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Faecal Sludge Characterisation, Treatment and Management Facilities: A Review

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Abstract - *Inadequate management of faecal sludge from onsite sanitation systems poses severe public health and environmental risks, especially in rapidly urbanizing areas of developing countries. This review paper provides a comprehensive assessment of the critical challenges and potential solutions for safe and sustainable faecal sludge management (FSM). Methods for reliably estimating quantities and qualities of accumulated sludge are evaluated, including surveys, empirical data analysis, and testing approaches. Decentralized treatment technologies are examined, with a focus on affordable options like waste stabilization ponds, drying beds, and composting that enable resource recovery of products such as soil conditioners, animal feed, and energy. Integrated policy frameworks, institutional models involving stakeholder coordination, financial mechanisms combining tipping fees with public-private partnerships, and community engagement strategies are analyzed. Real-world case studies across cities in sub-Saharan Africa and South Asia showcase attempts at implementing comprehensive FSM programs through a combination of technical interventions and enabling environments. The findings highlight the need for context-specific solutions tailored to local socio-economic and environmental conditions. Key recommendations emphasize developing robust quantification techniques, promoting decentralized resource recovery-oriented treatment, formulating supportive governance structures, ensuring sustainable financing, and fostering multi-stakeholder collaboration to collectively address the escalating urban sanitation crisis.*

Key Words: *Faecal sludge management, onsite sanitation, developing countries, decentralized treatment, resource recovery, quantification methods.*

1.INTRODUCTION

Faecal sludge refers to the sludge and semi-solid material that accumulates in onsite sanitation systems like pit latrines, septic tanks, and un-sewered public toilets. As global urbanization accelerates and urban infrastructures lag behind, a growing number of cities and towns in low and middle-income countries rely primarily on these onsite containment systems for sanitation needs. However, the improper management of the vast quantities of fecal sludge generated poses a severe public health and environmental hazard.

Globally, around 2.7 billion people rely on onsite sanitation systems like pit latrines and septic tanks, generating vast quantities of fecal sludge that is often indiscriminately dumped in the environment due to lack of proper management. This results in staggering economic and health costs, especially in densely populated urban areas. The United Nations' Sustainable Development Goal 6 specifically targets achieving adequate and equitable sanitation access and halving the proportion of untreated wastewater by 2030.

Effective fecal sludge management is therefore a key priority for achieving these international goals on sanitation, public health and environmental protection. However, it requires addressing a range of interlinked technical, governance and financial challenges through contextualized solutions. Innovative approaches combining affordable decentralized treatment technologies, resource recovery business models, strengthened regulations and service chains, stakeholder partnerships and robust data management can pave the way.

According to the World Health Organization and UNICEF's 2021 estimates, 3.6 billion people globally lack access to safely managed sanitation services that hygienically separate human waste from human contact. A staggering 43% of the global population relies on pit latrines, septic tanks or other onsite sanitation facilities where the fecal sludge requires emptying and further treatment (WHO/UNICEF 2021). In urban areas across nations in sub-Saharan Africa, southern Asia, and parts of Latin America, this proportion exceeds 60% in some cases (Bashir et al. 2020) [13].

The Faecal Sludge Management: Residential Report by the Bill & Melinda Gates Foundation estimated that globally around 48 million tons of fecal sludge is produced annually from onsite sanitation facilities in urban areas alone (Hutton et al. 2018) [14]. However, a large proportion of this sludge is indiscriminately dumped into the environment due to inadequate management and treatment solutions.

Unsafely managed faecal sludge can contaminate water bodies used for drinking, bathing, and irrigation purposes, thereby transmitting a range of communicable diseases such as cholera, typhoid, hepatitis, polio and diarrheal diseases. The WHO estimates that inadequate sanitation causes around 432,000 diarrheal deaths annually (WHO 2019) [16]. Furthermore, the untreated fecal sludge releases nutrient loads into receiving waters, fueling eutrophication and algal blooms that disrupt ecosystem health.

Even if faecal sludge is collected from containment systems, the lack of adequate treatment facilities leads to indiscriminate dumping in both urban and peri-urban areas, contributing to the spread of vector-borne diseases, contamination of soil and groundwater, as well as air pollution through emissions of volatile compounds (Tayler 2018) [15]. These adverse impacts disproportionately affect the health, economic productivity and quality of life of vulnerable urban populations residing in informal settlements and slum areas.

From an economic perspective, the costs imposed globally by inadequate sanitation were estimated at a staggering $223 billion annually in terms of health care, premature mortality, productivity losses and other consequences as per The Sanitation and Hygiene Poverty Risks report (Hutton et al. 2018) [14]. Addressing the challenge of fecal sludge management is therefore crucial, both from health, environmental and economic standpoints, especially in rapidly urbanizing areas of developing nations where safe, centralized sewerage and wastewater treatment facilities may not be immediately viable.

This necessitates a comprehensive approach involving reliable data on faecal sludge characteristics and quantities, development of decentralized and affordable treatment technologies, resource recovery models to offset costs, supportive policy and governance frameworks, and community engagement strategies to collectively address the escalating challenge of faecal sludge management.

2. LITERATURE REVIEW

Koné and Strauss, (2004) [9] described the development of an integrated fecal sludge management scheme in the cities of Burkina Faso, led by the National Utility for Water and Sanitation (ONEA) and the Department of Water and Sanitation in Developing Countries at Eawag (Sandec). Most urban Burkina Faso residents utilize on-site sanitation systems, which produce a lot of faecal sludge but are neither treated nor managed. ONEA sought to address this by creating an institutional structure and constructing faecal sludge treatment plants (FSTPs). The project involved developing legal documents and agreements between stakeholders for faecal sludge collection, transport, treatment, and reuse; conducting research studies on faecal sludge characterization and the viability of planted drying beds in Ouagadougou; and offering technical advice on suitable FSTP technologies. For the FSTPs, unplanted drying beds with waste stabilization ponds were used. According to research, FSTP capacity can be adjusted despite being overdesigned due to erroneous calculations of the strength of faecal sludge. Plants that could be used in planted drying beds were discovered. Service provider decrees, licences, and cooperation agreements were drafted, and roles and duties were specified through interactive workshops with private waste collectors and municipal authorities. West Africa's first integrated faecal sludge management programme with a defined legislative framework and stakeholders was the product of this cooperative approach. For cities that depend on on-site systems, the strategy can be used as a model for putting in place sustainable sanitation systems.

B. Mougoué et. al., (2012) [12], The PDF analyzes faecal sludge management in the cities of Douala and Yaoundé in Cameroon. It concludes that these cities generally have inadequate faecal sludge management. There are dump sites, but they don't offer any pre-disposal treatment. Service providers are not very organized and work informally. The collection and transportation of faeces is an unregulated activity conducted by private entrepreneurs in Douala and Yaoundé. Prices change according to status and client negotiation. Untreated sludge is deposited in peri-urban areas. Pollution and health risks result from this. The random, dis-organized system is described in the paper. There is no monitoring organization in place, although a number of actors—including regulators, middlemen, service providers, and fee collectors—are involved. The only proactive management provided by the state and municipalities is the collection of taxes and fees. Drivers of outdated tanker trucks put themselves at risk of illness by operating them without safety gear. Several concerns are noted such lack of control and coordination, financial restrictions, unmaintained waste sites, and lack of treatment. Improved state/municipal management and law, the formation of associations among collectors, routine dump site upkeep, treating sludge before to disposal, and public education are some of the attempted remedies. The research examines the inadequate handling of faecal waste in the major cities of Cameroon. In order to promote public and environmental health, it emphasises the necessity of an integrated waste management approach combining stricter legislation, funding, and stakeholder participation.

M. Bassan et.al., (2013) [10], examines the use of planted sludge drying beds for treating fecal sludge from septic systems in Ouagadougou, Burkina Faso. In underdeveloped nations like Burkina Faso, where the majority of homes utilize septic tanks or other on-site sanitation systems, managing faecal sludge is a serious problem. These systems frequently release untreated wastewater and sludge into the environment, endangering human health. In contrast to an unplanted drying bed, this study examined the use of planted drying beds including two native plant species, Andropogon gayanus and Cymbopogon nardus, for the treatment of faecal sludge. Overall, the planted beds outperformed the sludge in terms of lowering contaminants like BOD, COD, nutrients, and faecal coliforms. A. gayanus-planted beds outperformed C. nardus beds in terms of COD removal, with the former removing BOD5 with 90% efficiency. Every bed removed 77–79% of the orthophosphates. The Kjeldahl nitrogen was successfully removed at high removal rates of 94–97.5% thanks to favourable nitrification conditions. The amount of pathogen removed was only about one log unit. The results show that faecal sludge can be effectively treated in this situation by planting drying beds containing these species, albeit further treatment would be required prior to release. Through transpiration, the plants assist in removing moisture, supply root systems for advantageous microbial biofilms, and absorb nutrients. The beds' capacity to remove pollutants may get better with continued growth and root development during extended use. In regions where on-site sanitation is necessary, the study presents a suitable localised approach for managing faecal sludge and reducing health concerns.

S. Semiyaga et. al., (2015) [6], reviews decentralized technologies and practices for faecal sludge (FS) management in urban slums of Sub-Saharan Africa. Slums frequently employ on-site sanitation systems, such as pit latrines, but improper FS disposal and emptying can have negative health and environmental effects. The absence of sewer networks makes centralised treatment difficult. The use of technologies such as artificial wetlands, waste stabilisation ponds, co-composting, and drying beds for decentralised FS treatment is covered in the study. But these need large spaces, which are not available in slums. As a result, the research focuses on reclaiming valuable goods from FS that might encourage appropriate management. Soil conditioners, vermi-compost, bricks for construction, animal feed made from the larvae of black army flies, biogas for electricity, and solid fuel briquettes are a few possible products. Every product has advantages in terms of making money, enhancing environmental preservation and sanitation, and creating jobs and means of subsistence, but it also has disadvantages in terms of marketability, space requirements, and treatment requirements, social acceptance, and costs. The study concludes that while no single solution is ideal for every slum, decentralised approaches to improving FSM through resource recovery in Sub-Saharan Africa's urban slums can be sustained through the development of low-cost, decentralised technologies to transform FS into locally needed, high-value products through business models tailored to the local context. Engagement of stakeholders such as the community, government, private sector, and NGOs, along with intensive marketing to shift perceptions and create demand are also necessary.

H. Ganpathi (2017) [11], addresses the necessity of managing faecal sludge properly in New Delhi, one of India's most populated cities. Faecal sludge is defined in the paper as the raw, partially digested slurry or semisolid that is left over after excreta from on-site sanitation systems, such as pit latrines and septic tanks, is collected, stored, and treated. It's critical to manage faecal sludge properly to prevent contamination and health problems. According to the report, a large portion of New Delhi continues to rely on onsite sanitation techniques unconnected to sewage systems. The sewage infrastructure that is currently in place is inadequate due to population growth. Therefore, it is necessary to treat faecal sludge decentralized. The three types of treatment treatments are biological (aerobic decay, black soldier fly larvae), chemical (lime, urea addition), and physical (dewatering, aeration). The necessity of an integrated management strategy that involves cooperation between the local community, NGOs, government, and service providers is emphasized in the article. This includes developing capacity, creating policies, educating the public, and generating demand. The final products of the treatment have advantageous uses such as fertilizer, fuel, irrigation, etc. In conclusion, the study promotes a comprehensive approach to faecal sludge management in New Delhi that makes use of technology, community involvement, and planning to treat waste in an environmentally friendly manner and recover valuable resources.

L. Strande et. al., (2018) [1], discusses methods to reliably estimate quantities and qualities of faecal sludge (Q&Q) for designing treatment technologies and management solutions in low-income countries. It claims that there is little information on the overall amount of accumulated Q&Q and that present urban sanitation relies on non-standardized onsite systems including accumulated faecal sludge. The creation of a suitable infrastructure for management and treatment is hampered by this information gap. In order to estimate Q&Q for the entire city, the study suggests averaging out complexity at the size that matters for treatment options. The method entails gathering surveys for consumers and service providers, empirical emptying data, and spatially analysed demographic, technical, and environmental (DET) data (SPA). It was tested in Kampala, Uganda, and the estimated accumulation rates for septic tanks and pit latrines were 280 and 270 litres per capita year, respectively. Public restroom sludge did not differ considerably from septic tank sludge, however it was more diluted than pit latrine sludge. An important portion of the sources were not from households, and they had distinct qualities. Sludge quality was connected with variables such as income, water connection, number of users, confinement volume, and frequency of emptying. The ratio of COD to TS was 1.09 ± 0.56. The study finds that the substantial diversity in the individual pit latrine data used in prior attempts has led to incorrect results. For the purpose of developing management solutions, the suggested method of using questionnaires, SPA-DET data, and lab analysis yields trustworthy city-wide Q&Q estimations.

K. Junglen et. al., (2020) [4], characterized and predicted fecal sludge (FS) parameters and settling behavior in informal settlements in Nairobi, Kenya. At a Sanergy-run waste transfer site, FS samples were taken from manually emptied pit latrines. Chemical oxygen demand (COD), pH, electrical conductivity (EC), ammonia, total suspended solids (TS), and turbidity were measured in the samples. Significant correlations between TS and turbidity, TSS, and COD were found in the data. TSS and COD were also linked with turbidity. These correlations make it possible to estimate challenging parameters like COD and TSS with simple or quick measurements like turbidity and TS. A threshold was discovered by settling testing for TS, COD, and TSS over which settlement did not take place. Settling got better inside particular EC levels. These findings can help improve treatment through FS fractionation and the use of several waste streams. The study concludes that quick or simple parameters can be used in place of challenging or time-consuming laboratory testing. This could lower FS characterisation costs, which is crucial in places with limited resources. Additionally, mixing incoming FS decreased variability when compared to single samples. Designing a treatment system with settling behaviour and its ranges in mind can help it work better. In general, treatment activities in informal settlements can benefit from a correlation between FS characteristics and settling.

R. Devaraj et. al., (2021) [7], reviews the design and technologies for faecal sludge treatment plants (FSTPs). The combination of excreta, water, and solid wastes gathered from on-site sanitation systems such as pit latrines and septic tanks is known as faecal sludge. Faecal sludge must be properly processed in order to avoid health risks and environmental contamination when it is released into the open. A typical FSTP's planted gravel filter, polishing pond, anaerobic baffled reactor, screening, sludge thickening tank, and sludge drying beds are all covered in this paper. It goes over the differences between sewage wastewater and faecal sludge, including the former's higher levels of solids, nutrients, organics, and pathogens. The research also looks at biological (aerobic, anaerobic digestion, composting), chemical (pH control, disinfection), and physical (dewatering, filtration) treatment strategies. A variety of faecal sludge treatment methods are examined, such as burning, black soldier fly treatment, waste stabilisation ponds, co-composting, and vermicomposting. It is detailed how treated faecal sludge products are used as fertilizers, soil conditioners, irrigation water, protein from black soldier fly larvae, and energy recovery through biogas and biodiesel, among other applications. The study comes to the conclusion that treating faeces sludge is necessary to recover valuable resources from human waste and establish sustainable sanitation systems around the world. Safe faecal sludge management requires inclusive business models and pilot-scale FSTP projects.

S. Simiyu et. al., (2021) [2], examines faecal sludge management practices in low income settlements in Nakuru, Kenya. The goal of the study was to evaluate the procedures and difficulties involved in containing, emptying, transporting, treating, and recycling faecal sludge. The study employed qualitative techniques, including as focus groups and in-depth interviews with a range of stakeholders, including women's organisations, pit emptiers, and local leaders. The findings demonstrated that while pit latrines, or on-site sanitation facilities, predominated in the villages, they were insufficient, unclean, and soon filled up as a result of heavy use. Pit latrines were emptied by trained emptiers manually or with the use of mechanised equipment. The sludge was then taken to collecting stations by wheel carts or trucks, where it was treated at a plant run by the Nakuru Water and Sanitation Services Company (NAWASSCO). The sludge was recycled into briquettes at the factory. The study brought to light a number of obstacles in the faecal sludge management chain, such as unfavourable public perceptions, insufficient protective equipment for emptiers, expensive transportation, and a lack of knowledge about sludge recycling options. The main suggestions were to keep enhancing emptiers' capability and health protection, to engage the community more, to quantify the volume of sludge, to look into other methods for sludge recycling, and to combine data to help with decision-making and sanitation goal tracking. All things considered, the study offers helpful insights into the methods and difficulties of managing faecal waste in low-income urban settlements in secondary towns like Nakuru.

Stevani and Soewondo (2021) [3], are comparing conventional and mechanical fecal sludge treatment plants (FSTPs) in Indonesia. It assesses four FSTPs: two mechanical (Sumur Batu in Bekasi and Duri Kosambi in Jakarta) and two conventional (Keputih in Surabaya and Betoyoguci in Gresik). Faecal sludge from on-site systems, such as septic tanks, is treated using FSTPs. Performance indicators, such as cost, human resource, treatment, and collecting efficiency, are analysed in this paper. The best collection efficiency was recorded by Duri Kosambi, with an overall treatment efficiency of about 60%. Efficiency in human resources was 80% for all FSTPs. Cost effectiveness was only acceptable for Duri Kosambi. Conventional FSTPs such as Keputih and Betoyoguci should prioritise collection, treatment, and funding in their development plan. Mechanical technology can improve efficiency, but expenses are higher due to electricity and chemicals. Keputih might increase solids-liquid separation at a 150 m3/day capacity by adding mechanical equipment such a screw press and sludge acceptance facility. An approximate of Rp 7.7 billion is to be invested, with an annual O&M expense of Rp 1.2 billion. It is advised that Betoyoguci optimise its 45 m3/day capacity before constructing more units. In conclusion, the study finds that while mechanical technology can increase the efficiency of conventional FSTP, the costs are higher. It is necessary to analyse supply and achieve design capacity in order to implement mechanical units. Prioritising data integration and capacity optimisation above new unit investments is advised.

R. Tanoh et. al., (2022) [5], assessed the costs of operating fecal sludge treatment plants (FSTPs) in Ghana and evaluated whether the tipping fees charged to trucks delivering fecal sludge could enable cost recovery. There were five sizable FSTPs in Ghana that used mechanical dewatering and waste stabilisation ponds as of June 2017. The FSTPs processed 2870 m3 of faecal sludge per day on average. According to the report, FSTPs' typical operation, maintenance, and management (OM&M) expenses per 1000 m3 treated ranged from $89 to 1743, with an average of $525. Advanced technology Accra FSTP had significantly higher OM&M costs. The average tipping amount for faecal sludge vehicles was $421, with fines ranging from $310 to 530 per 1000 m3. For many simple waste stabilisation pond systems, tipping fee revenues were more than operating and maintenance (OM&M) costs; but, the sophisticated Accra FSTP's costs were not met. Although encouraged in Ghana, private sector participation in FSTP operations was limited to the Accra FSTP, which had a service agreement with the government. If proceeds were allocated to the FSTP, less expensive waste stabilisation pond systems might be able to offset OM&M expenditures from tipping fees. Nonetheless, the study came to the conclusion that tipping fees by themselves are unable to support large-city intensive mechanical FSTP cost recovery. It implies that in order to make such FSTPs financially viable, value recovery from treatment byproducts, public-private partnerships, and subsidies will also be required.

K. Samal et. al., (2022) [8], analyzed low-cost options for treating faecal sludges (FS) in developing countries. FS features differ significantly depending on the kind of on-site sanitation systems that are employed. Septage is the primary FS created in areas where septic tanks are the norm. Constructed wetlands, unplanted drying beds, and settling ponds or tanks are examples of pre-treatment methods for septage. Separating solids from liquids eliminates 60–80% of the solids. Additional polishing by wetlands or ponds is required to satisfy discharge regulations. Sludges from public restrooms are more dense and erratic in many African cities. In ponds, its high ammonia level (400–4000 mg/L) prevents algae development. Settling tanks offer a certain amount of organic and solids removal, but not much nitrogen removal. Drying beds without plants remove 35–70% of nitrogen. 55–60% of nitrogen is removed from constructed wetlands by sludge accumulation in sludge layers. However, effluent ammonia levels are still too high to release safely. Strong sludges from public restrooms provide difficulties for inexpensive treatment methods. Excessive ammonia is a common cause of pond system failure. Anaerobic digestion and nitrification/denitrification in artificial wetlands are two promising alternatives. It is necessary to create suitable, affordable treatment alternatives or substitute on-site sanitation systems that collect urine in a different area. Urine separation, wetlands treatment, and anaerobic digestion all require more fieldwork.

3. CONCLUSIONS

The above research papers and case studies examine the critical issue of faecal sludge management (FSM) in developing countries and urban informal settlements that lack access to sewerage infrastructure. Faecal sludge refers to the semi-solid waste accumulated in onsite sanitation systems like pit latrines and septic tanks.

Key Points:

- There is a lack of information on the overall amounts of accumulated fecal sludge, hampering proper infrastructure planning for treatment and management.
- Methods suggested include surveys of consumers and service providers, empirical emptying data, spatial demographic/technical/environmental data analysis, and laboratory testing.
- Faecal sludge characteristics and quantities vary based on factors like income levels, water access, containment size, emptying frequency, etc.
- Common challenges include insufficient facilities, rapid filling of pits, manual emptying under poor conditions, lack of treatment before disposal, negative public perceptions.
- Decentralized options like planted drying beds, waste stabilization ponds, composting are evaluated, with resource recovery of products like soil conditioners, animal feed, biogas highlighted.
- Case studies from cities like Kampala, Nakuru, Douala, Burkina Faso showcase attempts at integrated faecal sludge management through a combination of infrastructure development and stakeholder engagement.
- Analysis of treatment plants found mechanical technologies improve efficiency but at higher costs compared to conventional waste stabilization ponds. Tipping fees alone are often insufficient for full cost recovery.

In summary, the research highlights faecal sludge management as a crucial sustainable sanitation challenge, providing insights into quantification methods, technological options focusing on resource recovery, integrated policy and planning approaches, and real-world cases across different countries. Developing comprehensive, context-specific FSM solutions involving technical, institutional, financial and community elements is emphasized for achieving safe, sustainable management of faecal waste.

The research compiled provides a useful knowledge base by analyzing quantification approaches, evaluating technological options through the lens of resource recovery, examining policy and planning frameworks, and documenting real-world implementation experiences. This can guide efforts towards developing comprehensive faecal sludge management systems customized to local socio-economic and environmental conditions. Overcoming the sanitation crisis requires such integrated efforts spanning technical interventions, institutional reforms, targeted investments and active community involvement.

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