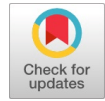


Analysis of Independent Faecal Sludge Treatment Plants in West Bengal, India towards Sustainable Faecal Waste Management



Susanta Ray, Papita Das, Pankaj Kumar Roy

Abstract: 60% of toilets in India are constructed with an onsite sanitation system (OSS). In the West Bengal (WB) State of India, 78% of the urban population is covered with unsewered and OSS systems. There is no detailed study that compares the economic benefits of FSTP in India with those of a Sewerage Treatment Plant (STP). This study is done to derive the anticipated outcome and benefits which may be achieved from independent Faecal Sludge Treatment Plants (FSTP) concerning economic aspects and control of environmental pollution caused by untreated discharge of Faecal Sludge (FS) and Septage into open ground and water bodies. The study was conducted in an indigenous and unique manner, following rigorous literature reviews and data collection. The study emphasises the immediate implementation of FSTP in each city where an unsewered sanitation system exists. To establish an independent FSTP with 100 KLD capacity, it is concluded that the average capital cost (CapEx) for construction and its operation and maintenance cost (OpEx) for 15 years are around INR 106.5 million and INR 330 million, respectively. Considering this, the total CapEx plus OpEx (15 years) incurs around INR 985 per capita for using FSTP. On the other hand, the same approach, using STP, amounts to approximately INR 18,000 per capita, comprising capital expenditure (INR 9,000) and Operational Expenditure (INR 9,000 for 15 years). The economic benefits of adopting FSTP over STP are expected to reach INR 251 billion within the first 15 years. Moreover, end products of FSTPs add resource recovery, control environmental pollution, ensure sustainable development goals and promote a circular economy.

Keywords: On-site Sanitation Systems; Un-sewered Sanitation System; Two Pits Pour Flush Toilet; Operation and Maintenance Cost; Circular Economy.

Abbreviations:

OSS: Onsite Sanitation Systems
ULB: Urban Local Bodies
KMC: Kolkata Municipal Corporation
WB: West Bengal
FS: Faecal Sludge
NAA: Notified Area Authorities
MC: Municipal Corporations
MWW: Municipal wastewater
ODF: Open Defecation Free

Manuscript received on 10 May 2025 | First Revised Manuscript received on 26 May 2025 | Second Revised Manuscript received on 16 October 2025 | Manuscript Accepted on 15 November 2025 | Manuscript published on 30 November 2025.

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SBM: Swachh Bharat Mission

GOI: Government of India

BMGF: Bill and Melinda Gates Foundation

NOGs: Non-Governmental Organizations

CDD: Centre for Decentralised and District

FSTP: Faecal Sludge Treatment Plants

SDGs: Sustainable Development Goals

TMC: Town Municipal Council

BIS: Bureau of Indian Standards

I. INTRODUCTION

People worldwide use on-site sanitation systems (OSS), such as pit latrines, pour-flush toilets, septic tanks, cesspools, and other similar systems. About 2.7 billion people worldwide depend upon Onsite Sanitation systems (OSS) technologies, which are expected to increase to 5 billion by 2030 [1]. As such, they rely on an unsewered or non-sewered sanitation system.

In a non-sewered sanitation system, human excreta are mixed with water, resulting in a waste mixture of solid and liquid, which is referred to as faecal sludge (FS). The FS generated in septic tanks is also referred to as septage. The FS contains many faecal coliform bacteria, other harmful pathogens, helminths, and other organic and inorganic matter. These are highly contaminated and pose a risk to public health if not handled properly and scientifically. It is found that 65% to 100% of urban sanitation in urban areas is covered with OSS [2]. Most (60%) of toilets in India are constructed with OSS [3]. In West Bengal (WB), India, approximately 78% of urban citizens are covered with unsewered and open sewer systems. In comparison, the remaining 22% of the population have access to a sewer system with an off-site sanitation system. As per the 2011 census, the urban population in West Bengal was 29 million, and the present population is around 30.90 million [4]. Sewered sanitation system covering 22% of the population exists in Kolkata Municipal Corporation (KMC) and 8 (eight) other Urban Local Bodies (ULB). Most of the towns in WB, which have 7 Municipal Corporations (MC), 118 Municipalities, and 3 Notified Area Authorities (NAA), depend on OSS.

In the past, the stakeholders and engineers did not consider OSS before this, and little attention was paid to it, resulting in the spread of public health risks. Hence, proper Faecal Sludge and Septage Management (FSSM) FSSM is necessary to address the pollution issues for sustainable development and a circular economy. India followed its sanitation approaches to the extent possible, drawing inspiration from them.

From them. From the developed Western countries. Nowadays, there is a broader acceptance of low-power and strong, eco-



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friendly treatment technologies, as well as a greater appreciation for more cost-effective decentralised systems. Out of the total water supplied in each ULB, about 80% turns into wastewater. Municipal wastewater (MWW), or sewage, contains a substantial concentration of pollutants, including pathogenic bacteria, viruses, and organic and inorganic materials. If the septage and FS are generated from untreated and uncontrolled waste disposal, there are enormous chances for contamination and pollution of surface water and groundwater.

The issue of FSSM's sustainable and safe disposal has been neglected and unattended in the past, resulting in risks and hazards to public health due to the open disposal of untreated septage and FS in open areas. In India, the ULBs were declared Open Defecation Free (ODF) in 2019, ensuring 100% access to toilets. However, most cities and towns lack a proper and scientific FSSM system [3]. An off-site sanitation system is quite expensive, as STPs, sewerage networks, and various costly electro-mechanical components, along with ancillary structures, need to be installed to establish the facilities. It is also expensive in terms of operation and maintenance. In comparison, the OSS and FSSM systems are less expensive. Recently, the mindset of engineers has shifted worldwide, and they have focused on a decentralised system of FSSM, which is sustainable, cost-effective, and eco-friendly. The cost of FSSM technologies is five times less expensive than that of conventional sewerage-based technology, depending on local conditions [5].

A. Present Situation of FSSM in India

Part A: Policy and Governance Aspects: The Government of India (GOI) has identified gaps in the existing sanitation system and taken various positive steps to achieve the country's Open Defecation Free (ODF) status. To address the sanitation issue under the Swachh Bharat Mission (SBM), the government introduced a national policy in 2017 on FSSM. The government introduced ODF+ and ODF++ policies on FSSM under the Swachh Survekshan and SBM initiatives. Some magnificent missions, such as AMRUT and NMCG, have been launched. In this way, the GOI is making vigorous and continuous efforts to implement FSSM in all urban areas of the country. Several progressive actions have been initiated since 2013 and are ongoing to ensure proper management and achieve 100% safe sanitation. In CPHEEO, the Guidelines for Septage Management were included in 2013 [6].

After achieving the target of ODF status, SBM-G Phase II has been launched to attain Sampoom Swachhata (sustaining the ODF status and managing solid and liquid waste by 2024-25) and transforming all the villages from ODF to ODF Plus status. The AMRUT scheme was launched in 2015 for urban infrastructure development in conjunction with the FSSM. The first FSTP was commissioned at Devanahalli, Karnataka, in the same year. Then, some remarkable targeted activities were executed. NFSSM Alliance supported the Ministry of Urban Development (MoUD) in 2016 for the preparation of a rapid assessment technique for FSSM budget preparation by ULBs. Thus, the National Policy on FSSM was implemented in 2017. Many states and Union Territories published their policies and guidelines to promote FSSM in 2018-2019. Accordingly, several towns and cities invited tenders to establish FSTPs. As in 2020, various stages of FSSM were implemented in over 700 towns and cities.

The united endeavours of different government departments,

such as the Ministry of Housing and Urban Affairs (MoHUA)-GOI, various state governments and UTs, CPHEEO, Central Pollution Control Board (CPCB), ULBs, as well as many Non-Governmental Organizations (NGOs) and philanthropic organizations like the Bill and Melinda Gates Foundation (BMGF), have reinforced the entire FSSM scheme throughout the country.

Consequently, more than twenty states and UTs have adopted FSSM policies based on the GOI's Guidelines. Meanwhile, DPR and the Plan of more than 700 committed FSTPs have been finalised and approved by the concerned authority, of which 220 FSTPs are under construction [7] and 150 FSTPs are operational in full swing. Meanwhile, 19 states out of 36 states and Union Territories have already published their state-specific FSSM guidelines, expecting all Urban Local Bodies (ULBs) to set up Food Safety and Standards Training Providers (FSTPs) in a unified manner, following the standard FSSM guidelines, to address sustainable issues, including aspects of pollution control, sustainable development, and cost-effectiveness.

In this respect, some states can be referred to where state-level FSSM guidelines and regulatory frameworks were established between 2016 and 2019 to facilitate early adoption of FSSM. These are the states of Maharashtra, Andhra Pradesh, Karnataka, Telangana, Tamil Nadu, Rajasthan, Odisha, and Uttar Pradesh.

Devanahalli is a small rural town located near Bengaluru International Airport. The first FSTP with a 6 LKD capacity was established here in 2015. According to SBM data, this town has 6,400 households, and 90% of these have access to toilets, while 10%, or nearly 620 households, lack toilets and resort to open defecation. When the FSM concept was unfamiliar, the Centre for Decentralised and District (CDD) Planning played a vital role in establishing the FSTP. After successful testing, operation and commissioning, the plant was handed over to the Town Municipal Council (TMC) in 2019. It is being operated effectively and successfully with minimal effort and expertise. Devanahalli becomes India's pioneer in the FSM drive field [3].

Along with some other states of India, the Government of Odisha (GoO) has taken the FSSM drive seriously and significantly. Odisha has set up the FSSM in a systematic and phased manner. Odisha Urban Septage Management Guidelines, focusing on FSSM, were released in 2016 to comply with the SDG goals set by the United Nations and the Swachh Bharat Mission, 2014. Till now, eleven FSTPs have been set up and successfully operated in various cities, with capacities ranging from 18 KLD to 75 KLD [8].

Apart from these, MoHUA under the GOI has been conducting numerous awareness programmes and campaigns with various states to raise awareness among people about implementing FSSM with minimal investment and achieving maximum outcomes, among other objectives, to achieve sustainable sanitation solutions. Undoubtedly, FSSM is a viable and sustainable option for safe sanitation, and many actions are still pending to achieve 100% success under the 6.2 target of the Sustainable Development Goals (SDGs).

Moreover, after implementing extraordinary measures for safe sanitation schemes since 2014, India declared itself Open Defecation Free (ODF) in 2019 by constructing 66 lakh household toilets and more than 6 lakh

community and public toilets to achieve universal toilet access for all citizens. Yet, 40% of cities and urban areas have a sewerage network sanitation system, and STPs are operational or under construction at approximately 1,200 locations. OSS still plays a vital role in the lives of roughly 60% of people in urban areas. Considering these situations, a comprehensive and integrated FSSM is cost-effective and can be built and implemented more quickly, ultimately leading to an FSSM for the entire urban population. It is stated that one five cum truck dumping FS into open land becomes equivalent of open defecation by 5,000 people [9].

Subsequently, FSSM stresses and prioritizes proper management of human excreta in faecal sludge and septage form to keep the spreading of diseases under control, reuse of treated water and treated by-products as soil conditioner, and co-composed manure. Indeed, these are achieved through low-cost and eco-friendly technology, utilising minimum energy and obtaining optimal outcomes and benefits, thereby sustaining the flow of the circular economy.

Unlike other developing countries, urbanisation has rapidly increased in India over the last two to three decades. To make it possible, various parameters are associated, including the development of basic infrastructure such as planned networks of roads, water supply, sewerage, electricity, and internet services. An enormous capital cost is being invested to complete these successfully, wherein complicated engineering inputs are coordinated, which requires considerable time. In most cases, the scheduled completion time of these projects does not align with the actual one, due to various reasons and hindrances that lead to an increase in project costs. At the same time, the sewerage network system is confined to the core areas of almost all metro cities. It is hardly possible to extend into the peripheral regions of urban locations, which remain practically unserved. On the contrary, sanitation systems with sewerage networks are less common in small and medium cities. Therefore, it is seen that the rate of expansion of sewerage networks is not proportional to that of the overall expansion of urban areas over the last few decades [3].

As it happens, the existing sanitation system, which is insufficient, negatively impacts public health, particularly among women and the poor, due to a lack of proper support systems, inadequate livelihoods, and fragile health. Compared to a sewerage connection system using an OSS system, the user experience is more expensive. OSS-dependent households are forced to bear an unequal and extra burden. In most sewerage cities and towns, residents receive subsidised services. On the other hand, urban poor people must pay higher charges to access FSSM facilities, which further burdens them. It is reported that the cost incurred in FSSM for human waste and excreta management varies from INR 200 to 250 per capita annually, towards providing rapid and sustainable sanitation for all urban people, i.e. the mean cost required is INR 225. Eventually, the cost incurred for a more comprehensive sewerage network system is between INR 7,000 – 11,000 per capita per annum, with an average of INR 9000 [10]. Comparing these two facts, it can be inferred that FSSM may be an ideal alternative for safe human excreta management, including faecal sludge and sewage management, at a comparatively lower cost. It is a viable option to achieve SDG-6.2.

OSS, such as septic tanks and pit latrines, are widely used in both rural and urban areas in India for defecation and sanitation

purposes. Although notable improvement under SDGs to top up the number of improved sanitation has been taken place, there are still many obstacles and impediments in each phase in connection with collection from OSS, disposal, and treatment of faecal sludge (FS), keeping up extreme safety provisions, which becomes a serious and real challenge. Frequently, unscientific treatment occurs due to insufficient services and awareness among people who dispose of the FS unsafely. Unsafe disposal of FS leads to unexpected health hazards and environmental pollution. SDG 6.2 (sanitation and hygiene) priorities and emphasizes for safely managed sanitation services, which state the provision of FSM beyond toilets [11]. In addition to household toilets, it also emphasises ODF in the community-based toilet systems.

Faecal sludge and Septage management have become essential when resources are confined to a sewerage-based approach to sanitation. Faecal sludge management aims to address the bottleneck and find solutions for the gaps identified in the sanitation value chain, particularly in on-site sanitation systems.

Part B: Technology aspects: The type, orientation, and engineering design of different units of an FSTP depend upon various factors, and they largely vary from place to place. Here, nineteen existing FSTPs have been mentioned in ten states with variable climatic conditions. FSTP is set up at Leh in Jammu and Kashmir, a tourism-based city where the weather remains extremely cold, whereas Lalsot, a small town in Rajasthan, remains hot most of the year. Various types of technologies have been adopted to set these FSTPs. It categorizes as i) Passive which require low skill and low energy to run, ii) Mechanical system which requires low land and a little bit more energy and iii) Thermal technologies, where a portion of FS is used to treat the rest part of it.

Passive technology includes DEWATs-based options, which are decentralised plants. This system treats human excreta and faecal sludge through transportation, disposal, and treatment processes (primary, secondary, and tertiary) [12]. The FSTPs of Devanahalli (Karnataka), Phulera (Rajasthan), Bhubaneswar, Sircilla (Telangana), Leh (J&K), Nashik (Maharashtra), Brahmapur (Odisha), Dhenkanal (Odisha), Puri, Unnao (U.P.), Lalsot (Rajasthan) are of this type. The mechanical system includes a Moving Bed Biofilm Reactor (MBBR) based wastewater treatment process. It is an economic solution for wastewater treatment, enabling advanced wastewater treatment to be done efficiently (NIUA, 2019; Cost analysis of faecal sludge treatment plants and Rahul Mankotia et al., 2019). The FSTPs of Jabalpur (M.P.), Tenali (A.P.), Brahmapuram (Kerala), Sinnar (Maharashtra), Periyannayakan Palayam (Tamil Nadu), Kovilpatti, (T.N.), Tirumangalam (T.N.) are of this type.

In Thermal technologies, organic waste materials are decomposed with regulated oxygen and high temperature to convert sludge to biochar efficiently without any external energy. The FSTPs of Warangal (Telangana), Wai (Maharashtra), Narsapur (A.P.) are of this type.

B. On-Site Sanitation (OSS) System

Septic tanks are one of the most used units in the OSS system. It comprises a sedimentation and digestion tank, which is a compound structure. In the septic tank, the sewage mixed with human excreta is accumulated, and after a one to



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three-day retention period, the suspended solids (SS) are deposited at the bottom. At the same time, the sludge, SS, and liquid are digested through the anaerobic process. Through this digestion, a substantial reduction in sludge volume is brought about, and biodegradable organic matter is broken down. Additionally, gases such as carbon dioxide (CO₂), methane (CH₄), and hydrogen sulfide (H₂S) are released. Although the septic tank's effluent is primarily clarified through anaerobic digestion, it still contains many pathogens, including dissolved, suspended, and organic solids. These materials need further treatment [6]. Therefore, the effluent from the septic tanks should be disposed of very carefully, considering the safety of all concerned and the environment. If the frequency of cleaning intervals and emptying the septic tanks is decreased, then the sludge concentration is also reduced, and the quality of effluent becomes relatively better. Moreover, the sludge concentration depends on various factors, including the quantity of water used during defecation, the frequency and number of toilet uses, location, environmental factors, and the food habits of the inhabitants. Therefore, the septic tank is preferable and recommended only for individual houses, small communities, and institutions due to its unsatisfactory effluent quality and difficulty in disposing of waste. Typically, septic tanks are used where the user population are within 300. For communities with larger populations, septic tanks can also be adopted to ensure proper facilities for treating and disposing of effluent. In both cases, discharging the sewage from the septic tank to a lined channel is very much necessary.

C. Global Scenario of Faecal Sludge Management

Based on a few literature surveys, knowledge and ideas have been gained. From all the published papers and journals, countries and researchers collectively emphasise the importance of supporting and implementing proper faecal sludge management in a sustainable and eco-friendly manner to achieve the SDGs. Many developed and advanced countries have already made significant progress in implementing the appropriate FSSM. In contrast, all developing countries are striving to achieve the goals of a pollution-free environment and meet the SDGs through faecal sludge and septage management. On-site sewage systems (OSS), such as septic tanks and cesspools, are commonly used in many developing countries in Asia and Africa to treat human excreta and toilet wastewater. However, due to various reasons, including a lack of funds, inadequate technologies, and improper management policies, the performance of existing functional faecal sludge treatment plants (FSTP) in many cities is unsatisfactory. Consequently, it causes environmental pollution, leading to public health risks to people residing nearby [13].

FSTP is an effective, safe solution for sanitation in all urban areas. Integrated FSTPs require lower initial capital expenditure and operation and maintenance costs compared to the conventional centralised sewerage system. FSTPs are a viable solution and eco-friendly technology that needs low energy and yields maximum environmental benefits, conforming to the circular economy by reducing, reusing, and recycling waste and water through proper scientific treatment [14].

A comparative study was conducted between the FSM with onsite septic tanks, collection, transport, and drying beds, and the Parallel Sewer Based (PSB) system with activated sludge. Here, SB was found to be more expensive (around 40 times) than FSM

for implementation. It illustrated that an FSM can improve and make more affordable sanitation systems with a low investment, which is much needed in poor countries [5]. A study conducted in Ghana, a developing country, concluded that the water and other waste products obtained after treatment from FSTP can be used for agriculture [15]. Another study conducted in Kigali city recommended that FSM is the best option for achieving a sustainable solution to safe sanitation. This study emphasises proper policy making and involvement of all stakeholders, including institutions, for the success of FSSM [16]. In Indonesia, around 95% of human waste and excreta remain untreated and are discharged into the open environment, adversely affecting human health and obstructing economic development. The study recommended implementing proper FSSM here [17].

Another research conducted on Croatian islands found that OSS is the only sanitary option not connected to public sewerage networks. In this study, it is also recommended that the implementation of FSSM follow the directives of the EU and its guidelines with an emphasis on circular economy [18]. A study was conducted to compare and assess FSSM performances in Five Cities in Philippine islands with the help of Faecal Waste Flow Diagrams and Service Delivery Scorecards. Positive and effective efforts were also observed towards better efficiencies of FSTPs in cities [19].

Another study highlighted that the implementation of FSSM is urgently needed for sanitation solutions worldwide, particularly in light of the increasing population growth and rapid urbanisation trend. All countries, including developing and poor countries, require proper FSSM for abatement of environmental pollution and reusing treated products as sustainable water resources and organic manure to achieve SDGs as well as the circular economy wheel [20].

In developed countries, such as the European Union and the USA, faecal sludge usually undergoes co-treatment. Due to low population density, faecal sludge is comparatively low compared to wastewater. In the co-treatment process, the faecal sludge is transported from on-site or decentralised sanitation facilities to wastewater treatment plants and treated together. In these countries, the proportion of households connected to OSS is very low, and most are linked directly to the standard sewer system. As a result, no such technical problems arise when a small amount of FS is mixed with a large amount of wastewater.

From the various studies and research conducted over the past few decades, all countries now unanimously recognise that a sustainable sanitation system is essential to treat faecal sludge and septage through FSSM. All global communities are rethinking the speedy implementation of FSSM to get quality services. This is particularly relevant in the case of low- and medium-income countries and developing countries, where it is essential to emphasise FSSM for the sustainable development of water resources and faecal sludge management. Discharging of untreated faecal sludge into the open environment and water bodies causes a serious risk to public health. According to the World Bank report, it is estimated that around USD 260 billion is incurred annually in costs related to poor sanitation, resulting in approximately 1.5 million people being affected. Children die yearly [1].

D. Existing Conditions in West Bengal

In West Bengal, OSS is



predominant in all unsewered urban local bodies (ULBs). Septic tanks (ST) are built in all these ULBs for human excreta treatment. As mentioned above, the effluent of the septic tank requires further treatment. Such effluents are typically disposed of into surface drains, whereas they are supposed to be discharged into soak pits, which are often absent in most households. ULB authorities empty the sludge and septage from septic tanks upon request from users, for which they must pay fees fixed by the authorities. But the available services are inadequate. Proper planning, infrastructure, investment, and sufficient workforce deployment are lacking due to the inadequacy of faecal sludge collection, transportation, disposal, and treatment at FSTP. There are practices in many urban local bodies (ULBs) in West Bengal where faecal sludge and septage are dumped in open spaces without control, resulting in environmental pollution and risks to public health. In some municipalities, private agencies are emptying and desludging septic tanks at the request of residents. Most private agencies neither adhere to the scientific system in sludge desludging from the ST nor ensure safe treatment and disposal. The question of reusing dried sludge does not arise in this case. Somewhere faecal sludge is disposed of into open nallah, outflow of channels, water bodies, which cause rivers at last. The traces of high faecal coliform concentration found in many rivers are due to the direct disposal of faecal sludge and improper treatment.

There are 41 ULBs in the Kolkata Metropolitan area. Under various planned schemes launched by Government of India (GOI) from time to time such as Ganga Action Plan (GAP)-Phase-I, GAP-Phase II, and Namami Gange several Sewage Treatment Plants (STP) had been set up in many towns and cities along the bank of the river Ganga (Hooghly) towards abatement of river water pollution. Number of intercepting sewers was laid and STPs were built under GAP-I and II to treat the diverted sewage, intercepted sewage, and sullage in many towns and cities along either bank of the river Hooghly (Ganga). On the other hand, several sewerage networks, pumping stations and new STPs have been constructed in a few towns under the NGP. However, there is no provision for receiving the FS and septage at these newly set-up STPs for treatment.

In WB urban areas, septic tanks are a vital component of toilets, whereas other types include on-site single-pit pour-flush toilets or two-pit toilets. There is still practice in some towns of using on-site deep single-pit toilets. Very few septic tanks and pit latrines exist in towns and cities where sewage treatment facilities and sewerage systems exist. In these areas, FS and septage are treated in sewage treatment plants (STPs). Therefore, FSTPs are required in unsewered towns and cities to treat F by the guidelines and norms of the GOI. Subsequently, in villages along the River Ganga where STPs with intercepting sewers are available but lack sewerage networks, FSTPs must be provided.

It is observed that most of the STs and pit latrines do not conform to the specified design criteria stipulated in the code of practice of the Bureau of Indian Standards (BIS) or the CPHEEO manual. The STs and pit latrines primarily observe substantial variations and erroneous design. Some deficiencies are observed in ULBs for FSSM, such as limited capacities and resources, people's unawareness of the regular cleaning of STs, inadequate services provided by ULBs or their contracted private agencies, and FS is dumped into open drains and open areas, causing a significant risk to public health and environmental pollution. Additionally, sanitary workers often fail to take the necessary

precautions with protective gear and tools when cleaning septic tanks (STs) and pit latrines.

Considering the above bottlenecks and hindrances, managing the FS and septage holistically, as produced from OSS, is necessary, taking into account local conditions and various other parameters. To address these issues, FSSM must be implemented in all cities and towns of WB where no sewer system is available. FSSM can manage FS and septage rapidly by setting up an FSTP at a comparatively low cost, providing a safe and eco-friendly sanitation outcome. After the treatment, one of the resource recoveries, such as treated water, can be used in horticulture, pisciculture, irrigation and many other purposes, and the treated sludge, on the other hand, can be used as a soil conditioner and manure, mixing with some organic co-compost available from solid waste management plants. As a result, the Sustainable Development Goals (SDGs) can be achieved and the circular economy can be maintained. Moreover, new employment opportunities can be generated, and a clean environment can be achieved as a result.

This study has been carried out to evaluate the current scenario of FSSM in urban areas in West Bengal state, India, and to derive the anticipated outcome and benefits that may be got from independent and integrated FSTP in terms of economic aspects and abatement of the environmental pollution caused by untreated discharge of faecal Sludge (FS) and septage into the open environment. The study emphasises the implementation of FSTP in all WB's unsewered cities and towns to achieve the Sustainable Development Goals (SDGs) and promote eco-friendly pollution control.

II. STUDY AREA

In this study, the current sanitation status of all urban local bodies (ULBs), including municipal areas, has been revisited. All ULBs have been targeted to achieve a safe and sustainable sanitation system by setting up FSTPs in all non-sewered urban regions. The management of solid and liquid waste through proper disposal is the primary objective in urban local bodies (ULBs), with the core objectives of mitigating pollution, promoting resource recovery based on the '3 R' concept (i.e., Reduce, Reuse, and Recycle), and conserving natural resources.

FSSM Policy only deals with OSS. Therefore, only the towns in WB that OSS serves have been considered in this study, and towns and cities with conventional sewerage systems and sewage treatment plants (STPs) have been excluded from consideration. However, it will focus on the feasibility of co-treating FSTPs and synchronising treated faecal sludge with co-composting organic materials obtained from solid waste for resource recovery. The scope of the study encompasses all sanitation services in urban and peri-urban areas of the Western Balkans (WB).

In Kolkata Municipal Areas (KMA), 11 municipalities require independent FSTPs. On the other hand, in non-KMA towns across 23 districts of WB, 87 towns require either STPs or FSTPs to be constructed immediately to comply with government directives. As the time and capital Costs for constructing STPs are substantially higher than those of FSTPs. FSTPs can be set up as soon as possible to address the issues of FS and septage treatment, ensuring safe sanitation and pollution control.

Moreover, as per the GOI guidelines, SBM—Urban 2.0



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guidelines and AMRUT 2.0 Mission, towns with a population of less than 1 lakh have also been newly incorporated for FS management, unlike cities with a population of more than 1 lakh.

The above-mentioned KMA towns are Uluberia, Barasat, Baruipur, Madhyamgram, New Barrackpore, Rajarhat-Gopalpur, Rajpur-Sonarpur, Dankuni, South Dum Dum, North Dum Dum, and Dum Dum municipality.

The non-KMA municipalities /towns are in 23 districts, which are (until 2021) West Burdwan, Bankura, Birbhum, East Burdwan, Alipurdwar, Coochbehar, Uttar Dinajpur, Dakshin Dinajpur, Jalpaiguri, Darjeeling, Kalimpong, Malda, Murshidabad, Nadia, East Midnapore, West Midnapore, Jhargram, Purulia, North 24 Parganas, South 24 Parganas, and Hooghly.

FSTP and its technology options vary across different cities, states, districts, and locations, depending on various factors and parameters, such as geographical conditions, landscape patterns, capacity, and user food habits. Despite these facts and wide variation of parameters, a review, comparative study, and analysis have been carried out based on available literature and journals on faecal sludge treatment options in urban areas under WB, India, focusing on sustainable development of water resources and eco-friendly pollution control. For this analysis, a comparative study has been done concerning capital expenditure and recurring operation and maintenance costs of FSTPs. The anticipated average cost estimate for the proposed FSTPs has been calculated based on this basis.

In this study, only 87 towns and cities in different districts of West Bengal (beyond the jurisdiction of the Kolkata Metropolitan Authority, i.e., non-KMA towns) have been considered for analysis, to implement FSTPs in areas where an unsewered sanitation system exists.

III. MATERIALS AND METHODS

The study's detailed critical analysis, including comparative studies of estimated costs for construction and 15 years' operation and maintenance, has proposed FSTPs in 87 non-KMA towns. These calculations are based on the latest current market rates from the PWD (WB) Schedule of Rates. The estimated cost has been verified with that of actual capital cost of many FSTPs constructed in near past in various states of India, which have available literatures and journals on FSTPs in terms of technology options adopted in each FSTP, capital cost expenditure incurred for setting up of the plants as well as recurring operation and maintenance cost to have and solid idea. Then, these costs, CapEx and OpEx, were compared with those of the Sewerage Treatment Plant (STP), which were collected from the literature and journals.

Finally, this study has demonstrated the overall economic benefits that can be gained by adopting independent FSTPs instead of STPs for Faecal Sludge and Septage management, utilising eco-friendly and sustainable technology. Furthermore, resource recovery options, including the availability of end products such as treated water and co-composted sludge manure, as well as the mitigation of environmental pollution and the continuity of the circular economy, have been outlined.

Furthermore, the study aims to emphasise the rapid establishment of FSTPs in all ULBs in WB to achieve a safely

managed sanitation system at a relatively lower cost, which is a viable option to achieve SDG 6.2. It also shows the total anticipated outcome in terms of money that the state of West Bengal can save yearly through the implementation of integrated FSSM in non-KMA towns and cities.

IV. RESULTS AND DISCUSSION

All stakeholders, including government bodies, institutes, public bodies, NGOs, and ULBs, make considerable effort. At first, they convey proper awareness to ordinary users. Still, many activities remain to be completed to fully implement FSTPs for successful and safe sanitation, in line with regulatory guidelines and provisions stated in SDG 6.2. FSSM presents an effective alternative for achieving a nationwide safe sanitation system. FSSM is one of the most essential and integral parts of the Swachh Bharat Mission (SBM), as well as the sustainable development of water resources and the abatement of pollution. Therefore, more advanced research and practices should be continued to accelerate the FSSM mission nationwide. In the meantime, many states have geared up the FSSM mission and finalised its policies, establishing FSTP investing relatively little capital funds, as the FSSM is a cost-effective and eco-friendly solution.

According to the analysis of the literature of NFSSM [10], it is reported that in Maharashtra, there are 69 Co-treatment FSTPs with existing STPs and 327 Integrated FSTPs, which cover all towns. In Tamil Nadu, there are 50 Co-treatment FSTPs with existing STPs and 59 Integrated FSTPs covering about 75% of the population in 600 cities. There are 28 Co-treatment FSTPs with existing STPs and 77 Integrated FSTPs covering all towns in Andhra Pradesh. In Telangana, 12 Co-treatment FSTPs with existing STPs and 141 Integrated FSTPs cover all towns. Only two co-treatment FSTPs with existing STPs and 97 integrated FSTPs are available in Odisha, covering all cities and towns.

A. Existing FSTP Technologies and Capacities in Selected Cities

The type and orientation of different units of FSTPs, as well as their landscape and layout, depend on various factors and vary widely from place to place. The characteristics and parameters include the population covered, plant capacity, environmental factors such as temperature, humidity, and rainfall, the technology adopted, and surrounding infrastructure like roads, existing sewerage systems, and vacant land availability near the considered Urban Local Body (ULB), as well as the food habits of users. FSTPs have been built and are being operated successfully in many states, including Jammu and Kashmir, Uttar Pradesh, Maharashtra, Telangana, Andhra Pradesh, Odisha, Karnataka, Tamil Nadu, Kerala, and Rajasthan. Various types of technologies have been employed to establish these FSTPs in these states. The FSTP technology covers as i) Passive, which requires low skill and low energy, ii) Mechanical system, which requires low land and quite more energy and iii) Thermal technologies, where a portion of FS is utilised to treat the rest of it. These FSTPs were constructed and operational from 2015 to 2020. Many FSTPs are under construction.

The first FSTP with a 6 LKD design capacity and passive type were commissioned in 2015 in Karnataka.



B. Cost Analysis of FSTP

There is a variance as the present capital cost of FSTP is over 10 to 40 times higher than that of conventional sewage treatment plants (STP). The reason for the higher cost of FSTP remains the higher organic load (10-100 times) in FS and septage. FSTPs are small-scale plants with capacities ranging from 15- 100 KLD, in contrast to the MLD scale in the case of STPs [12].

The selection of FSTPs for rapid activation is possible with a costing benchmark across all available technologies over time. Here, two parameters have been considered for cost assessment: capital cost (Cap Ex) and operational and maintenance cost (Op Ex). The FSTPs have different capacities, ranging from 6 KLD to up to 100 KLD.

Table 1 presents the details of FSTPs, including their covered population, design capacity, land used, capex, and OpEx. From Table 1 and Chart 1, the details of FSTP design capacities, population coverage in different urban areas, corresponding CapEx (in INR Million) and OpEx (INR Million) for 15 years have been derived and shown. It is assumed that after 15 years, the mechanical and electrical parts will need to be replaced, and major restoration will be required in civil structures and units of FSTPs. It is found that the average capital expenditure (CapEx) per KLD of FS is around INR 0.76 million, which was commissioned between 2015 and 2020. The current fee will be increased due to the escalation of material and labour prices. An

average increase of 7% per annum (CPWD Works Manual, Govt of India, 2022) for three years (mean) would be around INR 0.94 million/KLD.

The capacity of FSTPs does not depend on the number of populations. Similarly, the establishment cost does not depend on design capacities or the population covered in a town. The design and type of FSTP in a city are dependent on various factors, as already mentioned. However, based on the above real data and information, further research and development can be conducted to achieve better design and outputs from future FSTPs.

In the state of WB, 87 non-KMA towns and cities are in 23 districts, where OSS systems are used primarily for treating septage, human excreta and FS. The OSS system includes septic tanks and two pits for flush toilets. In these towns, tentatively 15 Lakh STs and around 22,000 two-pit PF toilets are functional. Quantity of 'septage generation' from ST and 'digested FS generated from two pit PF toilets' are about 3425 KLD and 25 cum/day respectively, assuming ST cleaning interval as 3 years. In other non-KMA towns, such as Durgapur, Katwa, Nabadwip, Rampurhat (Tarapit), Berhampore, etc., functional STPs are available that can cater to the treatment of FS along with sewage water, i.e., co-treatment options will be followed. Hence, this study has not considered these cities (UD & MA Department, Government of West Bengal, 2021).

It has been calculated that the population in these 87 cities and towns was around 11 million as of the 2011 census, and it has increased to around 15 million currently [21].

Table-1: Details of Some Existing FSTPs in India

Sl. No.	City	State	Year of Commission	Design-ed Capa-city (KLD)	Land Allocated (Acres)	Popula-tion (2011 Census) in Million	Cap-Ex (INR-Million)	Op-Ex (INR-Million for 15 Years)
1	Sircilla	Telangana	2019	18	0.62	0.143	16.00	10.44
2	Leh	Jammu & Kashmir	2017	12	0.18	0.031	5.20	18.00
3	Devanahalli	Karnataka	2015	6	0.16	0.028	11.10	19.80
4	Brahmapuram	Kerala	2015	100	0.25	0.357	40.00	26.64
5	Nashik	Maharashtra	2017	20	1.48	1.486	80.00	13.50
6	Sinnar	Maharashtra	2019	70	0.38	0.346	20.50	27.54
7	Wai	Maharashtra	2018	20	0.5	0.036	17.50	36.00
8	Bhubaneswar	Odisha	2019	75	2.5	0.843	28.50	20.34
9	Brahmapur	Odisha	2019	40	1.5	0.357	24.80	14.04
10	Dhenkanal	Odisha	2018	27	1.5	0.067	29.60	14.40
11	Puri	Odisha	2017	50	0.25	0.201	17.40	20.16
12	Narsapur	Andhra Pradesh	2018	15	0.29	0.007	15.00	45.00
13	Warangal	Telangana	2017	15	1.0	0.616	15.00	27.00
14	Unnao	Uttar Pradesh	2019	24	1.6	0.178	35.00	32.22
15	Lalsot	Rajasthan	2019	20	1.85	0.034	37.50	5.94
16	Phulera & Sambar	Rajasthan	2019	20	1.3	0.022	28.20	15.66
17	Periyannayakan Palayam	Tamil Nadu	2019	25	0.5	0.026	25.00	27.00
18	Kovilpatti	Tamil Nadu	2020	40	1.8	0.095	39.40	27.00
19	Tirumangalam	Tamil Nadu	2020	40	1.8	0.051	43.00	27.00
20	Jabalpur	Madhya Pradesh	2017	50	0.94	1.082	5.10	13.68
21	Tenali	Andhra Pradesh	2018	20	1.30	0.165	2.00	9.00
		Total		707	21.7	6.17	535.80	450.36

Ref: NFSSM Alliance and NITI Aayog, 2021 [3] and NIUA, 2019 [12]

C. Design of a typical FSTP at a Municipality in South 24 Parganas and Estimated cost of Construction (CapEx)

The design capacity of the FSTP is 100 KLD, covering around 13,300 households and 0.56 million population, for which around 2.47 land area will be required. The FSTP will consist of the following unit operations:

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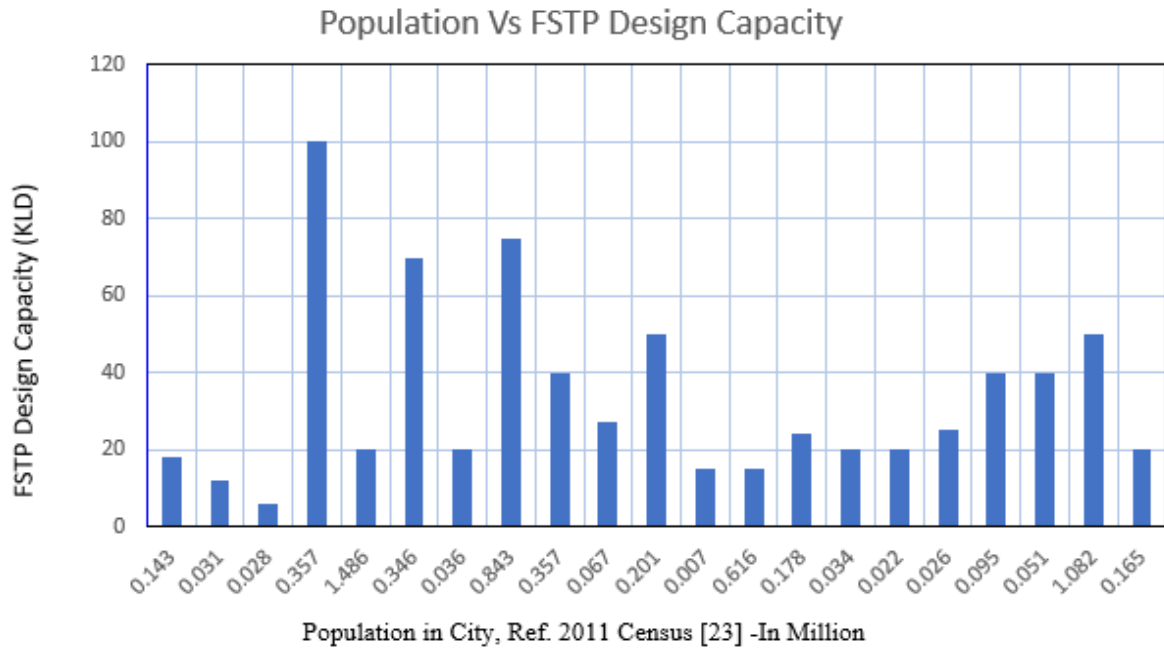


Chart-1: Population of Indian City Vs FSTP Design Capacity (KLD) [derived]
Ref. Census 2011 [23], NFSSM Alliance and NITI Aayog, 2021 [3] and NIUA, 2019 [12]

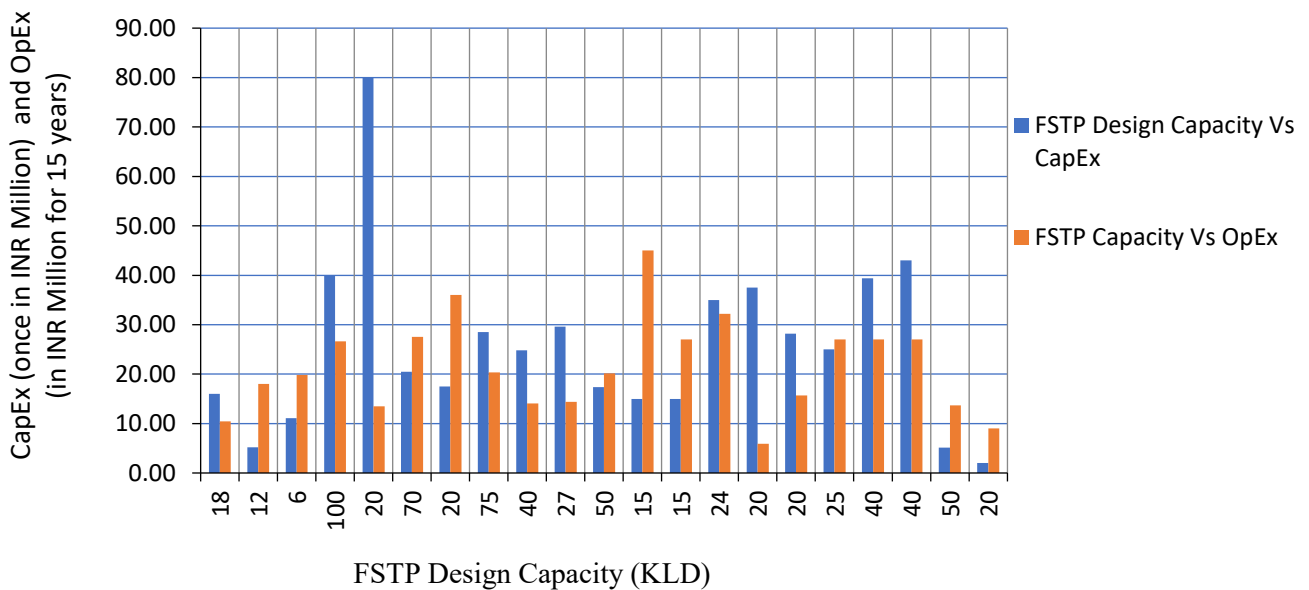


Chart-2: FSTP Design Capacity (KLD) Vs CapEx (INR Million) and OpEx (INR Million) for 15 Years [derived]
Ref. NFSSM Alliance and NITI Aayog, 2021 [3] and NIUA, 2019 [12]

i) Dumping station, including open pit with coarse screen and hose connection, ii). Lime Dosing Tanks, iii) 2 numbers Primary Anaerobic lagoons in Parallel, iv) 2 numbers Lime Stabilisation unit with Lime Handling doser, v). Sludge drying bed (2 nos), vi). Secondary Anaerobic Lagoon (1 no), vii). Aerated Facultative lagoon (1 nos), viii). Horizontal Constructed Wetland (4 nos), ix). Pressure Sand Filter (PSF) and x). Pumps and pumping arrangements.

Estimated cost of Construction (CapEx) of this typical independent FSTP has been calculated that comes to INR 106.5 million, that is the cost per KLD derived to INR 1.07 million/KLD, which include construction of above operation

units, new procurement cost of required cesspool vehicles, boundary wall, high mast, internal road, hard stand ground and ancillary utility buildings complete. This value of CapEx is nearing the derived amount shown above (i.e. INR 0.94 million/KLD). The estimate has been calculated and prepared based on the latest PWD SOR of the Government of West Bengal (2017) and updated corrigenda. [22] and Market rates. The components of various parts are provided hereunder (Table 2).

Table-II: Abstract of Estimated Cost (Typical)-Calculated

Sl No.	Part	Description	Cost (INR in Million)
1	Part - I	Construction of Integrated Faecal Sludge Treatment Plant (FSTP)	32.49
2	Part - II	Supply, delivery, testing and successful commissioning of 2 nos. 3000 L and one no. 6000 L truck-mounted (compact) cesspool tanks fitted with all machinery, pumps and equipment.	8.15
3	Part - III	Construction of Boundary Wall	4.32
4	Part - IV	Construction of High Mast	1.29
5	Part - V	Development of Ground and area in connection with Integrated Faecal Sludge Treatment Plant (FSTP).	32.6
6	Part -VI	Construction of Various Buildings, establishments for Administrative and Services in connection with FSTP	22.6
7		Sub-Total=	101.44
8	Part - VII	Add contingencies @ 5%	5.06
		Total= INR	106.50 million

D. Discussion and Analysis

This subsection provides a detailed discussion and cost analysis of FSTPs about STPs. Subsequently, the findings and outcomes in terms of cost savings are worked out and discussed. The objective here is to determine and calculate the net savings if FSTPs are established at various non-KMA towns, 87 in number

in West Bengal, instead of conventional STPs during the first fifteen years of installation and commissioning.

Based on the typically designed integrated FSTP and its capital cost estimate (CapEx) below in Table 3, the projected Operation and maintenance cost (OpEx) per year and for the next 15 years are calculated and stated here.

Table-III: Analysis of Overall Cost of FSTP in Terms of Capital Expenditure and Operation and Maintenance Expenditure and Estimation of Anticipated Savings and Outcome

I): General information and data		Ref.	Value
1	As per the 2011 census, the total urban population in West Bengal	[21]	29 million
2	Current total urban population in West Bengal in 2022 =29 x 1.3187		38 million
3	Urban population has access to Sewerage and STP facilities @ 22%, i.e. off-site sanitation system	[4]	8.36 million
4	The total urban population used OSS at a rate of 78%, including both KMA and non-KMA areas.		29.64 million
5	Urban population use OSS in Non-KMA areas (till 2021)	[21]	15.00 million
6	Urban population use OSS in KMA Areas (till 2021) =Sl.Nos. (4 – 5)	= (29.64 -15.00)	14.64 million

(II): Non-KMA Towns and Cities: Capital Cost (CapEx)

1	Total Urban population use OSS in Non-KMA Areas at 87 cities & towns in 23 Districts (till 2021)	[21]	15 million
2	Number of functional Septic tanks (tentative)	[4]	15 Lakh
3	Number of functional two-pit PF toilets (tentative)		22,000
4	The estimated septage quantity (assuming 2.5 cum volume per emptying activity, and cleaning interval of ST as 3 years).		3,425 KLD
5	The estimated quantity of septage and digested (matured) sludge to be de-sludged		3,450 KLD
6	Estimated cost of Construction (CapEx) of a typical FSTP of 100 KLD capacity [dumping station, lime dosing tanks-2 nos., 2-primary anaerobic lagoons in parallel, lime stabilization unit (2 nos) with lime handling doser, sludge drying bed (2 nos with five segments in each bed), Horizontal Constructed Wetland (10 nos), Pressure Sand Filter (10 nos), Pumps and pumping arrangements etc.] – consisting of integrated FSTP, Cesspool vehicles, boundary wall, high mast, internal road and hard stand, utility buildings etc.	Ref. Table-2	INR 106.5 million
7	Average Capital Cost per KLD of FS and Septage = 106.50/100		INR 1.065 million/KLD
8	Average Capital Cost for 87 ULBs for FSTPs = INR 1.065 million/KLD X 3450 KLD	1.065 × 3450	INR 3674.25 million
9	Average Capital Cost per capita for FSTPs = INR 3674.25 million/15 million	3674.25/15	INR 245 per Capita
10	Average Capital Cost per capita for FSTPs as per NITI Aayog. (January 2021 and K. C. Rao et al, 2020. (An average value of INR 200 and INR 250 taken)	[10]	INR 225 per Capita
11	Consider the mean of these two values (INR 245 and INR 225) as CapEx per Capita.	Average of Sl. Nos. 9 and 10	INR 235
12	Total CapEx for Setting up FSTP in 87 Non-KMA ULBs =15 million × INR 235 = INR 3525 million = INR 3.53 billion	= INR (15 × 235)/1000 billion (Ref. Sl. No.1 above)	INR 3.53 billion
13	Total CapEx for Setting up 'Networked sanitation system: Sewerage', i.e. STPs in 87 Non-KMA ULBs @ Average INR 9000 per capita = 15 million × INR 9000 /1000 = INR 135 billion	[3]	INR 135 billion
14	Total Savings of CapEx for Setting up FSTPs instead of STP in 87 Non-KMA ULBs = INR (135 – 3.53) Billion = INR 131.47 billion.	(Sl. No. 13 – Sl No. 12)	INR 131.47 billion, i.e. a Minimum of INR 131 billion

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III): Non-KMA Towns and Cities: Annual Operation and Maintenance Cost (OpEx) per Capita		Ref.	Value
1	Annual Operation and maintenance cost (OpEx) @ 20% of CapEx per year for the FSTP of 100 KLD capacity – consisting of integrated FSTP, Cesspool vehicles, boundary wall, high mast, internal road and hard stand, utility buildings, etc.	[10] and SI No. II/6 above = (INR 106.5 × 0.20) = INR 21.30 million, Say INR 22 million	INR 22 million
2	Annual average Operation and maintenance cost (OpEx) per KLD of FS and Septage	Ref. SI. No. II/6 = INR 22/100 = INR 0.22 million	INR 0.22 million
3	Annual average Operation and maintenance cost (OpEx) for 87 ULBs for FSTPs	Ref. SI.No.II/5 and III/2 = 3450 × 0.22 = INR 759 million	INR 759 million
4	Annual average Operation and maintenance cost (OpEx) per capita for FSTPs	Ref. SI.No.II/1 and III/3 = 759 / 15 = INR 50.00	INR 50.00 per capita
5	So, Total Annual Average OpEx for FSTP in 87 Non-KMA ULBs	Ref. SI.No.II/1 and III/4 = INR 50 × 15 / 1000 = 0.75 billion	INR 0.75 billion
6	Total Annual OpEx for 'Networked sanitation system: Sewerage', i.e. STPs in 87 non-KMA ULBs @ 6.65% (mean) of CapEx	[10] and SI No. II/14 above = INR 131.47 × 0.065 = INR 8.75 billion, Say INR 9.00 billion	INR 9 billion
7	Total Annual Average Savings of OpEx for Setting up FSTPs instead of STP in 87 Non-KMA ULBs	(SI. No. III/6 – SI No. III/5) = INR (9.00 – 0.75) billion = INR 8.25 billion	INR 8.25 billion, i.e. a Minimum of INR 8.00 billion
8	Total Annual Average Savings of OpEx for 15 years with setting up FSTPs instead of STP in 87 Non-KMA ULBs	15 Years × INR 8 billion = INR 120 billion	INR 120 billion

Therefore, the total average savings in 87 non-KMA ULBs in WB for setting up FSTPs instead of conventional STPs during the first 15 years = [CapEx + 15 years OpEx] = (SI.No.II/14 + SI.No.III/8) = INR (131+120) Billion = INR 251 billion.

V. CONTRIBUTION OF THE STUDY

If FS and septage are not adequately treated, managed scientifically, and disposed of in designated areas, they can cause environmental pollution. The pollutants carrying the FS pollute surface water bodies, soil, ground water, and air, affecting natural habitats and posing a risk to public health. Though faecal sludge management poses a national problem, it can also be considered a potential resource. Thus, resource recovery is also a vital part of the FSSM, in addition to pollution mitigation. Properly managed, faecal sludge can be a valuable resource rather than waste. Some plant nutrients, such as nitrogen and phosphorus, as well as other organic matter, are present in FS and septage. The treated FS waste, co-composed with organic matters obtained from solid waste treatment plants and other sources, can be used as manure for the cultivation of crops and horticulture. In this way, FS can be a partial alternative of chemical fertilizers. It can also be mixed with chemical fertilisers to obtain sufficient nutrients for producing crops with high yields.

On the other hand, the underground drainage network with STPs cannot be set up rapidly at every ULB; instead, FSTPs can be constructed faster and are suitable for small to medium-sized cities and towns. It can be synchronized with existing and new STPs in towns when proper planning, engineering, and sufficient funds exist. Thus, FSTPs can be an ideal alternative to STPs where sewerage networks and STPs are absent for FSSM and treatment of human excreta collected from OSS in the form of septage and Faecal sludge (FS).

This study demonstrates that the implementation of FSTP in all ULBs and towns can result in substantial savings, ranging from medium to small amounts of government money. The FSTP is not only an eco-friendly and pollution control mechanism but also very effective in terms of cost and efficiency. To attain the SDG goal, FSTP can be an ideal option and a vital part of the circular

economy. In this work, it is found that through the implementation of FSTP in all 87 towns of West Bengal under the Non-KMA zone, a net savings and gain may be achieved in the next fifteen years after commissioning to an amount around INR 251 billion, that have the unique potential of being a significant and remarkable contribution.

VI. CONCLUSIONS

The FSTP sector is growing rapidly, and numerous research and development projects are being conducted in institutes, as well as public and private organisations. There is a need to learn from the scientific and systematic developments. There is an immediate need to build credibility around the FSTP technologies. Sometimes, concerned authorities consider the initial capital expenditure for new and advanced technology, but overlook the recurring and long-term costs associated with operation, maintenance, and the life-cycle costs of the plants. Generally, in many cases, smooth operations are hindered due to a lack of proper maintenance, periodic repair, and renovation of the establishments, which is a common problem. This issue should be kept in mind to prevent such problems from arising in the future. Hence, authorities and decision-makers should consider the costs at the planning stage, including one-time investment costs (CapEx) and long-term recurring costs for operation and maintenance (OpEx), as well as replacement and life cycle impacts.

The objective of this study was to find out the outcome, benefit, and savings for implementing FSTPs instead of conventional STP and sewer systems in many small and medium towns in a quicker time. Accordingly, a detailed analysis has been conducted based on a comprehensive literature survey and the findings. Subsequently, the



study reveals that some economic value and positive outcomes have been achieved, which the West Bengal government and other state governments in India can adopt, thereby benefiting from the investment of government allocations and the public exchequer. At the same time, FSTP may be an ideal alternative to STP, as it has enormous potential for mitigating environmental pollution. And proper water resource management.

Additionally, it has resource recovery aspects related to sustainable development (SDG) through the reuse of treated water from septage for irrigation and other purposes, as well as the use of sludge as manure, co-composted with organic wastes obtained from solid waste treatment plants. Here, the economic gains obtained from the manure sludge and treated water from FSTPs are not considered in this study, although their impacts would be minimal concerning CapEx and OpEx. However, this aspect would be the subject of future research. Thus, FSSM ensures sustainable water resource development through reducing, reusing, and recycling waste from human excreta, emphasising the continuity of the circular economy.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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