on whether a water supply system is needed or not, as well as the form of power system employed, such as photovoltaic cells or electricity. These systems are ideally suited to water collection and treatment systems, but they come with a high initial investment and ongoing operational costs. Figure 24 below shows the arrangement of Scenario C type toilets.

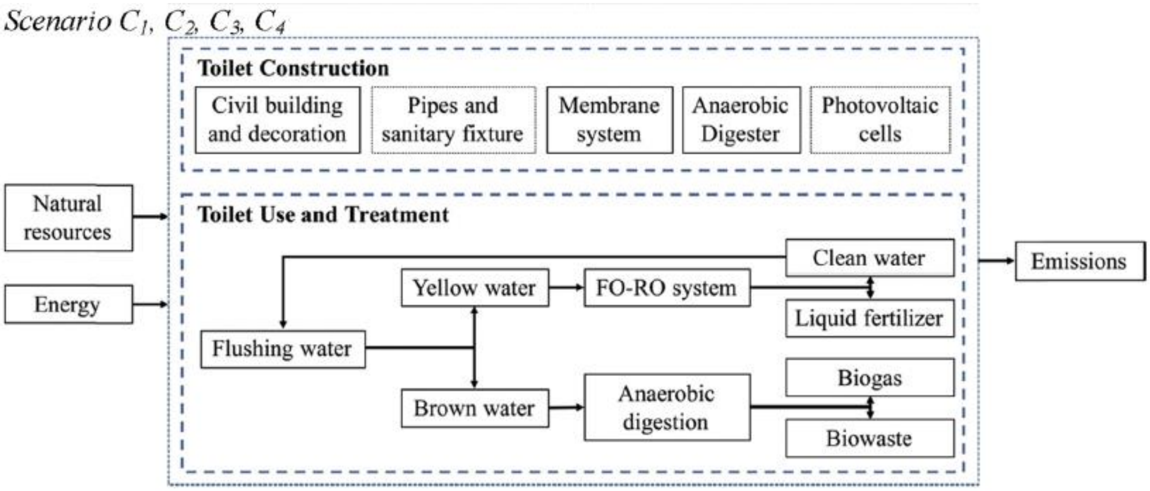


Figure 23: Scenario C1, C2, C3 & C4 Type Toilets [33]

Summary of aspects consist with different toilet systems described above are tabulated as follows.

Table 2: Processes Needed for Various Toilet Systems

Scenario	Supply of Water	Drainage	Yellow Water - Treatment	Brown Water - Treatment	Solar Power
A	✓	✓	☒	☒	☒
B1	✓	✓	✓	☒	✓
B2	✓	✓	✓	☒	☒
C1	✓	☒	✓	✓	✓
C2	✓	☒	✓	✓	☒
C3	☒	☒	✓	✓	✓
C4	☒	☒	✓	✓	☒

Source: ([33])

According to the results of the evaluated toilet systems for each scenario, resource-oriented toilet systems provide higher economic and environmental benefits than traditional toilet systems. This can be used to accomplish the best possible pollution management, resource recovery, and economic efficiency in both rural and urban regions. All toilet systems are designed and tested with the same capacity as two urinals and eight closet pans over a 20-year period. Cost of construction in resource-oriented toilets are higher comparatively with the conventional toilets and operating cost is lower. As per the evaluation results of the six types of systems in terms of both economic feasibility and environmental sustainability, the partial resource oriented toilet (B1) is the best choice, while entirely independent resource oriented toilet systems (C3) can be utilized to replace current conventional type toilets in rural locations without access to external facilities such as water, drainage or facilities to treat sewage.

The main disadvantages of resource-oriented systems include the unpredictability of using specialist equipment, fluctuations in urine and faeces content, and system instability. Furthermore, more study is required in order to improve the membrane system's efficiency. Technical feasibility and cost of construction must be further analysed when implementing the systems in the rural areas.

2.2.4 Composting Toilets

Composting toilet concept is fit with the todays understanding of sustainable concept by reducing water and wastewater flow out from the building. However, there are few barriers for acceptance and implementation of the composting toilet systems due to a lack of understanding and awareness [11]. Composting toilets are gaining popularity with the sustainability concept and knowledge gaps in the engineering of composting toilets to be developed.

Majorly there are two type of sanitation systems namely water based (flushed by water source) and composting based (flushed by foam or pint). Dry toilets, biological toilets, bio – toilets, and waterless toilets are all terms for composting toilets. [50]. Materials used for construction of composting toilets are plastic, ceramic or fiberglass. The toilet and composting tank are the two primary components of the system. The fan and vent pipe to eliminate the created stench are frequently included in the setup.

Composting tank in the system collect all the waste and digested them aerobically or with use of earth worms [51] [52]. Bulking agents or amendment such as saw dust, leaves and food waste are required based on the variety of waste, altering the carbon-to-nitrogen ratio and increasing the porosity of the compost produced. Sawdust is widely utilized due to the features listed below. [53] [54].

- Produce and environment for bacteria to flourish with its high porosity
- Higher water and air retention ability and acceptable drainage properties.
- Low density saw dust(0.19 g/cm^3) is caused to reduction of energy requirement for mixing in the mechanical mixer attached to the composting toilet system to homogenizes the compost matrix to maintain favourable conditions for aerobic digestion(Organic matter is oxidised into ammonia, carbon dioxide and humus).

Final products from these toilets contains stable, high molecular weight and dissolved organic matter which can be recycled as soil fertilizers. Figure 6 below shows the typical arrangement of composting toilet system. Composting prior to use as natural fertilizers for plants is the only treatment necessary for dry or non-water-based toilets.

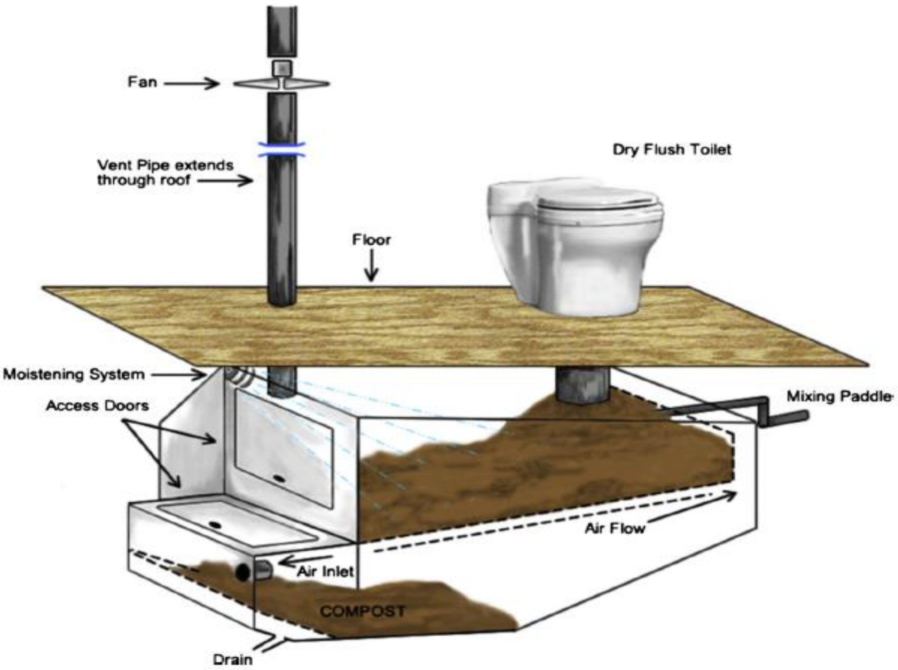


Figure 24: Composting Toilet System [11]

Design approach of the composting toilet system is illustrating in the Figure 25 below.

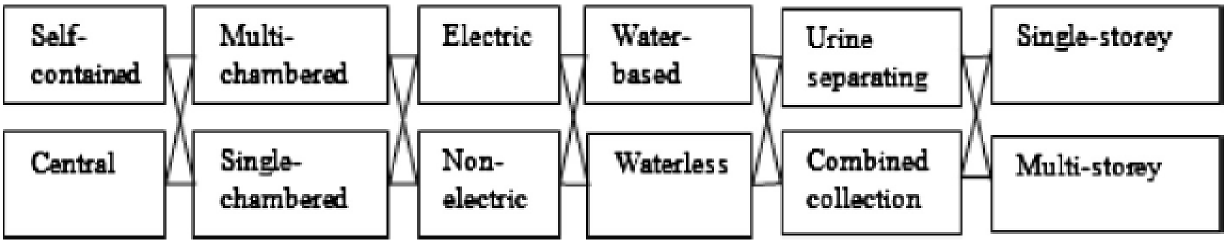


Figure 25: Design Approach of the Composting Toilets [11]

Variety of Composting Toilets

A Self-contained composting toilet (Figure 26) combines the toilet and composting chamber into a single unit. Central composting toilets (Figure 27) feature larger composting chambers than self-contained toilets since they are connected to several toilets on the same or separate floors. Faecal matter is transport into the composting tank via angles pipes or flushing with use of water or foam.

Figure 26: Self Contained Composting Toilet [11]

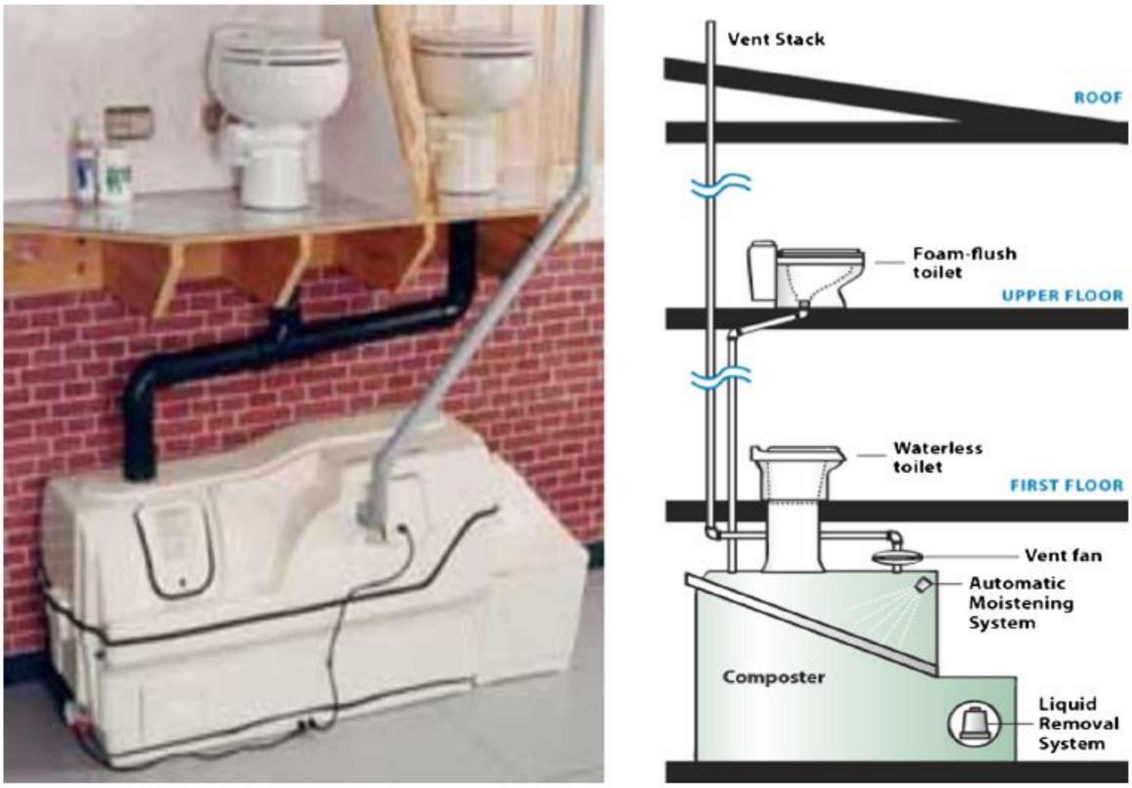
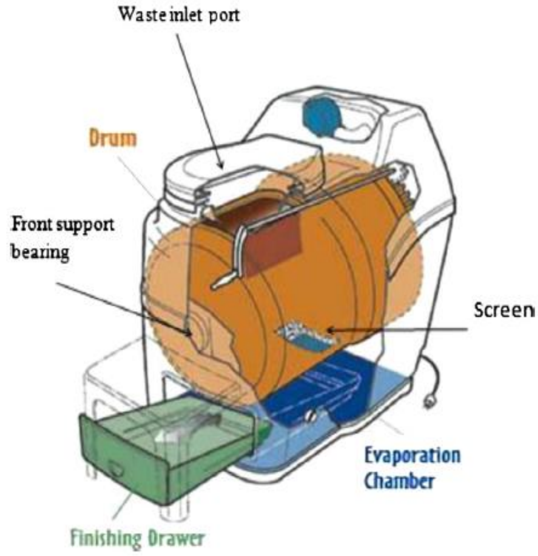


Figure 27: Central Composting Toilets [11]

Single and multiple chambered – Single chambered composting toilets compost both fresh and old waste in a single chamber. Main disadvantage of the system is same operating conditions for all stages of the composting. Multi chambered system can separate the composted material from fresh wastes. Also, it allows to replace the filled chamber with empty one. Carousel composting is a type of multi chambered arrangement with interchangeable composters. With arrangement of this system toilet is connected only for a one chamber at a given time and when it is filled tank is rotated to allowing waste to enter into the empty chamber [55]. Design of it has to be ensured that finish of composting material in the chamber one when the time of fourth chamber is filled [56].

Another type of multi chambered composting system is a bio drum-based multi chambered composting multi chambered composting system. Garbage is collected and circulated in a drum with multiple chambers for composting, evaporating, and finishing waste in batches. Rear screen in the bio drum allows to leach excess water to the evaporating chamber. Backword rotation of drum is required when the compost is ready and shift into the finishing chamber. Finishing chamber is separated from the fresh waste and user can safely aces it to removal of compost without expose into fresh wastes. Figure 28 below shows the carousel composting tank (a) and multi chamber bio drum (b).



(a) (b)

Figure 28: Carousel Composting Tank (a) and Multi Chambered Bio Drum (b) [11]

Waterless or water-based toilets – Waste is conveyed via vertical pipe in waterless toilets. With micro flush toilets (I pint = 0.47 L) or foam flush toilets (6 oz = 0.17 L), water-based toilets are utilized with angled pipes. Foam is a good choice for the job since it forms biodegradable foam, which improves user comfort, cleaning and waste removal.

Electrical Based and Non-Electric Toilets – This type of composting toilets is equipped with electrically powered blowers and heating systems. The heater is used to blow heated air to eliminate excess moisture and vented via vent pipes, and the fan is used to draw air into the toilets to prevent any aromas in the located room. By creating a vacuum, energy can be used to transport waste in electric toilets. Vacuum flush toilets benefit from the ease with which waste may be removed from the pipes. As seen in Figure 29, these systems are available in single tank or double tank variants.

Figure 29: Vacuum Based Composting Systems [11]

Separating and Combined Collection Systems for Urine – Combined collection system collects urine and faeces into a single chamber and in urine separating toilet allows manage urine and faeces separately, typically with the end user of fertilizer. Urine separation offers various benefits, including decreasing undesired odour and extra moisture in the compost. Aside from that, pee is a good fertilizer because it is high in nutrients and low in germs. Urine is contained 7 – 10 times more nitrogen, 2 – 3 times more potassium, and 2 – 3 times more phosphorous than in faeces. Urine separated vermicomposting toilets functions better than combined one in the means of pathogen elimination, compost quality, mass reduction and operational cost involvement.

Figure 30: Urine Separating Toilet (Water Based) [57]

Climate conditions, water availability, type of infrastructure (single or multi - story building), population density, and availability of end product management are all elements to consider when choosing and installing the best composting system [57]. Space for installation and maintenance must be carefully analysed prior to introduce a system into existing building. End product management must be available to use the product for farming, gardening or dispose with other matters under safe conditions.

When introducing composting toilets in metropolitan settings, a number of challenges must be solved, including public acceptance, laws, and higher costs compared to traditional flush type systems, odour creation, and lack of expertise and experience in design, operation, and maintenance. There are limited number of case studies have been carried out in the composting toilet sector and much research and practical applications must be implemented and analysed to further improvement and convince the appropriateness to use in small or larger scale applications.

2.2.5 Electrochemical Disinfection of Toilet Wastewater

Research and testing have carried out to check feasibility of the use of wastewater electrolysis cell (EC) for toilet water disinfections. Treated toilet water is checked for suitability of use for toilet flushing and agricultural irrigation [58].

Pilot scale photo voltaic powered self-contained mobile toilet system is tested at California Institute of Technology as shown in the Figure 12 below

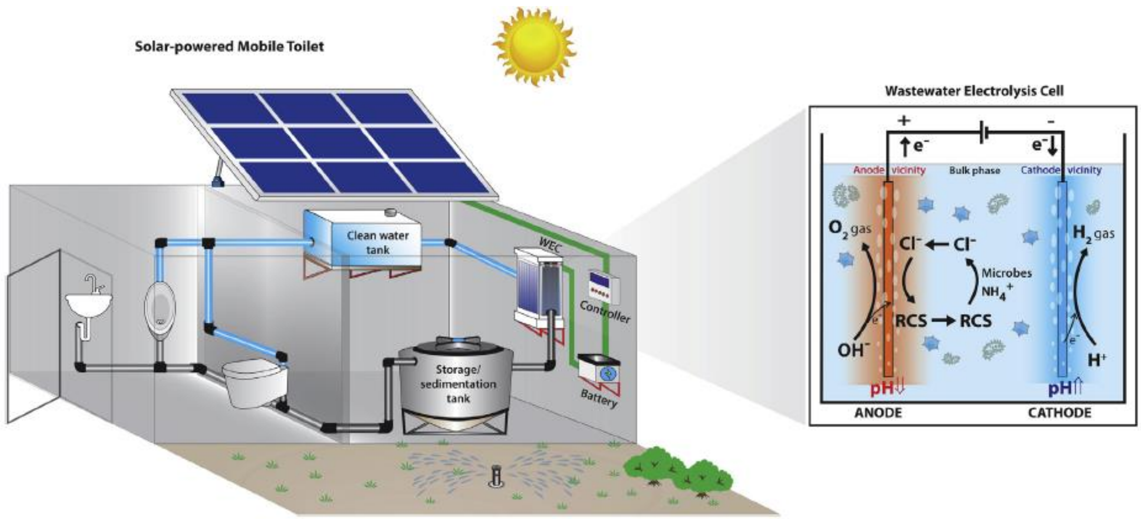


Figure 31: Solar Powered Mobile Toilet with Wastewater Electrolysis Cell [60]

The EC reactor is used to treating 20L of wastewater in batch wise. Storage or sedimentation tank of toilet water is acted as anaerobic digester (Four seeded microorganisms of Escherichia coli, Enterococcus, recombinant adenovirus serotype 5, and bacteriophage MS2 is used) [58]. Supernatant collected form top of the sedimentation tank is fed into the reactor. The treated effluent is collected to a clean water for reuse. Bench scale experiments on toilet wastewater is carried out by taking samples while pilot toilet system is in continuous operation.

As per the test results obtained, electrolysis cell disinfection can effectively remove both virus and bacteria in toilet wastewater without using any supporting electrolytes. This type of systems is possible to develop up to commercial scale with self-sufficient solar powered mobile toilet for decentralized wastewater treatment. The wastewater electrolysis treated toilet wastewater is suitable for use as flushing water and agricultural purposes.

2.2.6 Black Water Treatment Using Solar Septic Tank

Lack of improper sanitation systems effect not on only to environmental and health effects, it is caused to major economic losses through lost productive time, health care costs and morality [59]. Introduction of centralized wastewater treatment plants are appropriate in developed countries as currently practicing in most of the developed countries. However, it seems not appropriate to use in developing countries due to the high investment cost and skilled labour requirement for operation.

The up – flow solar septic tank (UTST) and multi – soil layering (MSL) system is possible low budget solution for developing countries. The research and testing works are carried out to evaluate the functionality of the integrated system to treat black water under actual conditions over a one year period n]by Asian Institute of Technology [60].

A field testing of the system has been carried out under actual conditions of fluctuating flow rates, ambient temperatures and black water characteristics at communal toilets located at central Thailand.

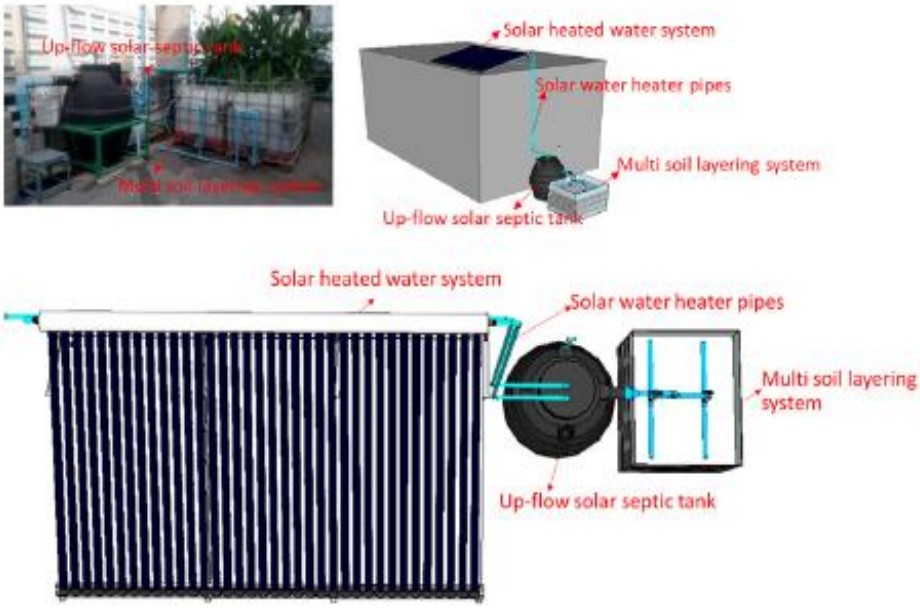


Figure 32: Integrated UTST and MSL System [63]

Estimated users for the system is 10 persons per day. UTST tank is designed with the capacity of 600 L and designed hydraulic retention time is 24 hours with organic loading rate of 4 g/L day. The up flow hydraulic mode obtained by modified influent piping is caused to improve hydraulic mixing and contact between anaerobic microorganisms and black water which will be resulted in better treatment performance than conventional solar septic tanks.

As per the tested results obtained from the real conditions run following average treatment efficiencies are highlighted [60].

In UTST

92 ± 10% for total chemical oxygen demand (TCOD)

79 ± 10% for soluble chemical oxygen demand (SCOD)

93 ± 9% for total 5 – day biochemical oxygen demand (TBOD)

90 ± 12% for soluble 5 – day biochemical oxygen demand (SBOD)

In MSL

95 ± 3% removal of total Nitrogen

88 ± 15% of total Phosphorous

Finally, removal for ISO requirement were obtained by feeding the effluent of the UTST through the MSL. Therefore, performance of the system is well within the standards to be maintained and cost involvement, operational maintenance feasibility and life cycle costing must be further analysed prior to recommend the systems for developing countries.

2.2.7 Indigenous Urine Water Purification Method in Sri Lanka

Research work has been carried out on low-cost filter media to be used in the modification of an ancient urine filtration system in Sri Lanka. The fraction of the urine in domestic wastewater is about 1% and it contributes to 80% of the nitrogen and 55% of the phosphorus in the urban waste water content [61]. Hence, it is required to adopt urine treatment technologies to recover these important nutrients. There were series of pot system used in the ancient Sri Lanka to filter the entered urine before discharge into the soil. Those pots were filled with sand, charcoal, calcite as filter media. Research was carried out to investigate the feasibility of use mentioned materials in a modern low-cost filter to use of urine filtration. Urine was sensitive to the variations of its pH values due to being a mixture of hundreds of organic and inorganic compounds. It was found that formation of light amber colour turbid clouds in the urine at elevated pH values (after 8.5 pH). This increase of turbidity is caused to increase the filtration ability in sand beds. Hence, it was investigated for the minimum calcite bed height required increase the pH value of urine to above 8.5. Total suspended solid removal was directly correlating to the sand particle size. It was found that Naththandiya silica sand which has smaller particle size (703.97 µm) shows the highest TSS removal [61]. There were about 12 different types of charcoal investigated to recognize their adsorption capacity. Charcoal (active carbon) prepared from Kohomba branches showed the highest ability of adsorption.

Following areas were highlighted in the research report published by the IWMI (International Water Management Institute) under topic of "Urban wastewater and Agricultural Reuse Challenges in India". In India still many sewers ending without directing to treatment plants and discharge into rivers [62]. Wastewater management in India is turning into large scale challenge with urbanization and economic development are improve greater than the required infrastructural development. Municipalities are more focus on increasing demand of the drinking water and water is transported from rural agricultural waterscape located more than 150 km. Treatment of wastewater is importance asset when looking at the present cost involvement for lifting water, energy prices, pollution of river water and ground water and water scarcity. Treatment of wastewater required to protect the groundwater, ecosystems and reduce downstream effects where number of livelihoods are survived [63].

As per the research work carried out in above it is cleared that water content in the urine can be filtered and treated up to drinking conditions. Mini filters can be introduced in the building level in apartments, offices and houses to filter the urine. Recovered water can be used for washing, flushing or plantation purposes. In addition to that solid portion can convert into to soil improvers or fertilizers.

2.2.8 Producing Biogas

Biogas is a production of gases from anaerobic digestion of biological or organic materials. Biogas can be made with use of livestock waste (Urine and Excreta) and waste feeds in domestic scale. Biogas produced during methanogen bacteria breaks into the organic material in the absence of oxygen [64].

Composition of the biogas is as follows [64].

- Methane 40 – 70%
- Carbon Dioxide 30 – 40%
- Low amounts of other gases such as hydrogen, nitrogen, and hydrogen sulphide

Weight of the biogas is 20% less than the air and its ignition temperature is varies from 650 ^{0}C to 750 ^{0}C. It has similar burning flame as LP gas, and it burns with a clear blue flame. Biogas is a renewable energy source due to it is produced from waste treatment.

Benefits of Biogas Technology

Methane is the main output from the biogas plant, and it can be used for cooking and lighting and effluent can use for soil nutrients or fertilizing properties. Other applications of the biogas are fuel for combustion engines and for absorption fridges.

Carbon dioxide emission is reduced significantly due to biogas production. It is also help to lower emissions of greenhouse gases due to storage and utilization of untreated animal manure as fertilizer.

Cooking energy can be cheaply produced with use of biogas. Two cubic meter biogas plant is sufficient to produce 26 kg of liquid petroleum gas or 37 litres of kerosene or 88kg of charcoal or 210 kg of firewood per month.

Biogas plant can produce high quality and valuable soil fertilizer which is rich in nitrogen, phosphorus, potassium and micronutrients that improve the yield of plant production [64]. Organic matter produced during the biogas production is useful in multiple ways such as provide beneficial effects in providing plant nutrients, enhancing soil aggregation, increasing water holding capacity of soils.

Components of a Biogas System

Digester – Retain organic mixture to digest and anaerobic microorganisms to produce biogas

Biogas holder – Collect the gas produced during the digesting process

Gas pipe or System – Distribute the gas to the end user such as special lighting lamp or cooking burner.

Outlet discharge pipe – Collects and carry the digested slurry to the end user.

Outlet Tank – Accumulate digested slurry

Compost pit – Collect the slurry and allow composting

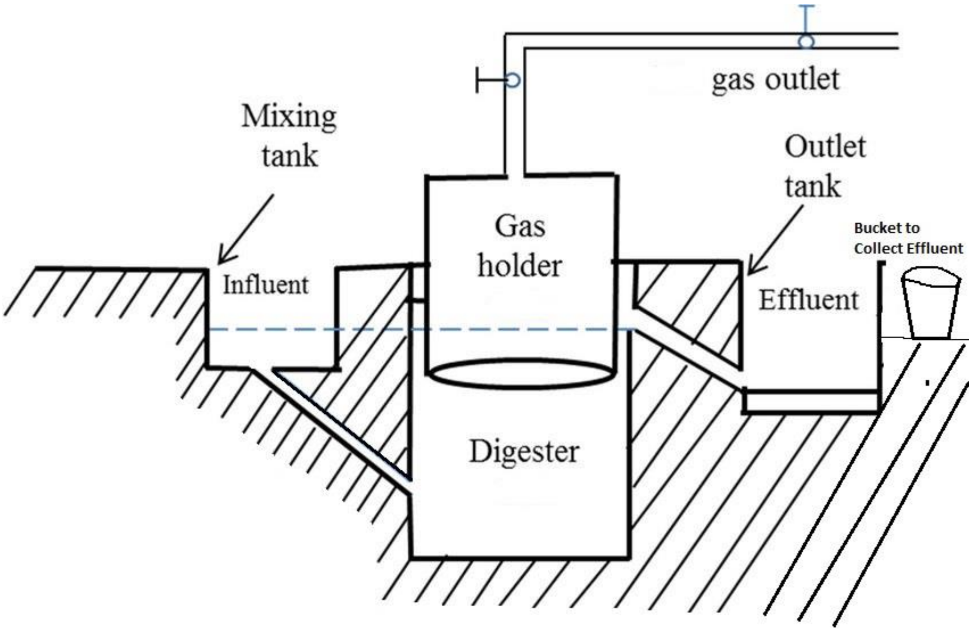


Figure 33: Biogas Plant

Inputs for Biogas production

As per the theory any biodegradable organic material can be used as an input of the bio digester. Some common examples are organic household waste, human excrement or night soil, animal excrements and fresh plant materials.

Table 3: Biogas Production from Different Sources

Ref.	Type of Dung	Gas Production Per kg (m^3)
1	Cattle (Cows and Buffaloes)	0.023 – 0.040
2	Pig	0.040 – 0.059
3	Poultry (Chickens)	0.065 – 0.116
4	Human	0.030 – 0.050

Modern portable biogas toilets are available for residential use.

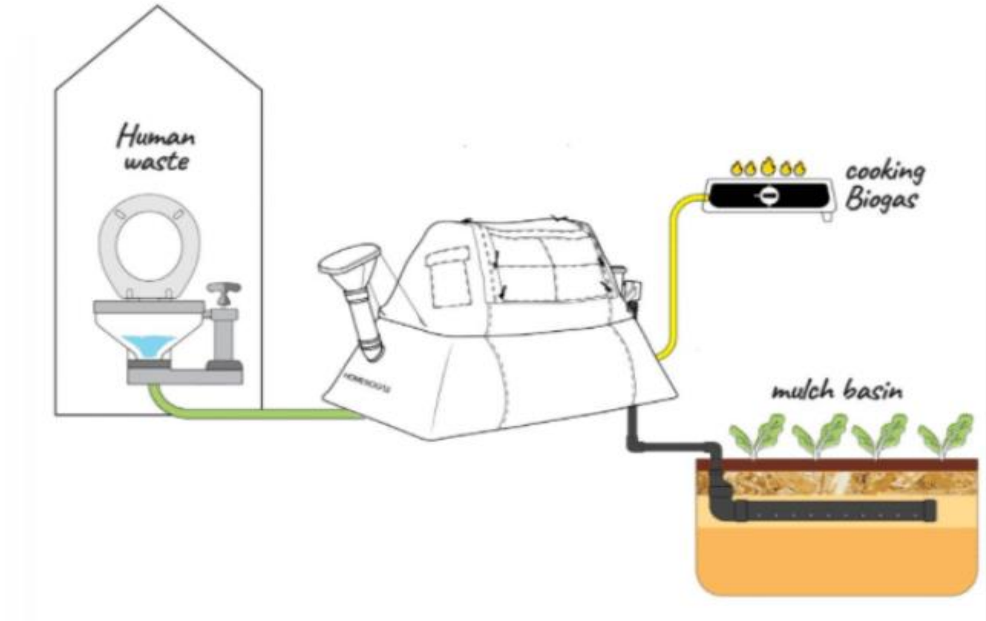


Figure 34: Modern Bio Toilet [65] [66]

Figure 35: Installed Modern Bio Toilet [66]

Home bio toilet kit is a great alternative for regular composting toilets. This product allows to live in self sustainable manner by converting the own excreta and urine into biogas for cooking. These products are easy to install, safe, hassle free, off grid and environmentally friendly. There are modern systems developed to use based on the occupancy and it ensures that production of one-hour free cooking gas for a three-member family with use of per day discharge of human excreta and urine. In addition to that capacity can be increased by feeding food waste. Water requirement for single flushing of this arrangement is 1.2 litters [67].

2.2.9 Composting or Fertilizing of Human Waste

Co - composted dewatered faecal sludge (FS) with organic fraction from municipal solid waste (MSW) has high ability to be introduced as an agricultural fertilizer in Sri Lanka. There are several advantages of use FS – MSW fertilizers within the country such as cost recovery of waste management, closing the nutrient and carbon cycles between urban and rural areas area, potential substitution for mineral fertilizers and reduction of environmental pollution.

Currently, knowledge about the usage of FS – MSW as a fertilizer is very little and reasonable research and generate practical application are required for extended use. Co-composting of faecal sludge and municipal solid waste is incurring low cost technology that is capable in use for developing countries as a solution for waste and toilet waste management. Urban areas in the Sri Lanka mostly uses on site storage of faecal sludge and lack with the proper treatment procedure. Higher Nitrogen content in the faecal sludge increases the value and possible usage as a fertilizer. palletisation can use to reduce the bulk density and make simpler application in the field. Uncertainty is existed about effect on the soil and plant growth and cost effectiveness to be further studied.

2.3 Present Status of Septage Management

Human excreta was treated by centralized sewer systems about 35% of the world population, on site sanitation systems by 34% of the world population and rest of the 31% lack of access to adequate toilet facilities [31] [68].

Sewer systems combined with treatment caused to safely and effectively removing excreta from highly industrial cities and improve quality of life in cities for the past 100 years. Negative side of the above aspect is recourse and cost intensive. It caused to financially unattainable for many countries proving that the sewer systems are not most sustainable option. Onsite sanitation technologies can use sufficient access to sanitation when the entire treatment chain is managed properly. Other than that, it can be five times less expensive comparatively with sewer systems [69]. Onsite sanitation systems can be implemented in the rural and peri-urban areas where building sewers is not feasible.

There are two main type sanitation systems in Sri Lanka namely onsite (decentralized) and offsite (centralized) [70] [71]. Collection systems (sewers) transport sewage to a centralized treatment plant located away from the residential area make up centralized sanitation systems. Offsite management is required due to disposal or reuse of treated effluent located away from the origin. Decentralized systems consist of all equipment onsite in means of individual or communal. In Sri Lanka 76.5% of households have access to the separate water sealed toilet. [70] [72].

It is a common practice to use partial onsite systems in all townships where septate or night soil is managed by unloading the community latrine pits with aid of suction trucks to transport for additional treatment or disposal on land [71]. Water sealed latrines connected to a cesspit or septic tank to transport septate or nights soil to an offsite location for further treatment are the main layout of the partly onsite conventional sanitation system. The treatment method is chosen depending on the physical, chemical, and biological qualities of the excreta as well as the amount of water used. [70] [71]. Water intake, climate, diet, and occupation all have an impact on the amount of faces and urine output by a person [70] [73]. For a vegetarian diet in a tropical climate, the average amount of faces released by a person is about 400 grams, and the average volume of urine is about 1.4 litter [73]. To make black water, most Sri Lanka water-sealed latrines mix and dilute faces and urine with water. Fresh faces have $10^5 – 10^9$ faecal coliform and streptococci per gram of contamination [73].

Most conventional offsite systems are not successful because of variability of amount of sewage received into the system. Due to the inaccessibility of gully sucker un urban houses, manual septate removal is essential. Manual removal is a dirty, dangerous and a demeaning duty and labours do attend to it aiming at an additional income of Rs.

5000 – 6000 per pit in an average household [70]. However, this is not to humane job to do. Most prominent disposal procedure of night soil is land disposal which cause surface and ground water pollution, damage to the eco systems and risk for human health. However, this procedure is declining currently due to the non-availability of bare lands. At present there are two alternatives that have initiated as solutions to these issues.

Septage Concertino's to Fertilizer in Matara

Matara is a large city in Sri Lanka's southern region, located in the coastal belt, where only 96% of the population has access to a sanitary latrine. The Matara municipal council has been dealing with sanitary management issues such as the presence of natural shallow water table near the sea and a higher percolation rate of sandy soil in most coastal areas, which have hampered excreta treatment in the soil. The municipal council's (MC) gully suction trucks were overworked due to the frequent filling of septic tanks, and residents within the MC area had to pay Rs. 4,000 per load.

Matara MC uses 70 acres coconut land to offload septate trucks as a temporary solution, with the landowner's permission. Excreta is employed as a fertilizer for coconut trees, resulting in 20 percent increase in nut production and an annual savings of Rs. 100 per acre [8]. However, because to the partial disintegration of septage, there is a possibility of pathogen contamination, which could be a host for disease-causing organisms [74] [75]. When using septate as a fertilizer, it is critical to adopt a low-cost composting process. Most pathogens can be reduced to safe levels by composting. Instead of applying direct septate, another alternative is to utilize windrow composting as a secondary treatment [71]. According to the research, pathogens can be removed by aerobic composting night's soil or sludge with woodchips or other carbonaceous material [74].

Partial Onsite Sanitation Treatment System in Negombo

According to the Negombo municipal council data, 98 percent of households within the city limits utilize water sealed latrines, with 95 percent of them connected to cesspits. Average black water production per day is about 7787 m^3 per day. Frequent filling of cess pits is caused too many nuisances to the environment and people. According to MC's observations, during rainy days, 25-30% of people discharge sewage into storm water drains. In the past year, MC has used an open unloading pit near a stream, and the rural community has condemned the operational because to the foul odour in the region. Therefore, use of Sewage Treatment Plant (STP) is preferred.

Grit chamber, two collection tanks, four anaerobic digesters, two aeration tanks, main and secondary settling tanks, sludge drying beds, sand filter, disinfection tanks, and gas collecting chambers are all part of the STP. The plant's capacity is at 40 m^3/day.

There were number of technical and socioeconomic challenges that made it difficult to keep the plant running. The grit chamber in the first treatment was constantly becoming blocked due to gully waste contamination of polythene, shampoo packages, diapers, sanitary napkins, fish market waste, and glass bottles. With the practical operations, there were design parameter changes, such as the sludge level recorded in input sewage being over 30,000 mg/L of TSS, above the design capacity of 1,500 mg/L. Because of practical flaws in the gully clearance procedure and poor management of latrine pits by the person who allowed the disposal of solid wastes and solid components to the toilet pits, the first settlement was not given.

Social issues with the plant location selection is protest from the people who live nearby in facts of disposal of treated wastewater to the streams assuming that hazardous. Apart from that, the low dignity of sanitary labour is a problem because they are constantly exposed to sewage with no regard for their health.

Septage contains a lot of organic materials, inorganic salts, and faecal bacteria, thus it needs to be treated before being released into the environment [71]. Technical knowledge is very poor of the operators of the plant and inadequate institutional corporation are another two of issues to be faced. The issue network of partial onsite sanitation systems are shows in the Figure 36.

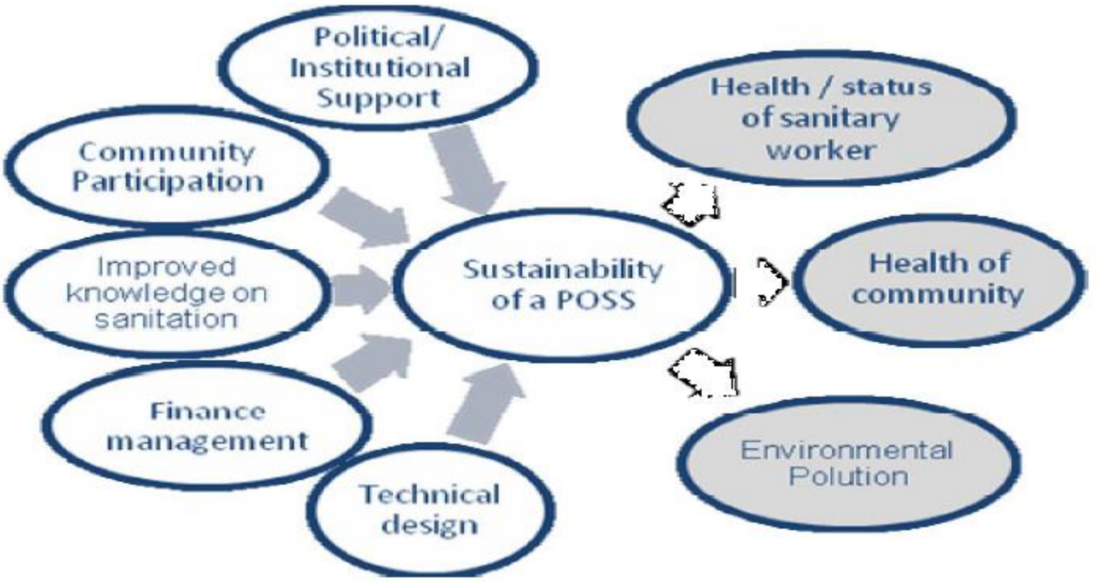


Figure 36: Issue Network of Partially Onsite Sanitation Systems [67]

2.4 Water Usage in Toilets

Existing water infrastructure in countries required higher amount of energy and use water of same quality for drinking, irrigation, and toilet flushing. In USA 3% of electricity is used for water and waste water treatment systems [11] [76]. Water made at higher energy consumption and use it for toilet flushing is inappropriate management of energy and water. Other than to that existing water supply and treatment infrastructures are incurred significant cost of maintenance and repair. Therefore, sustainable alternatives must be developed and implemented to reduce current burden on the infrastructure development on water supply and treatment.

Buildings are required high quality portable water. Portable water usage for toilet flushing can be mitigated by using of alternatives such as the utilization of grey water or rainwater and harvested storm water at desired level of purification. In this flush based toilet systems water is used as the diluted waste conveyance. Then, at wastewater treatment plant, energy is used to biodegrade the organic matter and separate the particles from the liquid.

Another possibility is the use of dry toilet systems such as composting toilets. Those systems are typically use in areas where with water shortages [77]. These solutions enable the toilet system to be disconnected from both the water supply and wastewater infrastructure. Toilet flushing is consumed significant amount of water. As a percentage of total water consumption in building types, residential it is about 27%, offices about 51%, school is about 60% and hotels are about 33% [78].

2.5 Identified Research Gaps

Sri Lanka is a developing country and human waste management infrastructure is still at the basic level. It is about 97% of commodities are still use water sealed latrines with onsite faeces and urine collection. Human waste treatment has not addressed severely, and viable cost affordable systems must be implemented, and extended research and experimental works must be carried out.

Composting toilet systems are reasonable adaptation under sustainable concept to reduce water usage for toilet flushing and human waste management. Potential design varieties, practical applicability, life cycle assessment and cost benefit evaluations must be further studied.

Sri Lanka is a tropical country and most of the areas have sufficient solar exposure during the daytime to operate solar powered human waste treatment systems. Novel concepts and designs are available and tested in the world. However, feasibility of implement such systems in Sri Lanka must be carried out.

Based on the identified research gaps it is desired to continue a case study by selecting a municipality and few apartment complexes, then collect data on quantity of production, method of disposal, the technology used for conversion, available data on the environmental impacts due to disposal of human waste into environment. Then set of recommendations and future research for developing guidelines on building design, as well as management of waste.

3. DATA COLLECTION

Third chapter is about data collection. The design for data collection, selection of sites for data collection, based on their location, number of occupants and the septic management practice are also presented in this chapter.

3.1 Design for Data Collection

Data was collected by questionnaire circulated among employees and residents of selected multi-storey apartments and office buildings located within the Colombo municipal council. Those questionnaires were oriented septate management during the construction phase of the site and during the utilization of buildings after completion. Questionnaires were structured with quantitative and qualitative aspects on current practice of septic management. Majority of the population of Sri Lanka lives in the western province. Municipalities of Colombo facing huge challenge to manage septic collected from residential dwellings, multi-story buildings and commercial buildings. Hence, 3 distinctive locations selected within the Colombo Municipal Council for the collection of data.

The residents' survey primarily aimed to collect data from residents on their current usage of existing septate discharge facilities, awareness of importance of proper septic discharge or disposal and suggested alternatives required in the current practice. The employee survey aimed to collect data from workers on how often they use the sanitary facilities provided within the workplace and method of disposal of Urine and Excreta. In addition, it was focused on the daily water usage and means of discharge of used water. 60% of data was collected by the oral discussions and 40% of data collected via structured questionnaire circulated directly and via electronic communication methods.

Mainly there were two different questionnaires used to collect data during the construction phase and during the use of the building. Main content of the questionnaires were based on the occupancy, how often do they use onsite or in-house sanitation facilities, collection procedure prior to discharge of septic mixture, process of collected septic mixture emptying and improvements to the current practice of septic management. Format of the circulated questionnaires are as follows.

Questionnaire 1 – For Residents

Questionnaire for the Survey on Sanitation Facilities, Discharge and Disposal of Faecal Contamination

1. Name (Optional): …..…………………………………………………………….

2. Number of persons living in the concession:

1		**2**		**3**		**4**		**5**		**Other (Specify)**	

3. Average percentage time stay within the apartment per day: …………………

4. Average Days of stay per week: ………………………………………………

5. What is the approximate quantity of water use …………….. (m^3 / day) or ……………. (m^3/ month)

6. What kind of sanitation facility do you have?

Ref.	Type	Tick
1	Flush toilet, directly connected to the sewer	
2	Flush toilet + septic tank, connected to sewer	
3	Composting Toilet (1 or Multiple vaults)	
4	Urine Separation toilet (1 or 2 vaults)	

If other, specify: ……………………………………………………………

7. Wastewater received in septic tank / discharge into the sewer system is from

Ref.	Type	Tick
1	Toilet	
2	Bathing	
3	Kitchen Water	

4	Washing	
5	Others	

Emptying of Septage Pit

8. When the pit is full, how do you empty the pit?

Ref.	Type	Tick
1	Do it by your self	
2	Do it by private sector service	
3	Do it by Municipalities	

9. What kind of emptying service do you use?

Manual

Mechanical

Other (Specify) :

…………………………………………………………………………

10. If manual emptying is used, who does it?

By Own Workers

By Third Party

11. Distance from the emptying trunk to the tank?
……………………………………

12. Practical issues/ difficulties to face

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

……………………………………………………………………………….

13. How much do you pay for the service (in LKR)? ……………………………

14. What is the frequency of emptying? …………………………………………

15. Do you or someone reuse the sludge? (If Yes Please Specify)

……………………………………………………………………………….

16. Do you pay or get paid for it?

……………………………………………………………………………….

17. For what is faecal sludge reused, in which period?

……………………………………………………………………………….

FSM (Faecal Sludge Management) Improvement

18. Where do liquid effluents after septic tank get discharged?

Drainage Channel	☐
River, Lake, Canal	☐
Open Space	☐

Other (Specify):

…………………………………………………………………

19. Where do other type of wastewater (Cleaning/ Washing/ Bathing) get discharged?

Drainage Channel	
River, Lake, Canal	
Open Space	

Other (Specify):

……………………………………………………………………

20. Do you care how your faecal sludge is disposed?

…………………………………………………………………………………….

21. Would you accept that sludge from your facility treated and marketed?

…………………………………………………………………………………….

22. Would you prefer to use recycled water of your septate discharged system for flushing/Gardening/ Washing?

…………………………………………………………………………………….

23. Would you prefer use of composting toilets in your house holds?

…………………………………………………………………………………….

24. What are suggestions to improve / alter the current practice of septate discharge?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

…………………………………………………………………………………….

Questionnaire Format 2 – For Office Workers, Site Workers and External Customers

Questionnaire for the Survey on Sanitation Facilities, Discharge and Disposal of Faecal Contamination

Use of Sanitation System by Official Workers/ Site Workers/ Customers to Discharge Excreta

1. How often do you use available onsite/ office sanitation discharge Excreta?

   ……………………………………………………………………………………
2. Does your system is equipped with dual flushing?

   ……………………………………………………………………………………
3. What is the approximate Water Usage per Flush?

   ……………………………………………………………………………………
4. What is the approximate Water Usage per washing?

   ……………………………………………………………………………………

Use of Sanitation System by Official Workers/ Site Workers/ Customers to Discharge Urine

5. How often (Number of Times) do you use the available onsite/ office sanitation discharge system?

   ……………………………………………………………………………………
6. How often do you flush the system?

   ……………………………………………………………………………………
7. Does your system is equipped with dual flushing?

   ……………………………………………………………………………………
8. Approximate Water Usage per flushing?

   ……………………………………………………………………………………

Discharge or Disposal of Urine, Excreta and Used Water

9. What is the discharge procedure of Flushed water?

   Common Septic Discharge Tank

   Separate Tanks for Urine and Excreta

   Other (Specify):

   ……………………………………………………………………

10. Is there an onsite treatment facility?

    Yes

    No

11. If yes, please clarify.

    ……………………………………………………………………………………

12. How often do you empty your Septic Collection Tank?

    ……………………………………………………………………………………

13. What are the practical difficulties to face during the process of septic collection and emptying?

    ……………………………………………………………………………………

14. How much is it cost for storage and emptying?

    ……………………………………………………………………………………

15. What are the suggested improvements to the existing practice of Septic Management?

    ……………………………………………………………………………………

3.2 Selection of Sites for Data Collection

Data were collected from three distinct multi story building complexes. It was considered that amount of Urine, Excreta and toilet water discharge per day or monthly during the construction phase and use of the building. In addition data were gathered on handling or management of septic mixtures, whether it is mixed with wastewater sources of the building, cost of handling and knowledge on impact of septic discharge to the environment and possible improvements to the current practice.

However, it was noted that knowledge on septic handling and disposal after discharge is at a very lower level and concerns on that fact is negligible. There is a very low level of importance to convert the urine and excreta to a commercial level end product and importance of reuse of the water discharge with the toilet systems.

3.2.1 Apartment Residencies – Colombo 08 (Location 1 (Case 1))

This location is based on the 20-story apartment project located in the Borella Sri Lanka within the Colombo municipal council. Data collected on handling of human excreta during the construction phase and during the building is occupied.

Construction Phase

There are about 180 – 200 workers working daily during the construction phase. Number of workers varies based on the workload and labour assignment. There are 4 water sealed latrines in the site for sanitary facilities. A 15,000-litter capacity temporary septic tank is maintained at the site. Capacity of the tank is sufficient for a 2-week period when site works are progressed in maximum capacity. Hence, it is required to remove the collected septic by gully bowser of the municipal council or private sector within an interval of 2 weeks. Average cost involvement for handling and removal of septic is about 30,000 LKR per month.

- Construction period of the project – 4 years (48 months)
- Cost of septate removal from the site – 1,440,000 LKR

It is noted that there is no separation of toilet water, urine and human excreta. All types of water are directed into the temporary septic tank. In addition, data on frequency of use of existing sanitation facilities during the office time, water usage for flushing, data of treatment and disposal methods use in the site were collected.

After Construction (During the use of the Building)

This building consists of 44 apartment units and 2 penthouses. Occupancy is about 200 including house holders and maintenance and management crew. Average quantity of septic and grey water collected per day is about 21,000 L per day. This site is located near the main municipal sewer piping system of septic collection. Therefore, daily discharges of septic, urine, and water used in toilets, cooking, bathing and other needs are directly discharged to the sewer network. This pipe guides the septic into a central location where sucking is performed by the municipalities to collect via gully bowsers to transport them to offsite treatment plants.

3.3 High Rise Apartment Complex – Colombo 03 (Location 2 (Case 2))

This is a luxury living high rise nature apartment complex. It consists of 4 towers of 40 floors each. Total number of apartment units is 608. This is a high-rise building and height is about 140 m from the ground level. Construction of project completed in the year 2019. However, still all towers are not the fully occupied. Data was collected from the workers and engineers during the construction of site and occupants during the time of the survey.

Construction Phase

This site was constructed with use of workers from locally and non-locally. Construction was continued full time on shift basis. Average number of workers per day is about 1,500. There were about 12 mobile type water sealed latrines used for the sanitation facilities. All of them were equip with single flushing cisterns of 7.5 litters per flush. Urine and faeces collected to temporary storage tanks and they discharged into the offsite treatment facilities with aid of gully bowsers from municipalities and the private sector. Retaining volume of the temporary septate tanks were sufficient for 3 weeks period and the cost incurred for handling, rent and disposal of septate collection were about LKR 125,000 monthly. Construction period of the project is about 60 months.

During the Building Occupancy

Generated septic with used water is directly discharged into the municipal sewer piping system available in the located area. Following data were collected during the survey.

Number of apartment units – 608
Number of occupants approximately – 2,400 (When fully occupied)
Generated septic mixture – 135 l per person (Including Washing, Bathing and Kitchen Water)
Average generation per day – 272,384 l per day approximately when fully occupied

Other than the apartments there are commercial areas consisting of restaurants, shops and offices of the maintenance staff. Central piping system is equipped with a location to allow suck the collected septic via gully bowsers of the municipal council or private sector to carry and dump into the remotely located treatment plants.

All kind of wastewater discharge is directed to the municipal sewer system. Separation of grey water and black water is not considered in this arrangement. Reuse of water not addressed and there is possibility of saving huge amount of water if treated and reused.

3.4 Government Office Building at Narahenpita (Location 3 (Case 3))

This building is in Narahenpita. Functionality of the building is the official purpose. Occupancy in the building is about 500 to 600 persons in the daytime. Municipal sewer piping system of septic collection is not available in this area. Therefore, onsite septic treatment plants are required to run as per the regulations of the Central Environmental Authority. Following has the details of the septic treatment plant. During the collection of the data this building is on the fully occupancy and it was unable to collect data relevant to septate disposal during the construction phase.

Type of Waste	- Toilet wastewater and Canteen wastewater
Plant Capacity	- 72 m^3 /Day
Treatment	- Equalization, Anaerobic, Aeration, Sedimentation, Disinfection & Ultra-Filtration

This building is used as a government sector office. Influent quality is as follows.

Table 4: Influent Quality

No.	Parameters	Value
1	Chemical Oxygen Demand (COD)	550 mg/L
2	Biochemical Oxygen Demand (BOD)	400 mg/L
3	pH	6.0 – 8.5
4	Suspended Solid	250 mg/L

Functionality of the existing treatment system is initiated from directing all sources of effluent up to the equalization tank of the system. Then effluent is pumped at a constant rate from equalization tank to the anaerobic tank. Gravity flow is used from there on to minimize operational and maintenance costs.

This treatment plant is constructed as an alone unit. The tanks were constructed as compact concrete units by reducing the land area. Operations of the treatment plant are fully automated with use of level controllers, timers & relays to use minimum number of operators. Treated water discharges into coastal areas according to the MEPA (Marine Environment Protection Authority) requirements and with complies to the CEA (Central Environmental Authority) regulations. Final treated water quality is as parameters of Table 5 below.

Table 5: Treated Water Quality

No.	Parameter	Value	MEPA	CEA	Acceptable or Not
1	COD (mg/L)	< 100	<150	< 250	Yes
2	BOD (mg/L)	< 15	<100	< 100	Yes
3	pH	6.0 – 8.5	5.5 – 9.0	5.5-9.0	Yes
4	Suspended Solid (mg/L)	< 02	<03	<03	Yes
5	Faecal Coliform	< 10 CFU	<60 CFU	<60 CFU	Yes

Flow diagram of the Treatment plant shows in the Figure 37 below.

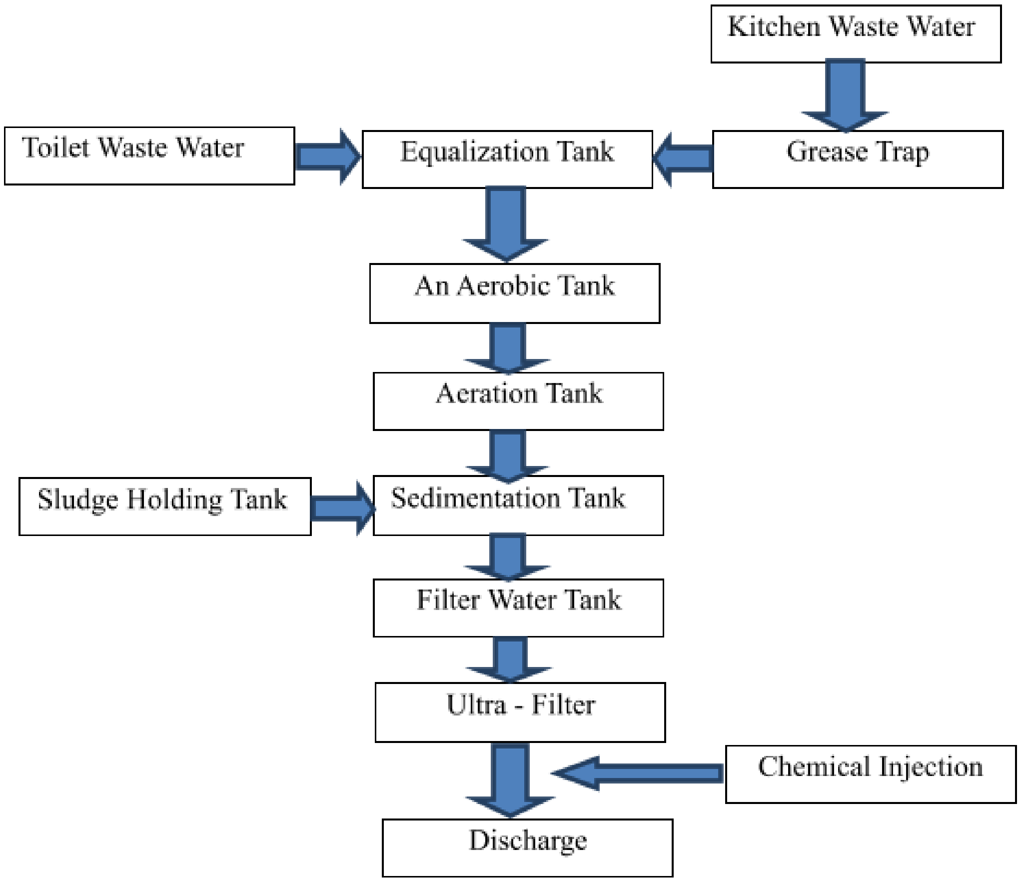


Figure 37: Flow Diagram of the Wastewater Treatment Plant

Equalization Tank

The raw sewage passes through a bar screen to prevent large floating objects such as trash, cloth, plastic sheets, cigarette butts from entering the sump. Then flow directs to an oil removal chamber for removal of oil. Screened sewage flows into the equalization tank of collection cum. Transfer pumps are used to pump accumulated cum in the equalization tank to the aerobic tank. These submersible pumps can handle solids up to 40 mm.

An aerobic Tank

Functionality of the anaerobic tank is to induce the nitrification reaction. In this chamber organic nitrogen and ammoniacal nitrogen are converted to nitrates. This facilitates the breaking down of nitrates for de – nitrification and further in the downstream aerobic units. The retention time of the existing anaerobic chamber is about 2 – 3 hours. The incoming effluent from the equalization tank is fed into the anaerobic tank. COD (Chemical Oxygen Demand) present in the incoming effluent use as the carbon source for the nitrification. Further provision of recycling part of the sludge from the aeration tank to the anaerobic tank is provided to sustain the organic carbon source intermittently.

The tank is equipped with the baffles to ensure the design retention time is achieved within the tank. Slow speed agitators are used to provide gentle agitation within the tank to prevent any settling of solids and intimate mixing within the tank to enhance the nitrification reaction.

Aeration Tank

The overflow from the anaerobic chamber flows by gravity to the downstream aeration process. The aeration basin operates with a combination of aeration and a submerged media for providing ideal conditions to generate biomass. The generation of biomass reduces the incoming BOD and COD to lower than 90%. The bio degradation is achieved in two stages via a series of reaction tanks. The first reactor is acting as the pre digester and the second reactor as the post reactor. The media provides a large surface area for the bacterial action to take place and the continuous movement of the media is useful to make uniform surface area exposure for the extreme fast film growth. As the film grows and thickens it slough off the media and is carried over to the downstream clarifier.

Twin lobe air blowers are used to maintain an adequate flow of air to the aeration tank. The aeration grid is placed to ensure uniform distribution of air throughout the aeration tank. The diffusers were installed to allow lift them for tank periodical maintenance.

The water containing the biomass from the aeration tank flows by gravity to the flocculation followed by the settling tank. The incoming water flows upward to the plates allowing heavy flow particles settled down to the bottom conical portion of the settler due to gravity. Settled sludge collected at the bottom discharge to sludge drying beds at a regular interval.

The clear water overflows by gravity to the clear water storage tank. Liquid chlorine solution is dosed in the clear water tank for disinfection.

Tertiary Treatment (Ultra Filter)

Feed pumps of the filter transfer the raw water through a 10 – 50 microns bag filter followed by Ultrafiltration membranes for removal of fine suspended solids and colloidal particles and make the water suitable for feed into the Ultra Filter. The filtrate will be stored in a storage tank.

An acidic/ alkaline cleaner and chlorine system uses chemicals as required as required during CIP (Chemical Cleaning in Place) of the Ultra – Filtration membranes. The backwash water from the UF and other filters flows into the drains.

The service of the Ultra Filtration unit is completely automated. PLC located control panel used for automatic service and backwash sequence. The PLC performs a programmed set of operations consisting of service, backwash, and forward flush of the membranes at a present sequence. Addition of chemicals initiated by the PLC, during backwash to enhance the cleaning efficiency. The operation sequence and changeover are done with use of pneumatically actuated butterfly valves.

Ultra-Filter Equip with Following instruments for the safe reliable operation and monitoring.

- Differential Pressure Indicator across the system
- Pressure gauges at across the UF and backwash pump discharge
- Rota meter at the Filtrate outlet
- Rota meter at the Ultra Filtration Outlet

Sedimentation Tank

The sludge (dead bacteria) receiving from the aeration tank is settled in this tank. Then settled sludge removed to the sand beds to make a cleaner effluent. Portion of this sludge moves to the aeration tank for grow bacteria density in pre-determined time period.

Sludge Collection

The settled sludge will be collected to the sludge collection tank.

Collection of Wastewater

Water collects from toilets are directly pour into the collection tank. Kitchen wastewater firstly directs across a grease trap prior to the collection tank. Grease trap requires to collect and reduce the amounts of fats, oils and greases which will be caused to create blockages, foul odours and pest infestation timely.

Treated water is discharged into the nearest canal through the UPVC pipeline.

3.4.1 Practical Issues of the Existing Septic and Kitchen Water Treatment Plant

- Operator is required to continuously monitor and correct malfunctions of the plant
- Regular breakdowns are possible, especially in pumps. Hence, stock maintenance of spares is required to timely complete the breakdowns.
- Lack of technical knowledge of the operator to ensure proper functionality of the plant.
- Short term and long-term maintenance are required, and quality of the discharges need to check regular basis.
- Energy consumption of the treatment plant is about 30 KWH per day. Monthly cost is about 20,000 LKR for electricity. In addition, operator’s salary, cost of spares maintenance, repairing and maintenance charges are incurred.

4. DATA ANALYSIS AND RESULTS

The data collected during the questionnaires listed in chapter 3 are analysed in this chapter to identify discharged volumes of excreta, urine, toilet water and other contents during the construction phase and the utilization of buildings. Most of the analysis is focused on data from locations 1 and 2 where onsite septic water treatment plant is not available. In addition, water treatment plant use in Location 3 is evaluated qualitatively.

4.1 Analysis of Apartment Residencies – Colombo 08 (Location 1 (Case 1))

This building's data was obtained in two phases: during the construction and when it was occupied. The study is based on the quantitative and qualitative data gathered.

Table 6 below shows the summary of data used for the calculations which were collected during the questionnaire and literature survey.

Table 6: Summary of Data Collected During the Construction Phase in Location 1 (Case 1)

Ref.	Description	Value
i	Average Workers per Day	200 (170 labours and 30 Officials)
ii	Number of Water Sealed Latrines	4
iii	Number of Urinals	6
iv	Water Consumption per Flush of Water Sealed Latrine	6 L
vi	Average Water Usage for Washing per Person in Single Use	1.5 L
vii	Water Consumption per Flush of Urinal	2 L
viii	Average Excreta Discharge by Person Per Day	130 g
ix	Density of Human Excreta	1.075 g/ml
x	Average Urine Discharge by Person per Day	1.4 L
xi	Percentage Dry Mass of Human Excreta	25%
xii	Percentage Dry Mass of Urine	10%

Accordingly to the data present in the Table 6 above values of i, ii, iii, iv, v, vi and vii were find out by questionnaire and values of viii, ix, x, xi, and xii were find out by literature survey.

Discharge Volume of Excreta

Excreta discharge was calculated separately for two groups as officials and labours due to the percentage of people belongs to each group use sanitary facilities for excreta discharge during the site vary significantly. It was noted that 10% of officials and 60% of Labours discharge excreta during the working hours at the site accordingly to the questionnaire results.

Discharge volume of excreta by Officials per Day (V_1)

$$\mathbf{V_1} = \frac{(30\text{Persons} \times 130\text{g/person}) \times 10\%}{1.075\ \text{g/ml}}$$

= 362.79 ml / day

= **0.36 L**

Discharge volume of excreta by Labours per Day (V_2)

$$\mathbf{V_2} = \frac{(170\text{Persons} \times 130\text{g/person}) \times 60\%}{1.075\ \text{g/ml}}$$

= 12,334.88 ml / day

= **12.33 L**

Total volume of Excreta Collected per day (V_3)

$$\mathbf{V_3} = \boldsymbol{V_1 + V_2}$$

= **12.69 L**

Water usage during the excreta discharge (V_4)

It is assumed that single flushing per person after discharge of excreta.

$\mathbf{V_4}$	$= (6+1.5)\ L \times (30 \times 10\% + 170 \times 60\%)$
	= **787.5 L**

Discharge Volume of Urine per Day (V_5)

It is observed that the number of times urine passes during the working hours about 3 times on average per person daily. Working time at site is ranging from 10 to 12 hours in a normal day. It can be assumed that 50% of generated urine of a person discharges during the working time.

$\mathbf{V_5}$	$= 200 \times 1.4\ L \times 50\%$
	= **140 L**

Water usage during the Discharge of Urine (V_6)

It is figured out that flushing of urinals does not accomplished by each single use of workers. It is assumed that flushing percentage is 50% from the number of uses.

$\mathbf{V_6}$	$= 200 \times 3 \times 2\ L \times 50\%$
	= **600 L**

Total Volume of Used Water Discharged per Day (V_7)

$\mathbf{V_7}$	$= V_4 + V_6$
	= **1387.5 L**

Total Volume of Septic Mixture Collected Per Day (V_8)

$\mathbf{V_8}$	$= V_3 + V_5 + V_7$
	= **1,540.19 L**

Table 7: Septic Mixture Content During the Construction of Site – Location 1

Ingredient	Volume per Day (L)	Monthly (L)	Percentage
Excreta	12.69	380.7	0.74%
Urine	140	4,200	8.27%
Water	1540.19	46,205.7	90.98%

Table 7 shows that 91% percent of septic mixture contains water. Wet volume of excreta collected is less than 1% in the total septic mixture. On average the dry mass of human excreta is about 25%. Hence dry volume of human excreta is discharged monthly is about 95.18 L. Water usage for sanitary facilities in monthly is 46,205.7 L. Used water is discharged to temporary sludge collection tanks without recycling. If this water is treated and reuse for flushing it can be saved about Rs. 4,158.00 per month. Treated water can be used for flushing and other non-drinking purposes. In addition to that requirement to keep temporary septic collection tanks during the construction period is minimized.

Following monthly savings are possible when use of onsite treatment facility during the construction phase.

- Savings from reuse of water - Rs, 4,158.00
- Savings from cost of removal of septic mixture – Rs. 25,000.00
- Savings from rent of excess temporary septic collection tanks – Rs. 7,000.00
- Total savings per month – Rs. 36,158.00.
- Total possible savings during the construction period – Rs. 1,735,584.00

However, to obtain above mentioned savings it is required to introduce onsite treatment facility at an initial capital cost. Cost of capital, installation, maintenance and operation of probable techniques must be further analyzed to obtain exact financial benefits. As identified in the literature survey technologies such as packaged onsite treatment facilities in Saitama Japan, forward osmosis toilet systems with resource orientation, composting toilets, electrochemical disinfection of toilet wastewater and black water treatment using solar septic tank are available technologies. However, cost involvement of mentioned techniques was not available in the literature. On the other hand, human excreta and urine-based fertilizers or soil improvers application are not commercially popularized in Sri Lanka. Additional income can be generated when commercialized use of human excreta and urine-based fertilizers are promoted.

Figure 38 illustrates the breakdown of the septic mixture collected daily during the construction phase.

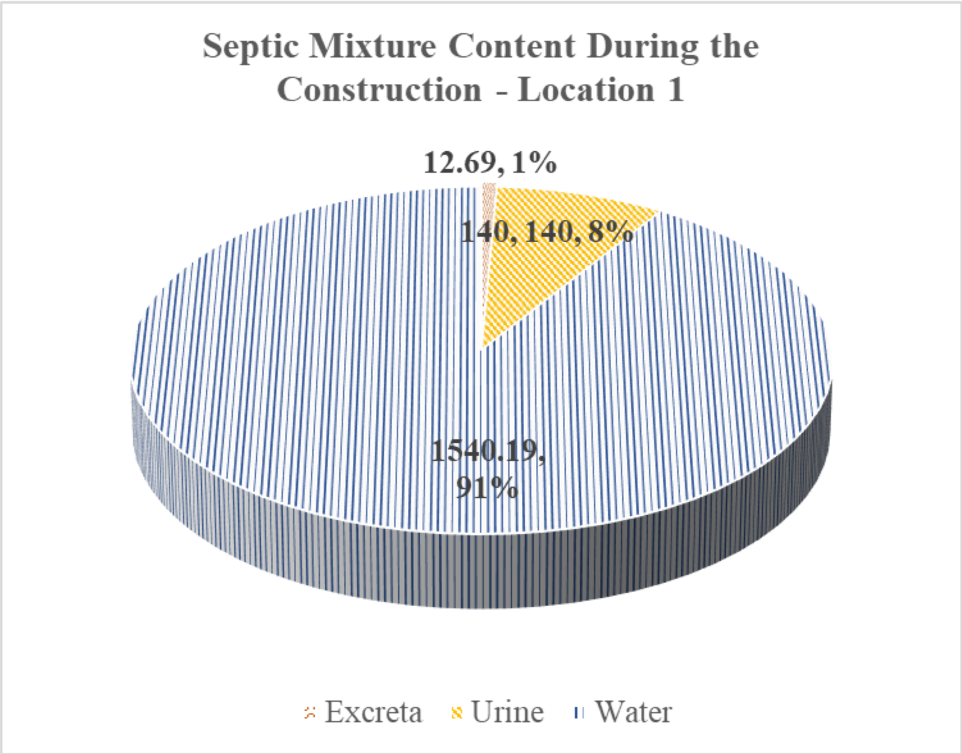


Figure 38: Septic Mixture Content During The Construction - Location 1

4.1.1 Septic Collection During the Occupancy of the Building – Location 1

This building is consisted with 44 apartment units and 2 penthouses. Accordingly, to the collected data all the bathrooms within this premises are equipped with water sealed commodes. There are separate piping arrangements to collect commode discharges and other used water discharges such as water from bathrooms, kitchen and wash areas. However, there is no separate collection or discharge of collected wastewater. All the used water sources (with septic) are directly discharged into the municipal sewer network.

Data were collected to figure out number of occupants, availability of occupants and amount of water consumption.

Table 8 shows the summary of data used for the calculations which were collected during the questionnaire and literature survey.

Table 8: Summary of Data Collected During Occupancy in Location 1

Ref.	Description	Value
i	Building Arrangement	Houses with 2 Baths – 22 Houses with 3 Baths – 22 Penthouses with 5 baths - 2
ii	Cistern Capacity of the Bathrooms	9 L per Flush
iii	Per Person Daily Water Consumption for Cooking	5 L
iv	Per Person Daily Water Consumption for Bathing and Toilets	85 L
vi	Per Person Daily Water Consumption for Washing Clothes and Utensils	35 L
vii	Per Person Daily Water Consumption for Other Needs	5 L
viii	Average Excreta Discharge by Person Per Day	130 g
ix	Density of Human Excreta	1.075 g/ml
x	Average Urine Discharge by Person per Day	1.4 L
xi	Percentage Dry Mass of Human Excreta	25%
xii	Percentage Dry Mass of Urine	10%

Discharge Volume of Human Excreta per Day (V_9)

Average building occupancy is about 80% accordingly to the stats obtained from the collected data.

$$\mathbf{V_9} = \frac{(200\text{Persons} \times 130\text{g/person}) \times 80\%}{1.075\ \text{g/ml}}$$

= 19,348.84 ml / day

= **19.35 L**

Discharge Volume of Urine per Day (V_{10})

All the residents do not stay within the apartment for whole day. Average staying time at the household is about 12 – 15 hours. Therefore, it is considered that 60% of the whole day time stays at the household.

$\mathbf{V_{10}} = 200 \times 1.4\ \text{L} \times 60\%$

= **168 L**

Other than the urine and excreta discharge water for flushing, washing in toilets, and bathing, washing of clothes and utensils and water from the kitchen are directly discharged into the common sever outlet as mentioned earlier without separation. Table 9 shows the expected flow volumes of septic and other used water sources into the common sever system.

Table 9: Septic Mixture Content during the Building in Use - Location 1

Ingredient	Volume per Day/ Person (L)	Diversity Factor	Total (L)	Percentage
Excreta	0.120	0.8	19.35	0.1%
Urine	1.4	0.6	168	0.8%
Cooking Waste	5	0.7	800	3.4%
Bathing & Toilet	85	0.8	13,600	65.1%
Washing	35	0.8	5,600	26.8%
Others	5	0.8	800	3.8%
Total	**131.52**		**20,987.36**	**100%**

As a result of the above calculations, approximately 95% of the septic mixture contains water. Water discharge without reuse approximately 19,938 L per day and 598,140 (598.1 m^3) monthly. Monthly savings of approximately 53,829 LKR are possible if wastewater is reused with or without separation and treat. Table 10 shows the percentages of black water and grey water volumes in the discharged septic water mixture.

Table 10: Discharged Black Water and Grey Water Volumes in - Location 1

Ingredient	**Amount (L)/Day**	**Percentage**
Black Water	5,627.36	26.81%
Grey Water	15,360	73.19%
Total	**20,987.36**	**100%**

Grey water treatment is not complex compared to black water treatment. It is required to carry further research and analysis to identify most economical and effective treatment procedures which can be used to recover water and usable content of urine and excreta.

Monthly collected wet excreta volume is about 580.5 L (624.04 Kg). Obtainable dry mass of the excreta is about 156 Kg monthly. This can be used as a soil improver or convert into usable fertilizers with additives. Monthly discharged net urine volume is about 5,040 L (5135.76 Kg). Dry mass of urine discharge per month is about 462.22 kg which consists of inorganic salts and organic compounds.

If onsite separation and treatment of urine, excreta, and used water are implemented during occupancy, the following monthly savings are possible.

Potential savings from reuse of water - 53,829 LKR
Total dry mass collectible from urine and excreta – 618.22 Kg/ month

Water can be reused for flushing and plantation requirements. Dry mass of urine and excreta can be converted into useful compositions of soil improvers or fertilizers. However, the best technologies for separating urine, excreta, and used water are supposed to identify.

Latest government restriction is introduced to use of chemical fertilizers for agricultural industry. Organic matter in the human excreta and urine can be converted into suitable organic formations to cater organic fertilizer requirement in the country. Population of Sri Lanka is about 21,512,181 [79]. Daily discharge amount of wet excreta and urine is about 2,601,473.051 Kg and 29,967,217.31 Kg respectively. Dry components of the excreta and urine are about 650,368.26 Kg and 2,996,721.731 Kg respectively. If it is possible to convert 80% of the dry component to usable agricultural product daily amount will be 2,917,671.993 Kg. This amount can be fulfilling the organic fertilizer requirement of 1,459 acre of paddy [80]. On average 1,904,000 acres are cultivated during maha and 1,054,000 acres are cultivated during yala [81]. Total number of acres of cultivate paddy is about 2,958,000 yearly in Sri Lanka. Around 20% of the yearly organic fertilizer requirement can be fulfilled by converting of yearly discharge amount of excreta and urine.

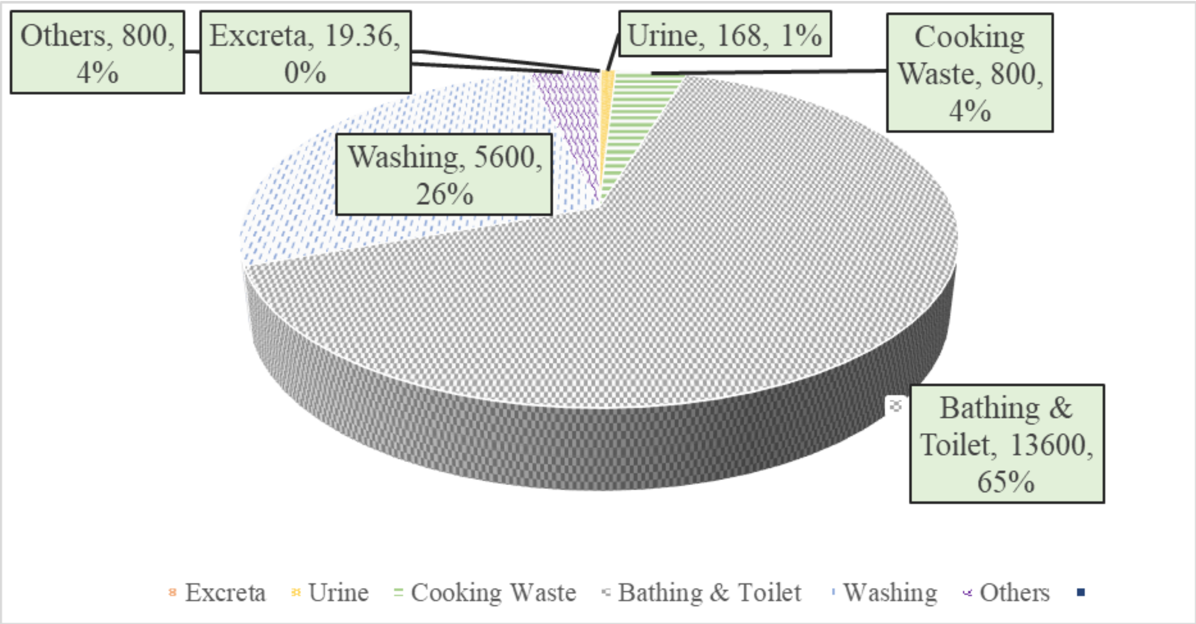


Figure 39: Pie Chart Illustration of Septic Mixture Content during the Building in Use – Location 1

4.2 Analysis of High-Rise Apartment Complex – Colombo 03

Data of this building is collected during the construction process and in the partial occupancy of the building. The study is based on quantitative data collected, and the collected data is used to forecast calculations of probable volumes of excreta, urine, and water discharge during the full of occupancy.

4.2.1 Septic Collection During the Construction Period – Location 2

Table 11 shows the summary of the data used for the calculations which were collected during the questionnaire and literature survey.

Table 11: Summary of Data Collected During the Construction Phase in Location 2 (Case 2)

Ref.	Description	Value
i	Average Workers per Day	1,500 (1,340 labours and 160 Officials)
ii	Number of Water Sealed mobile Latrines	12
iii	Number of Urinals	16
iv	Water Consumption per Flush of Water Sealed Latrine	7.5 L
vi	Average Water Usage for Washing per Person in Single Use	1.8 L
vii	Water Consumption per Flush of Urinal	1.5 L
viii	Average Excreta Discharge by Person Per Day	130 g
ix	Density of Human Excreta	1.075 g/ml
x	Average Urine Discharge by Person per Day	1.4 L
xi	Percentage Dry Mass of Human Excreta	25%
xii	Percentage Dry Mass of Urine	10%

Accordingly to the data present in the Table 9 above values of i, ii, iii, iv, v, vi and vii were find out by questionnaire and values of viii, ix, x, xi, and xii were find out by literature survey.

Discharge Volume of Excreta

Excreta discharge was calculated separately for officials and labours due to the percentage of people use onsite sanitary facilities to discharge excreta vary significantly. It was noted that 40% of officials and 80% of Labours discharge excreta during the working hours during the questionnaire. In addition to that it is noted that onsite sanitations facilities usage is higher compared to the location 1bacuase of the longer work shifts followed during the site works.

Discharge Volume of Excreta by Officials per Day (V_{11})

$$\mathbf{V_{11}} = \frac{(160\ \text{Persons} \times 130\text{g/person}) \times 40\%}{1.075\ \text{g/ml}}$$

= 7,739.53 ml / day

= 7.734 **L**

Discharge Volume of Excreta by Labours per Day (V_{12})

$$\mathbf{V_{12}} = \frac{(1{,}340\text{Persons} \times 130\text{g/person}) \times 80\%}{1.075\ \text{g/ml}}$$

= 129,637.21 ml / day

= 129.64 **L**

Total volume of Excreta Collected per day (V_{13})

$$\mathbf{V_{13}} = \boldsymbol{V_{11}} + \boldsymbol{V_{12}}$$

= 137.37 L

Water Usage during the Excreta Discharge (V_{14})

It is assumed that single flushing per person for after discharge of excreta.

$$\mathbf{V_{14}} = (7.5+1.8)\ \text{L} \times (160 \times 40\% + 1340 \times 80\%)$$

= 10,564.8 **L**

Discharge Volume of Urine per Day (V_{15})

It is observed that the number of times urine passes during the working hours about 4 times on average per person daily. Working time at site is ranging from 12 to 15 hours in a normal day. It can be assumed that 60% of generated urine of a person discharges during the working time.

V_{15}	$= 1{,}500 \times 1.4\text{ L} \times 60\%$
	= **1,260 L**

Water usage during the Discharge of Urine (V_{16})

It is figured out that flushing of urinals does not accomplished by each single use of workers as in the location. It is assumed that flushing percentage is 40% from the number of uses.

V_{16}	$= 1{,}500 \times 4 \times 1.5\text{ L} \times 40\%$
	= 3,600 **L**

Total Volume of Used Water Discharged per Day (v_{17})

V_{17}	$= V_{14} + V_{16}$
	= **14,164.8 L**

Total Volume of Septic Mixture Collected Per Day (V_{18})

V_{18}	$= V_{13} + V_{15} + V_{17}$
	= 15,562.17 **L**

Table 12: Septic Mixture Content During the Construction of Site – Location 2

Ingredient	Volume per Day (L)	Volume per Month (L)	Percentage
Excreta	137.37	4121.1	1%
Urine	1,260	37,800	8%
Used Water	14,164.8	424,944	91%

Table 12 shows that 91% percent of septic mixture contains water. Wet volume of excreta collected per day is about 1% of the total septic mixture. According, to the stats obtain from the literature dry mass of human excreta is about 25%. Hence dry volume of human excreta is collected 1,030.28 litters monthly. 14,164.8 L of used water discharged to the septic tank daily and it can be reused if onsite treatment facility is introduced. Monthly it can be saved about 424,944 L of water. Treated water can be used for flushing and other non-drinking purposes during the site works.

Following monthly savings are possible, if onsite treatment facility is introduced to the site during the construction phase.

- Savings from reuse of water - Rs, 38,244.60
- Savings from cost of removal of septic mixture – Rs. 95,000.00
- Savings from rent of excess temporary septic collection tanks – Rs. 30,000.00
- Total savings per month – Rs. 163,244.60.
- Total possible savings during the construction period – Rs. 9,794,676.00

There are same practical issues as to address to obtain above savings during the site works as discussed under analysis of Location 1. It is required to introduce convenient onsite treatment facility at an initial capital cost. Latest available techniques such as packaged onsite treatment facilities in Saitama Japan, forward osmosis toilet systems with resource orientation, composting toilets, electrochemical disinfection of toilet wastewater and black water treatment using solar septic tank are required to analyzed. Cost of capital, installation, maintenance of mentioned technologies is required to identify. In Sri Lanka use of human excreta and urine-based composts, fertilizers or soil improvers are not popular yet. There is an opportunity to convert them into effective agricultural products and promote. This can be generated new job opportunities while contributing to the economy of the country, reduction of water usage and reduce potential damage to the environment because of improper discharge of septic.

It is observed that awareness and concern on importance of septic management among the workers are at very lower level. Instead of the workers officials do not take it much seriously and they do obey only to the minimum regulations to be adhered on septic discharge during the site works. Keen interest in this area is required to be overwhelmed in national level. Technology and knowledge transfer to public level is required to conduct aware importance of onsite septic management at the household level.

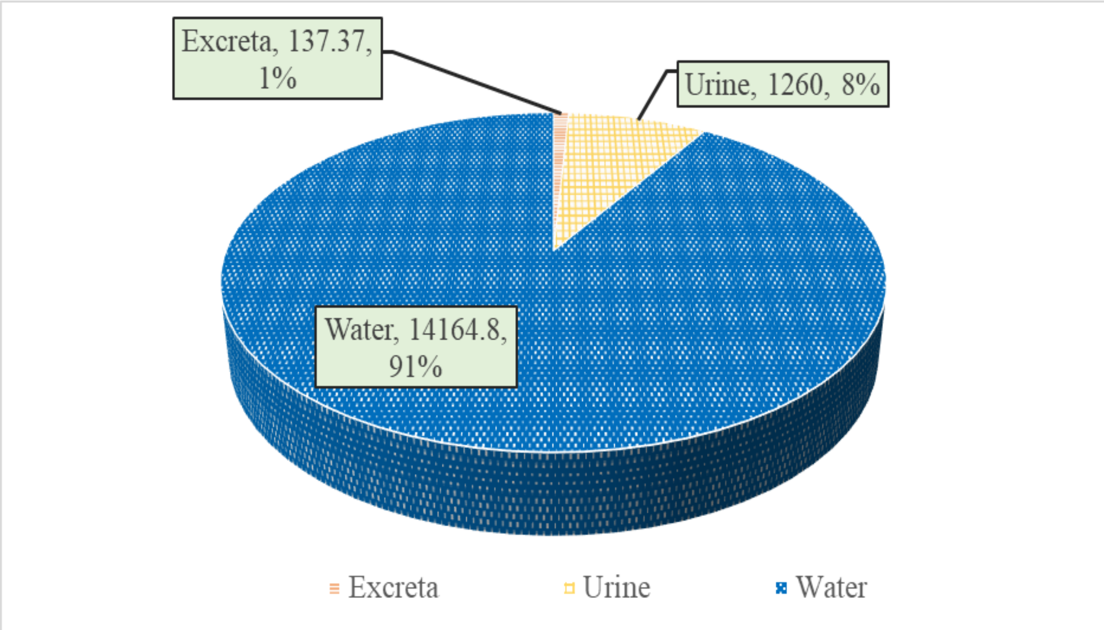


Figure 40: Septic Mixture Content during the Construction – Location 2

4.2.2 Septic Collection During the Occupancy of the Building – Location 2

This building is consisted with 4 towers of high-rise nature with 42 floors of each. There is about 608 apartments units, commercial area with shops, supermarkets, restaurants. All bathrooms and washrooms are equipped with water sealed commodes. There are separate piping systems to collect commode discharges and other used water from bathrooms, kitchens and wash areas. There is no separate collection or discharge of collected wastewater. All the used water sources are directly discharged into the municipal sewer network.

During the collection of data there was only 45% of occupancy in the building. Forecasted calculations were made during the total occupancy of the building assuming that similar nature of living pattern during the time of full occupancy. Discharged volumes of excreta, urine and wastewater were calculated using the collected data. Table 13 shows the summary of data used for the calculations which were collected during the questionnaire and literature survey.

Table 13: Summary of Data Collected During the Building Occupancy in Location 2

Ref.	Description	Value
i	Building Arrangement	Apartment Units - 608 Showrooms in the Commercial Area – 20 Restaurants - 4
ii	Average Total Occupancy in Apartments	2,400
iii	Building Maintenance, Operation & Security Working Crew	45
iv	Restaurant Working Crew	26
v	Show Room Regular Staff	35
vi	Average Customers from Outside	200
vii	Cistern Capacity of the Bathrooms	4.5 L per Flush
viii	Per Person Daily Water Consumption for Cooking	5 L
ix	Per Person Daily Water Consumption for Bathing and Toilets	70 L
x	Per Person Daily Water Consumption for Washing Clothes and Utensils	35 L
xi	Per Person Daily Water Consumption for Other Needs	5 L
xii	Average Excreta Discharge by Person Per Day	130 g
xiii	Density of Human Excreta	1.075 g/ml
xiv	Average Urine Discharge by Person per Day	1.4 L
xv	Percentage Dry Mass of Human Excreta	25%
xvi	Percentage Dry Mass of Urine	10%

Data represented in the numbers xii, xiii, xiv, xv and xvi were obtained from the literature survey carried out in the Chapter 2.

Discharge Volume of Excreta per Day (V_{19})

This building is occupied by different groups of people such as residents, officials, restaurant workers and outside customers. Occupancy and use of building premises vary depending on each category. Hence, different diversity factor is used for each category.

Volume of excreta discharge by occupants calculated using the Equation 1.

Equation 1

$$\textbf{Excreta Volume (ml)} = (\mathbf{X\ No.of\ Person}) \times (\mathbf{130\ g/Person}) \times \mathbf{DF\%}/(\mathbf{1.075\ g/ml})$$

Calculated values are shown in the Table 14.

Table 14: Discharge Volume of Excreta Per Day in Location 2

: Category	Occupancy (X)	Diversity Factor (DF)	Volume (L)
Residents of Apartments	2400	0.7	203.16
Maintenance Staff	45	0.6	3.27
Restaurant Workers	26	0.7	2.20
Showroom Officers	30	0.2	0.73
Customers (Outside)	200	0.05	1.21
Total (V_{19})			**210.56**

Discharge Volume of Urine per Day (V_{20})

Volume of urine discharge by occupants calculated using the Equation 2.

Equation 2

$$\textbf{Urine Volume (ml)} = (\mathbf{X\ No.of\ Person}) \times (\mathbf{1.4\ L/Person}) \times \mathbf{DF\%}$$

Calculated values are shown in the Table 15.

Table 15: Discharge Volumes of Urine Per Day in Location 2

Category	Occupancy (X)	Diversity Factor (DF)	Volume (L)
Residents of Apartments	2400	0.65	2,184.00
Maintenance Staff	45	0.6	37.80
Restaurant Workers	26	0.6	21.84
Showroom Officers	30	0.6	25.20
Customers (Outside)	200	0.1	28.00
Total (V_{20})			**2,296.40**

Used Water Discharge per Day

Amount of water usage is varied based on the occupant nature. Hence, separate calculations carried out to calculate the volumes of used water discharge by each group of occupants. Volume of used water discharge by occupants calculated using the Equation 3.

Equation 3

$$\textbf{Used Water (L)} = (\mathbf{X\ No.\ of\ Person}) \times (\mathbf{Y\ L/Person}) \times \mathbf{DF\%}$$

Volume of Used Water Discharge by Apartment Residents (V_{21})

Calculated values are shown in the Table 16 below.

Table 16: Discharge Volumes of Used Water by Apartment Residents in Location 2

Category	X	L/ Person (Y)	DF	Volume (L)
Cooking	2,400	5	0.7	8,400
Bathing and Toilets	2,400	70	0.8	134,400
Washing Clothes & Utensils	2,400	35	0.8	67,200
Others	2,400	5	0.65	7,800
Total (V_{21})				**217,800**

Volume of Used Water Discharge by Other Occupants (V_{22})

Calculated values are shown in the Table 17.

Table 17: Discharge Volumes of Used Water by Other Occupants in Location 2

Category	(X)	L/ Person (Y)	DF	Volume (L)
Maintenance Staff	45	13	0.9	526.5
Restaurant Workers	26	10	0.85	221
Restaurant Cooking & Washing	175	3	0.85	446.25
Showroom Officers	30	13	0.9	351
Customers (Outside)	200	1.5	0.8	240
Total (V_{22})				**1,784.75**

Total Volume of Septic Mixture Collected Per Day (V_{23})

$\mathbf{V_{23}}$	$= V_{19} + V_{20} + V_{21} + V_{22}$
	= **222,091.71 L**

Table 18: Septic Mixture Content During the Use of the Building in Location 2

Ingredient	Total (L)	Percentage
Excreta	210.56	0.2%
Urine	2,296.40	1%
Used Water by Residents	217,800	98%
Used Water by Other Occupants	1784.75	0.8%
Total	**222,091.71**	**100%**

Table 19: Discharged Volumes of Black Water and Grey Water During the Use of the Building in Location 2

Ingredient	Amount (L)/ Day	Percentage
Black Water	67,786.96	26.83%
Grey Water	184,845	73.17%
Total	**252,631.96**	**100%**

Accordingly, to the above calculated values in the Table 18, about 99% of septic mixture contains water. Contaminants accumulated in the used water such as soap, chemicals, food remaining, and other washouts are did not considered separately and percentage volume of those contaminants are smaller. Quantity of water discharged with septic mixture is approximately 6,329,610 L (6,329 m^3) monthly. Potential saving per month if the used water reused after treatment is about 569,664.9 LKR monthly. Saving of water can provide benefits in terms of monetary value as well as reduce burden on the municipalities to cater water demand in the city.

Monthly discharged wet excreta volume is about 6,316.8 L (6,790.56 Kg). Obtainable dry mass of the excreta is about 1,697.64 Kg monthly. This can be used as a soil improver or convert into usable fertilizers with additives. In addition, human excreta can be used to generate biogas when collected by larger quantities. The conversion of human excreta as biogas can provide various benefits in terms of environmentally and as an alternative energy source. However, due to the inconsistency of daily receival of human excreta, it should be collected excreta from multiple locations when introducing biogas plant. Monthly discharged net urine volume is about 68,892 L (70,200.95 Kg). Dry mass of urine discharge per month is about 7,020.1 kg which consists of inorganic salts and organic compounds.

Following potential monthly savings can be obtained when introduce onsite treatment facility for septic mixture.

Savings from reuse of water – 569,664.9 LKR
Total dry mass collectible from urine and excreta – 8,717.74 Kg/ month

However, it is required to identify optimum technology to introduce for separation of urine, excreta, used water and convert them into usable products. Further research and practical applications are required in the area.

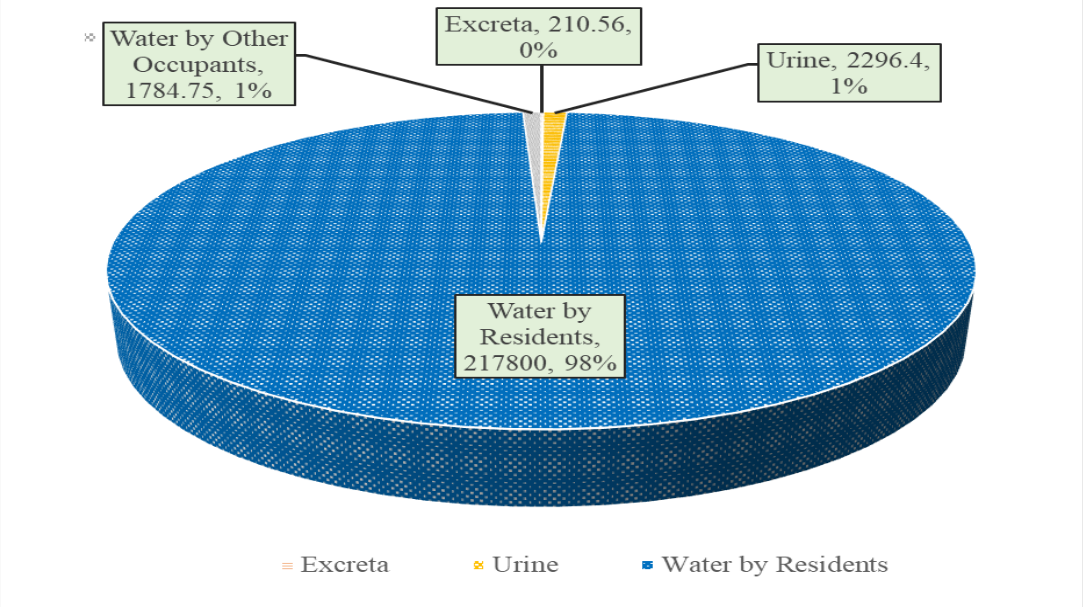


Figure 41: Septic Mixture Content During the Occupancy – Location 2

4.3 Analysis of Government Office Building at Narahenpita – Location 3 (Case 3)

Peak occupancy of this office building is 600 persons per day. Conventional wastewater treatment plant is there with capacity of 72 m^3/ Day. Treated water is discharged into the nearby canal without reuse. Sedimentation is transported as sludge. Energy consumption of the plant is 32.4 kWh per day when operate at its maximum capacity. Energy is consumed for conveyance and collection was caused massive use of energy. Electricity bill for use of the plant is cost approximately 12,500 LKR monthly. Despite of that cost for the spare parts, maintenance, repairs, and operation charges are incurred. Time has arrived to introduce new technologies such as resource recovered toilet systems, electrochemical disinfection and usage of solar septic tanks rather than rely on the conventional treatment systems.

5. DISCUSSION

Human generated waste management has become a national level concern with the increase of population in Sri Lanka. Current septic management procedure must overcome in certain aspects to deliver sustainable management of human generated waste. This study is carried out to identify current state of the art of the septic management in Sri Lankan context, and to investigate septic management techniques worldwide since ancient times to present. Data were collected from sites in Colombo as well as from the municipal council of Colombo which is one of high-density urban council in Sri Lanka. Data were analysed and results were derived about the present urban septic management approach in condominiums and apartments. This chapter discusses the effectiveness of current practice of septic management compared to the technologies available in the world.

In urban areas of Sri Lanka around 76.5% of households have separate connections to water sealed latrines [82]. About 5% use a central sewage collection system. In Tokyo more than 95% of septic is handled by central systems [83]. In cities like Mumbai and Bombay in India, about 40% of septic is discharged unsafely into the environment [84]. In Sri Lanka, as a rule, all buildings are supposed to use an onsite septic treatment plant or septic collection facility if central system is not available to discharge. In 2008, 66% of the population in Colombo had access to onsite sanitation facilities, 25% of them had connected to sewerage systems and 9% had no facilities [85].

In building sector there are two phases to handle septic. During the construction process of a building, septic is usually handled by using temporary septic storage facilities and discharge them via gully bowsers on monthly or twice a week. Three multi-storey buildings were selected for this study and two of them discharge septic into the central sewer system and third one uses onsite treatment facility. According to the calculation results of data obtained from Location 1 and 2 (Case 1 & 2), it was figured out that 98% of building discharges are contain water.

As per Table 10 and Table 19, grey water makes up about 73% of the discharged water mixture during the use of buildings in the Location 1 and 2 (Location 1 – 15,360 L/Day, Location 2 – 184,845 L/Day). The reuse of water from the discharged grey water is not considered in the current practice of sewage management system. However, water, urine, and faces were separated in the lavatories used in ancient Buddhist monasteries [14]. It can be found urine and faeces separation systems which are used currently in Japan and Germany [32] [51].

In addition to separation of urine and excreta in ancient era, there were examples found in the China and Japan on use of them as fertilizer after pre-treating. In currently there is no practice to use the faecal based agricultural fertilizers in the Sri Lanka in a commercialized level. There was an example found in the Matara district about use of direct discharge of excreta and urine as fertilizer for coconut cultivation. However, direct use was caused to health effects of workers and control of pathogens before application was required. There was a positive outcome of increase of the nut production by 20% [8]. Co - composted dewatered faecal sludge (FS) with organic fraction from municipal solid waste (MSW) has high ability to be introduced as an agricultural fertilizer in Sri Lanka. There are several advantages of use FS – MSW fertilizers within the country such as cost recovery of waste management, closing the nutrient and carbon cycles between urban and rural areas area, potential substitution for mineral fertilizers and reduction of environmental pollution. Currently, knowledge about the usage of FS – MSW as a fertilizer is very little and reasonable research and generate practical application are required for extended use. Co-composting of faecal sludge and municipal solid waste is incurring low cost technology that is capable in use for developing countries as a solution for waste and toilet waste management. Urban areas in the Sri Lanka mostly uses on site storage of faecal sludge and lack of application of the proper treatment procedure. Higher Nitrogen content in the faecal sludge increases the value and possible usage as a fertilizer. Palletisation can use to reduce the bulk density and make simpler application in the field. Uncertainty is existed about effect on the soil and plant growth and cost effectiveness to be further studied.

Human excreta have been shown good fertilizing characteristics, providing essential plant nutrients and organic content contributing to soil structure and controlling erosion [86]. With adequate heat treatment like composting, all harmful pathogens in human excreta can convert into safe product to apply in agriculture.

Demand for the food is growing and cost of the cultivation is getting higher are major challenges in the agriculture. Phosphorous reserves are diminishing, and production of nitrogen fertilizers are energy intensive [87]. It is required to focus on reuse of different organic fertilizers such as manures and excreta.

Phosphorous is a key nutrient requirement in crop cultivation. As per the estimates, current affordable and comparatively conveniently extractable phosphate rock reserves remains for another 50 to 100 years [88]. In addition to that quality of the phosphorous mineral is lowering. Continues production of nitrogen fertilizers is another key challenge to face in food production industry. Production of nitrogen is highly energy intensive.

Nutrients in the human urine can be reused with source separation and fertilisation. Human urine is a combination of main nutrients and micronutrients in soluble manner, however it contains chemicals, like pharmaceuticals and hormones [87].

Contamination of monthly collected human excreta and urine in the location 1 and 2 are tabulated below.

Table 20: Composition of Excreta and Urine Discharged in Case 1& 2

Parameter	Location 1 - Monthly		Location 2 - Monthly	
	Excreta (Kg)	Urine (Kg)	Excreta (Kg)	Urine (Kg)
Wet Mass	624.04	4,990.10	6,790.56	68,210
Dry Mass	156.01	499.01	1,697.64	6,821
Organic Matter	144.31	374.26	1,570.32	5,115.74
Nitrogen	9.36	84.83	101.86	1,159.57
Phosphorus (AsP_2O_5)	6.55	18.71	71.30	255.79
Potassium (AsK_2O)	2.73	18.71	29.71	255.79
Carbon (C)	74.10	69.86	806.38	954.94
Calcium (AsCaO)	7.02	26.20	76.39	358.10

[39]

Table 21:Potential Quantitie of N, P & K

Case	Description	Potential Dry Mass of N, P & K can be Recovered						
		Quantity (kg)	**N (kg)**	**%**	**P (kg)**	**%**	**K (kg)**	**%**
1	Excreta	156.01	9.36	6	6.55	4.2	2.73	1.75
	Urine	499.01	84.83	17	18.71	3.75	18.71	3.75
	Total	**655.02**	**94.19**	**14.38**	**25.26**	**3.86**	**21.44**	**3.27**
2	Excreta	1697.64	101.86	6	71.3	4.2	29.71	1.75
	Urine	6821	1159.57	17	255.79	3.75	255.79	3.75
	Total	**8518.64**	**1261.43**	**14.81**	**327.09**	**3.84**	**285.5**	**3.35**

As per Table 21 urine contains higher nitrogen percentage compared with excreta. Average price of solid nitrogen is about 35.7 USD/kg (LKR 7207.06). Total extractable quantities of phosphorus and potassium are less compared to the nitrogen. Reuse of organic and low cost production of N, P and K are important and much needed requirement with prevailing global situation.

As per the Table 20 monthly discharged organic matter from urine and excreta is about 518.57 Kg and 6,686.06 Kg respectively in Location 1 & 2. Organic fertilizer requirement of selected crops during the cultivation and number acres can use the organic portion of the urine and excreta generated in the Case 1(Location 1) and Case 2(Location 2) throughout the year is tabulated as below.

Table 22: Organic Fertilizer Requirement of Crops

Crop	**Number of Plants/ Acre**	**Organic Fertilizer Requirement/Acre (Until Harvesting)**	**Case 1 (Num. of Acres)**	**Case 2 (Num. of Acres)**
Paddy	Varies	2,000 Kg	3.12	40.08
Banana	550	5,550 Kg	1.08	14.4
Coconut	64	3,840 Kg	1.68	20.88

The Table 22 shows the probable capability of provide organic fertilizer requirement for paddy, banana and coconut by use of converted products of urine and excreta generated in Case 1 and Case2 [89] [90] [91] [92]. Organic fertilizer requirement of the above-mentioned crops can be fulfilled with proper conversion of the excreta and urine. Further studies and field testing are required to identify effectiveness comparatively with other available fertilizers. Recently in Madagascar it has been tested the use of human excreta-based compost (3 Different compositions) as a fertilizer in maze cultivation. They have observed the 20% increase of yield [93]. It is required to analyse overall discharged volumes of human excreta and urine in the entire urban Council or country to decide the possibility of convert them to use as current demand of organic fertilizer. Table 23 below shows that potential harvest of the crops mentioned in the Table 22 if use of converted organic matter of the urine and excreta generated in the Case 1 and Case 2 [94] [95] [96] [97] [98].

Table 23: Potential Crop Production with Use of Converted Urine and Fecal Sludge Discharged in Case 1 and Case 2

Crop	Average Harvest Per Acre	Potential Crop Production Per Year			
		Case 1		Case 2	
		Acres can Fulfil	Harvest	Acres can Fulfil	Harvest
Paddy	Varies	3.12	6,240 Kg	40.08	80,160 Kg
Banana	550	1.08	8,640 Kg	14.4	115,200 Kg
Coconut	64	1.68	10,164	20.88	126,324

As per the potential harvest shown in the Table 23 it possible to cater rice requirement of 1 month, banana requirement of the year and coconut requirement of 3 month of occupants in the Case 1 and 2.

Banana requirement per month for small family lives in Colombo is about 3 – 4 kg. Most of the fruits and vegetables are transported to the Colombo from Dambulla. Approximately 5,500 – 6,000 kg's of bananas can transport by using a medium size lorry in a single trip.

Population of Colombo city is about 619,000 [99]. There are more than 100,000 families live currently. Hence approximate banana requirement for families is about 300,000 kg per month. It is required to complete minimum of 50 turns of banana transport Lorries to cater monthly banana demand of the Colombo. CO_2 emissions from a gallon of diesel is around 10,180 grams CO_2/ gallon [100]. Round trip from Dambulla to Colombo is 320 km. 8.5 gallons of diesel is required for a single trip. Hence amount of CO_2 emissions are about 4326.5 kg per month. Mentioned amount of emissions can be reduced if households or farmers nearby the Colombo are motivated to grow banana within the city limits with use of organic fertilizer which can be generated by use of human excreta and urine. Conversion of human excreta and urine to useful fertilizers will be caused to generate new job opportunities and contribution to the greening.

Latest government restriction is imposed to use of chemical fertilizers for agricultural industry. Organic matter in the human excreta and urine can be converted into usable organic formations to cater organic fertilizer requirement in the agricultural sector of the country. Population of Sri Lanka is about 21,512,181 [79]. Daily discharge amount of wet excreta and urine is about 2,601,473.051 Kg and 29,967,217.31 Kg respectively. Dry components of the excreta and urine are about 650,368.26 Kg and 2,996,721.731 Kg respectively. If it is possible to convert 80% of the dry component to usable agricultural product daily convertible amount will be 2,917,671.993 Kg. This amount can be fulfil the organic fertilizer requirement of 1,459 acre of paddy [80]. On average 1,904,000 acres are cultivated during maha and 1,054,000 acres are cultivated during yala [81]. Total number of acres of cultivate paddy is about 2,958,000 yearly in Sri Lanka. Around 20% of the yearly organic fertilizer requirement can be fulfilled by converting of yearly discharge amount of excreta and urine. If daily discharged amount converts and use for banana it can be fulfil about organic fertilizer requirement of 525.71 acres. Currently in Sri Lanka there are about 60,000 Ha (204,000 Acres) of land use for banana cultivation [101]. 94% of the yearly organic fertilizer requirement of banana can fulfil with use of yearly discharge of urine and excreta of the country population.

Reuse of recycled water is an important aspect in sustainable management of water sources. In addition, it can be reduced the burden to supply water in the highly populated urban councils. In Colombo water demand per capita per day is about 112 litters [102]. Domestic demand for water is increased by more than 2.9 million cubic meters per year [102]. This amount is more than 5% of the existing water supply capacity. Discharged quantities of water, urine, and excreta in the Location 1 and 2 (Case 1 and 2) are tabulated below.

Table 24: Volumes of Water, Urine and Excreta from Apartment Residencies 1

Ingredient	Volume/ Day (L)	Volume/ Month (L)
Excreta	19.35	580.8
Urine	168	5,040
Water	20,590.14	617,704.20
Other	209.87	6,296.1

Table 25: Volumes of Water, Urine and Excreta from Apartment Residencies 2

Ingredient	Volume/ Day (L)	Volume/ Month (L)
Excreta	210.56	6,316.8
Urine	2,296.4	68,892
Water	217,362.83	6,520,884.90
Other	2,220.92	66,627.6

Separation of excreta, urine and water yields economic and environmental benefits by converting them to usable products. The commercial worthiness of this end product needs to be researched extensively. Phosphate, an essential fertilizer (how much) element for agriculture is found in faecal sludge [103]. On-site or off-site methods for treating or converting urine and excreta into usable fertilizer can be accommodated depending on room capacity, discharge volume, and end-product applications. According to the above statistics, if treated sewage water is used for gardening or flushing, an estimated monthly saving of LKR 51,948.00 from apartment complex 1 and LKR 624,366.00 from apartment complex 2 can be achieved. Yearly discharged amounts of used water are 7,412.45 m^3 and 78,250.62 m^3 in location 1 and 2 respectively. This amount is approximately 0.15% of the supply water currently available for all users.

Urban municipalities in Sri Lanka are faced a challenge in meeting the water demand and maintaining a stable water supply. Water discharge from buildings, industries and etc. can be treated primarily and secondary to convert them into reusable conditions. The technologies are used in Saitama, Japan, are real-world examples that can be implemented in Sri Lanka. The two apartment complexes considered for data collection in this study will save about 89,935.20 cubic meters of fresh water per year. To imagine real picture, further research is required to determine the amount of freshwater discharges to the ecosystem without reuse in Sri Lanka's densely populated urban councils in larger scale. Future study must be carried out to figure out most convenient treatment arrangement with concerns of space availability, technologies available and contribution to the environment. Aside from that, as in Tadotsu, Japan, treated water is reused to create ecological habitat and improve the natural environment in the area. Rather than discharge filtered or partially treated water into river streams or the sea, the attractiveness of urban areas and tourism enhancement can be accomplished by well-planned and maintainable implementation of such locations within the city [32].

In Sri Lanka 93% of the population has safe access to improved sanitation facilities [85]. Out of those more than 99% of them are water sealed latrines. Time has arrived to upgrade the current systems of sanitation to more sustainable technologies use in the world. Selection of sanitary system is supposed to carry out with concern of several aspects such as number of occupants in the location, number of lavatories, availability of water supply and usage, discharge procedure of septic, space availability in the location and possible ways to manage converted content in the septic mixture.

In 2015, China adopted six separate non – harmful lavatory systems to improve sanitation, hygiene, and reduce the spread of infectious diseases [25]. Five of the six is designed with the capability of treating human excreta and urine partially or completely on site. Those lavatories were designed for single-family use. However, the idea of techniques can be applied during the construction phase and during the occupancy of buildings. The following discussion address the applicability of each technique.

Three Septic Tank Type – Arrangement is making with three septic tanks which are allows to flow toilet waste from one after one. The first chamber serves as a settler, while the second serves as a post settler and scum separator, and the third serves as a storage tank. This arrangement requires centralized treatment plants and vacuum trucks to remove accumulated sludge. Urban areas of Sri Lanka have those facilities. However, allocate space for build-up tree number of septic tanks with larger volume are not practical. This arrangement reduces the amount of faecal sludge to remove by the municipalities by allowing reuse of partially treated water. However, removal of collected faecal sludge is supposed to be carried out at a cost.

Double Vault Funnel Type and Double Pit Alternative – Prefabricated vaults/ pits made out of ceramic, cements or composites are used to post composting of separated septate mixture liquid. Then it is applying as fertilizer or only used as soil improvement prior to plantation. Those arrangements are not practical to use in highly populated urban areas due to limited space availability to build up vaults/ Containers for certain days for post composting and non-availability of larger scale agricultural lands nearby.

Biogas Linked Toilet – Human waste is suitable for production of biogas which can be applied for cooking purposes and lighting. This system can be implemented in areas with warm climate. Most of the apartment complexes use LP gas for cooking. It is required to research on how effectively discharged human waste can be converted as biogas in the apartment complexes and potential economic benefits of the system.

Possible biogas production quantities as per the analysed data from Case 1 and Case 2 are calculated and results are shown in the Table 26 below.

Table 26: Potential Biogas Production in Case Studies

Case	Urine (kg/month)	Excreta (kg/month)	Total (kg/month)	Biogas Production (m^3)	Monthly Consumption (m^3/month)	Sufficiency
1	624.04	4,990.10	5,614.14	224.57	3.34	67
2	6,970.56	68,210	75,180.56	3,007.22	3.34	900

As per the Table 26 it was assumed biogas consumption of a 4-member family per month is about 3.34 m^3. Based on that in Case 1 and 2, biogas requirement of all apartment units can be fulfilled with conversion of daily collected volumes of urine and excreta.

Urine and Faeces Division Toilet – In this arrangement urine and faces are handled separately and diluted urine directly use as a fertilizer. For a safe treatment, faces are dehydrated. This is possible to implement within the apartment complexes, however, it is required initiate the process during the designing and construction phase. It is necessary to collect urine and excreta in two separate pits in order to use divisible units of urine and excreta. The disadvantages of implementing this scheme in urban areas include the need to reserve space for collection pits and the expense of transporting collected quantities to appropriate locations for further treatment or application. The market or financial value of the discharged material is unknown or has not yet been initiated.

Resource-oriented toilet systems combined with Forward Osmosis could provide a long-term solution for human waste management in Sri Lanka. In a resource-oriented toilet, forward osmosis (FO) technology can recover nutrients, clean water, nitrogen, biogas, and the heat from human urine and excrement [12]. Massive energy consumption, waste of resources, excess use of chemicals and cost of construction and maintenance are major drawbacks of the current sewage treatment plants. Under this consent there were seven different arrangements of lavatory systems. Table 27 below summarises different aspects of the seven varieties.

Table 27: Aspects of Seven Different Resource Oriented Lavatory Systems

Type	Options Available				
	Water Supply	**Drainage**	**Urine Treatment**	**Black Water Treatment**	**Use of Solar**
1	Yes	Yes	No	No	No
2	Yes	Yes	Yes	No	Yes
3	Yes	Yes	Yes	No	No
4	Yes	No	Yes	Yes	Yes
5	Yes	No	Yes	Yes	No
6	No	No	Yes	Yes	Yes
7	No	No	Yes	Yes	No

In this arrangement, urine and faeces are separated by vacuum urine diversion. Yellow water treatment is accomplished by combination of Forward Osmosis and Reverse Osmosis. Liquid fertilizer obtained by concentrating the yellow water via FO and simultaneously RO system is applied to recycling of the draw solution from FO system and recollect flushing water from same time. Blackwater is treated by anaerobic digestion by delivering Biogas and Bio waste as end products. According, to the tested results of above systems it is obvious that resource-oriented toilet systems provide higher benefits in environmentally and economically with comparison to conventional toilet systems and treatment plants [104]. The onsite treatment found in the Location 3 (case 3) under the data collection section do not yield commercially applicable end products. Treated water is dumped into a nearby canal without being reused, and sediment is hauled to cement plants. There was no possible way to recover the cost of construction and cost incurred for the plant maintenance and operation. The use of resource-oriented toileting systems or improvements to existing discharge procedures may be a more cost-effective and ecologically friendly alternative for the long-term management of human waste in Sri Lanka's urban areas. By evaluating the state of the art of the septate discharge from the two apartment residencies (Case 1 and Case 2), it can be converted into resource oriented facility by introduce modifications such as urine diversion, treatment facility (with membrane system, anaerobic digester, and solar cells), and alternate piping and pumping. Table 28 compares the expected benefits and drawbacks of the existing septate disposal system in the Case 1, 2 & 3 vs. a resource – oriented septate disposal system.

Table 28: Comparison of Existing Septic Management Techniques with ROS

Aspect	Municipal Sewer System (Apartment Complex 1 &2)	Onsite Septic Treatment Plant (Office Building Narahenpita)	ROS
Cost of Construction	Lower	Higher	Higher
Cost of Maintenance	Lower	Medium	Higher
Separation of Urine, Faces and Water	Not possible	Not Possible	Possible
Environmental Friendliness	Less	Acceptable	Higher
Burden for the Municipalities to Dispose Septage	High	Lesser	Lesser
Water Saving	No	No, Discharge into the nearby canal	Can reuse the water for flushing and gardening
End products with commercial value	No	No, only sediments collected by Cement Factories	Yes
Energy Consumption	Passive System	Higher	Less, can operate with solar energy
Return on Investment	No Return	No return on financially, End products are less harmful to environment	Higher

Composting toilet concept is a novel technique accordance to the todays understanding of sustainability by reducing water and wastewater flow out from the building. Lack of knowledge and awareness is caused to non-popularity of the concept. Interest on the composting toilets increasing in the worldwide with concept of sustainability [11].

Composting toilets do not use water and majorly rely on foam for flushing. Composting toilets are sometimes known as dry, biological, bio, or waterless toilets [11]. This system contains toilet and composting tank as the two primary components. This can be used as individual or centralized system for housing units. Composting tank in the system collect all the waste and digested them aerobically or with use of earth worms. Final products from these toilets produce stable, high molecular weight and dissolved organic matter which can be recycled as soil fertilizers [11]. Toilet flushing water use in apartment complexes 1 and 2 is 192 m^3 and 2,304 m^3 per month, respectively. When compared to the existing flushing fittings of two apartments, water flushed type composting toilets consume 92 percent less water. As a result, water usage in apartment complexes 1 and 2 can be reduced by 176.64 m^3 and 2,119.68 m^3 per month, respectively. Furthermore, the volume of excreta and urine discharged can be treated within the house without requiring municipalities to manage it.

However, because of composting toilets is a new technique, it will take time to educate home users about the technique and put lot of effort to instil a positive attitude toward their use. When introducing composting toilets to apartment complexes, another major challenge is end product management. After carefully analysing the space requirements for installation and maintenance, an existing building can be turned into a composting toilet system. Public acceptance, regulations, higher capital cost compared to conventional flush type toilets, odour and smell management, lack of understanding and considerable maintenance and operational requirements are the remaining barriers to new implementations.

In this study septic management of buildings considered during two major phases. During the construction phase, septic management is accomplished by the use of temporary storage facilities, with collected quantities conveyed to discharge areas by municipal gully bowsers or private sector gully bowser at a cost. According to statistics obtained from apartment complexes located in the Colombo municipality, there is minor concern about recycling of discharged urine, excreta and water during the site works. During the literature survey, it was identified applicable onsite treatment facilities which can be used during the site construction. In construction phase, technologies such as solar powered mobile electrochemical disinfection toilet units and black water treatment using solar septic tanks are ideal. The pilot scale photovoltaic powered self-contained mobile toilet system was tested at the California Institute of Technology. Electrolysis cell disinfection, according to the test results, may efficiently eradicate both virus and bacteria from toilet effluent. As a mobile toilet unit or decentralized wastewater treatment, this device must be developed to a commercial size. If the system is deployed during the construction phase of the residential complexes selected for this study, the following savings may be realized.

Apartment Residences - Colombo 08

Labour force used during the construction of the site is about 200 per day on average.

Average water discharge per day - 516 L (15,480 L/monthly)

Average saving from water if recovered – 1,400 LKR per month

Savings from the handling and removal of septic – 20,000 LKR per month

Total saving per month – 21,400 LKR

Total saving at the end of the building construction – 1,027,200 LKR (Period of 48 Months)

Apartment Residences – Colombo 03

Labour force used during the construction of the site is about 1,500 per day on average.

Average water discharge per day – 28,845 L (865,350 L monthly)

Average saving from water if recovered – 77.881.5 LKR per month

Potential savings from the handling and removal of septic – 125,000 LKR

Total saving per month – 197,881.50 LKR

Total saving at the end of the construction phase – 11,872,890 LKR (Period of 60 Month)

As a result, due to increase of water consumption with average number of workers, potential savings during the construction phase increase for larger scale projects. The initial disadvantages of mentioned techniques above are incurring of greater initial capital cost with compared to traditional lavatory systems and the need for specialized technical knowledge for operation and maintenance. In larger-scale projects, on the other hand, can save more money. As a result, the lavatory system should be chosen based on the project's duration, projected water demand, and expected septage collection. Those techniques can use during the occupancy of the buildings. However, it is necessary to conduct advance research in this area to identify best possible techniques to introduce in terms of contribution to the sustainability, environmental friendliness and cost effectiveness.

Because of the greater investment costs, trained labour requirements, and excessive maintenance of onsite or centralized sewage treatment plants in developing countries' are caused to create tremendous burden on municipalities. Alternative solutions must be found to alleviate the afore mentioned situation. The Asian Institute of Technology evaluated an up flow solar septic tank (UTST) and multi-soil layering (MSL) system that is a low-cost, effective option for underdeveloped countries. This system was put to the test in a real-world setting under a range of scenarios, yielding acceptable results within the testing country's norms. The adaptability of this technique in Sri Lanka must be investigated further.

Septic management is not a new notion. In the past, evidence of the use of environmentally friendly and safe disposal techniques were discovered through the literature review. Currently Sri Lanka is relied on the conventional practice of septic management without upgrading into technologies use in the modern world. Efficient management of septic is a national level issue in the country. New regulations to this sector must be implied to achieve sustainable management of human excreta, urine and used water. Public awareness on this must be increased via knowledge sharing sessions and conducting practical workshops with involvement of the public and the government sector.

6. CONCLUSION

Key findings, recommendations, limitations, and future directions are presented in this chapter.

Through this thesis the context of the human waste management strategies (Septage Management) incorporated in Sri Lanka are studied. Sri Lanka is a developing country consist with highly populated urban councils such as Colombo, Gampaha, Kandy, and Negombo. In Sri Lanka, 76.5% of households have access to separate water sealed latrines. In most domestic units, septate collects in a separate pit and it is manually removed on a regular basis. Usually, the period is depending on the size of the pit and occupancy. On average it is more than 5 years of time. With the growing population and the construction of high-rise and multi-story commercial and residential buildings in metropolitan areas, septate handling and disposal is becoming a major concern. Not all townships have access to the municipal sewer piping network for discharge septate. In densely, populated metropolitan areas, centralized offsite and onsite treatment plants are employed to assure the safe disposal of collected septate. However, functionality of the existing septic treatment plants is not up to the desired conditions.

Due to highly variable volumes of septic discharges, poor accessibility of gully sucker in urban dwellings, lack of operational knowledge, and poor system maintenance are caused to most of the current conventional onsite and offsite treatment systems in Sri Lanka are not the best solution to cater the increasing volumes of human generated discharges in sustainable manner.

Initially, literature survey was conducted to determine the various septate management approaches employed through history, from antiquity to the present day. Then data was collected from three buildings located within the Colombo municipal council. Structured questionnaires were used to gather, information on the volumes of expelled excreta, urine, and utilized water. Questionnaires were based on the quantitative and qualitative aspects. The importance of effective septic disposal, as well as public understanding of septic management and the obstacles encountered in present practice, were questioned. Septic handling, generated volumes and water usage were studied during the construction phase and during the occupancy of selected places. Collected data was further analysed to identify content of the septic mixture, identify possible volumes of water can be reused, and amount of dry masses can be collected to convert as fertilizers or soil improvers The analysed data was used to compare existing septic management practice with techniques use in worldwide.

During the comparison with the approaches and technologies used/tested around the world to manage septic, it was discovered that Sri Lanka relies on the traditional management systems. Poor attention on water consumption, minor actions to recover and reuse of used water, a lack of awareness of the potential long term and short term impacts on living beings and the environment due to improper septate discharge, and less understanding on the importance of septate conversion into usable products rather than discharge or disposal are all major flaws in Sri Lanka's current septate management practice. It is required to implement novel techniques available in the world in Sri Lanka to initiate sustainable management of septic rather than rely on conventional methods. This is a national level issue. Hence, government and public sector must focus on conducting of public awareness programmes and practical applications of latest techniques to develop keen interest on this sector.

6.1 Key Findings and Recommendations

Key findings of this research can divide into three categories: issues with the existing system, proposed mechanisms of septate treatment and their agro -economic potential.

6.1.1 Issues with the existing system

- In Sri Lanka 93% of the population has safe access to improved sanitation facilities. Out of those, 99% of them are water sealed latrines with collecting pit of septic. There is no separation and treatment of urine, excreta and used water.
- Offsite septic treatment plants use in the municipalities do not function as required due to lack of maintenance, lack of technical knowledge of operators and inability cater varying loads of septic collection.
- Septic collection tanks in construction sites, residential dwellings, and other locations are required to emptied by manually with use of gully bowser sucking or involvement of the direct labour. In Colombo only 25% of the population

has access to the central sewerage system and rest of the population is used onsite collection tanks. Non availability of access to the gully bowser and poor concern on heath of the workers who involved with manual cleaning are major issues with this procedure.

- Urban population of the Sri Lanka is about 25% currently. This will be increase by 65% by 2030. Rapid urbanization is caused to increase of construction of buildings in high rise or multi-storey nature. Management of septic during the construction phase and the utilization of the buildings will be a heavy burden to the municipalities with the current practice.
- At the discharge there is no separation of grey water and black water in most of the high rise/ multistore buildings at all.
- Importance of treat and reuse of used water is not recognized. Water usage of buildings selected to collect data are accounted for 0.15% of the supply water available for all users.
- Potential ability of convert urine and excreta as fertilizers or soil improvers to cater organic fertilizer requirement of the agriculture has not recognized. Based on the questionnaire, it was noted that more than 65% of the participants do not aware on importance of recycling of septic mixture.

6.1.2 Proposed Mechanisms of Septage Treatment

- For single dwellings: - Conventional pit latrines can be converted into the three septic tank type, double vault funnel type, urine and faeces diversion toilets or composting toilets.
- During the construction phase of the sites :- Current practice of the put burden on municipalities to remove septic from the construction sites can be reduced with introduction of resource oriented toilet systems, solar powered mobile electrochemical disinfection toilet systems or black water treated toilets using solar septic tanks with multi soil layering system.
- Buildings of high rise or multi-storey nature: - Onsite treatment mechanisms such as, biogas linked toilets, centralized composting toilets, resource-oriented toilet systems are best match to cater high volumes of generated septic in those buildings.

- In addition to above-mentioned on-site treatment/ management mechanisms of septic, it is required to introduce offsite/ centralized treatment facilities in highly populated urban councils such as Colombo, Kandy, Gampaha and Negombo. Primary and secondary treatment technologies that are used in the Saitama Japan and create ecological habitats to improve the natural environment in townships as Tadotsu, Japan are best alternatives.

6.1.3 Agro - Economic Potential of the Excreta and Urine

- Dry mass of human excreta contains 88 – 97% of organic compounds and it is comprised of 5-7% of Nitrogen, 3 – 5.4% of Phosphorous, 1-2.5 % of Potassium, 40-55% of Carbon and 4 -5 % of Calcium.
- Dry mass of human urine contains 65 – 85% of organic compounds and it is comprised of 15-19% of Nitrogen, 2.5-5% of Phosphorous, 3-4.5% of Potassium, 11-17% of Carbon and 4.5-6% of Calcium.
- Field application of converted human urine and human excreta-based soil improvers for maze cultivation in Madagascar was resulted to increase of yield by 20%.
- Direct application of human excreta mixture as fertilizer in coconut cultivated land located in the Matara, Sri Lanka has observed increase of nut production by 20%.
- 20% of the yearly organic fertilizer requirement for paddy cultivation or 94% of yearly organic fertilizer requirement for banana cultivation in Sri Lanka can be fulfilled by converting yearly discharged amount of excreta and urine by the total population of the country.

6.1.4 Recommendations

As a result of the research, the following set of recommendations are presented.

- It is recommended to introduce following mechanisms of the septic management systems based on the number of occupants.
    I. For a location with occupants persons less than 10 - three septic tank type, double vault funnel type, urine and faeces diversion toilets or composting toilets.

II. For a location with occupants between 10 to 500 - three septic tank type, resource-oriented toilet systems, solar powered mobile electrochemical disinfection toilet systems or black water treated toilets using solar septic tanks with multi soil layering system

III. For a location with occupants greater than 500 – biogas linked toilets, centralized offsite treatment facilities or create ecological habitats to improve the natural environment.

- Motivate farmers to apply human excreta and urine-based fertilizers by acknowledging the benefits can be encountered.
- Introduce and promote domestic level cultivation of fruits and vegetables within highly populated municipalities with use of converted excreta and urine. During the study of Case 1 and 2 it was identified that yearly banana requirement and 3 month coconut requirement of all occupants in the mentioned locations can be fulfilled with the potential harvest from residential cultivation of said plants with use of converted yearly discharged volumes of excreta and urine. In addition to that it will be helpful to reduce the carbon emission due to transportation of fruits and vegetables from far locations with contribution to the greenery. If banana requirement of the Colombo can be fulfilled within the city limits, it will be caused to reduce carbon emission by 51,918 Kg's yearly.
- Used water for toilets, bathing, washing, cooking and etc must be recycled to reuse for gardening and toilet flushing. Domestic demand for water is increased by more than 2.9 million cubic meters per year. This can be reduced with use of recycled water for non-drinking purposes. Water consumption in Case 1 and 2 is accounted about 0.15% of the supply water available for all users.
- Sanitary system must be selected based on number of occupants in the location, allowable discharge procedure of septic in the municipality, number of lavatories, availability of supply water, water usage and space availability in the location.
-

6.2 Limitations and Future Directions

There were certain limitations encountered during this research are mentioned below.

- Public attitude is not yet oriented towards this due to the lack of understanding about the long-term benefits of septic recycling and circular economy.
- Non availability of valid data on exact composition, life cycle after discharge from the human body and discharge quantities of human excreta.
- Limited practical applications of converted excreta and urine-based fertilizers were found in Sri Lanka.
- The feasibility of using the most up-to-date technology from around the world must be further investigated, and realistic practical testing must be conducted to determine effectiveness.

As per the findings of the study, following future directions are required.

This study was carried out majorly based on the collected data from 3 buildings located within the Colombo municipal council and data acquired from the municipal councils. Therefore, those details may not be the presentation of exact nature of the septic management of Colombo municipal council or country. It is required to conduct national level research to identify exact severity of the current issues of the septic management. Probable solutions must be recognized with incorporation of several authorities such as municipal councils, water supply and drainage board, environmental authorities, and agricultural authorities.

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8. APPENDIX 1

Brief Analysis on Apartment Block with Green Building Certification

Type - High Luxury Apartment Building at Rajagiriya

Number of spacious apartments – 171

Penthouses and Presidential suites

Number of Floors – 47

Green Building Rating – Platinum

This residence has been designed to provide its occupants the proper sustainable living, in addition to initiate a benchmark for future high-rise developments. This building has less cost to spend on upkeep and maintenance, whilst also enabling the residents at the forefront of conservation and responsible living.

Key Areas of Efficient Water Usage

Rainwater Harvesting

Rainwater is collected at ground level and used with recycled grey water for toilet flushing and plant irrigation. This is caused to reduce the water usage by 45%.

Grey Water Recycling System

Flushing consumes 30-40% water in an apartment building. Use of recycled water for flushing can reduce the total water usage in the building. Water collected form apartment showers, bathrooms and sinks are directed to a recycling system and it purifies the water to be less than 10 BOD (Bio Oxygen Demand). Recycled water is mixed with the harvested rainwater and directed to the bathroom water closets and to the drip irrigation system for use in the plantations.

In this apartment grey water and black water collected separately. Blackwater and grey water directed to the treatment plant through two separate channels. Flow diagram of the treatment process is shown in the Figure 1 below.

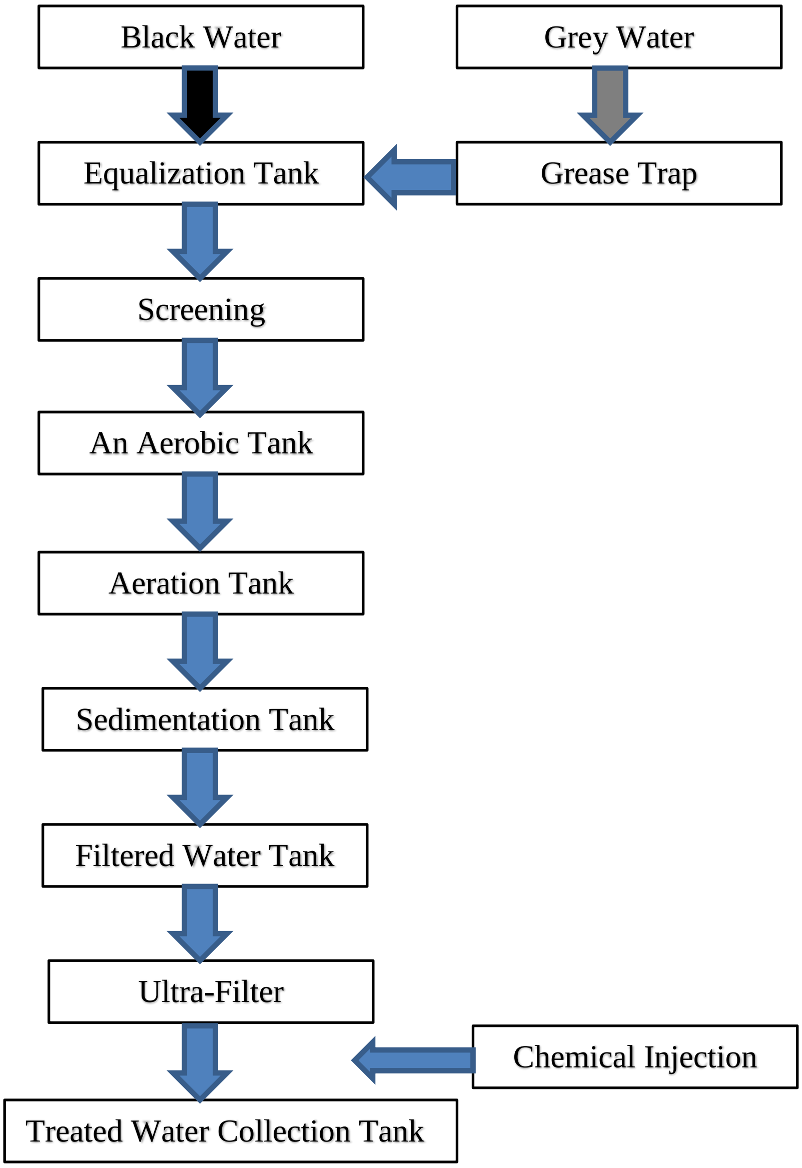

Figure 42:Grey Water and Black Water Treatment Process

Use of rainwater and treated wastewater is caused to reduce the overall water consumption by 30% in the building. However, sludge collected in the treatment plant discharge via gully bowsers and there is no proper manner to reuse them.

Green Certification Levels

Platinum – 70 Points and above

Gold – 60 to 69 Points

Silver – 50 to 59 Points

Certified – 40 to 49 Points

Seven Aspects in Rating System

1. Energy Efficiency – 27 Marks
2. Sustainable Site Planning and Management – 23 Marks
3. Materials and Resource Management – 20 Marks
4. Quality of Interior Environment – 13 Marks
5. Water Efficiency – 10 Marks
6. Green Innovation – 05 Marks
7. Socio-cultural Compatibility – 02 Marks

Total marks allocated to all seven aspects are 100.

Above discussed building has obtained the 9 marks out of underwater efficiency as shown in the below.

Table 29: Marks Attained in Green Building Rating

No.	Criteria	Total Marks Available	Marks Attained
1	Rainwater Harvesting	2	2
2	Wastewater Recycling and Efficient Use	4	4
3	Water Metering and Water Leaks	2	2
4	Water efficient tools/ Equipment	2	1