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Faecal Sludge Management Practices in Uganda: Challenges and Opportunities

Elisa Basika[1]*, Allan. J. Komakech[1], Musa Nsubuga[2], and Simon Kizito[1]

[1]Department of Agricultural and Biosystems Engineering, College of Agriculture and Environmental Sciences, Makerere University, P.O. Box 7062, Kampala, Uganda

[2]Department of Construction Economics and Management, College of Engineering, Design, Art and Technology, Makerere University, P.O. Box 7062, Kampala, Uganda

*Corresponding author details: Elisa Basika; ebasika21@gmail.com

ABSTRACT

In the global sanitation challenges over the years, sustainable faecal sludge (FS) management has always featured siting Sub-Saharan Africa and developing countries as the most affected. FS is currently being managed through conventional treatment plants, where it goes through a series of stages which include primary and secondary filters, sedimentation tanks, biological trickling filters, and secondary sedimentation tanks before being released into wetlands. While in wetlands it undergoes further biological filtration to remove heavy metals and the remaining nutrients. In Uganda, this system has been used since the 1970s. However, it has faced various challenges, mostly due to the rapidly growing population, poor quality of FS, low FS collection efficiency due to inaccessibility in slum areas, and the long distances moved by trucks to access the treatment plants. The objective of this review is to highlight the gaps in existing FS management practices, the level of involvement of the different stakeholders and their roles. It also highlights the existing policies, and institutional frameworks with challenges and business opportunities that can be harnessed from FS. The study employed a systematic review of literature through identifying, assessing and synthesizing relevant articles. The findings indicate gaps in government partnerships with private sector and academic institutions. Furthermore, there is increased informal participation of private sector in FSM, knowledge gaps among the public concerning FSM services. In conclusion, the government needs to strengthen partnerships with all stakeholders in the FSM sector as well as increase community sensitization about FSM management.

Keywords: faecal sludge management; global sanitation; Uganda; nanoparticles; biochar; waste management

1. INTRODUCTION TO FAECAL SLUDGE MANAGEMENT

After many years of ensuring proper sanitation practices in low and middle-income countries, the global sanitation community has realised that it is time to devise new approaches to accelerating access to quality services. Since the year 2000, the WHO/UNICEF, through the joint monitoring programs of the millennium development goals (MDGs) and now sustainable development Goals (SDGs), has consistently reported an increase in the use of proper sanitation facilities, i.e., pit latrines, septic tanks, and centralised sewer urban systems. Between 2000 and 2020, the global population increased by 1.7 billion, but 2.4 billion people gained access to safely managed sanitation services (UNICEF, 2021, WHO, 2022). However, by 2020, 3.6 billion lacked safely managed services; 580 million shared improved sanitation facilities with other households, and 616 million used unimproved facilities. Two-thirds of the people without managed services were dwellers in rural areas, while approximately half were from sub-Saharan Africa.

Uganda has a population estimated at about 47 million (World-Bank, 2020, UBOS, 2022). Out of this, 24.4% live in urban areas. Kampala is the largest metropolitan area with a population of 1.35 million (WPR, 2022), accounting for about 25% of the total urban population and about 18% of the total population (Kwiringira et al., 2021).

The management of FS in Uganda has been predominantly handled by the government body, that is, National Water and Sewerage Corporation (NWSC) and Kampala capital city authority (KCCA) for the Kampala area, including other stakeholders that are either directly or indirectly involved. The major role charged with all these stakeholders is to regulate private operators and provision of environmental certificates (KCCA), FS transportation licenses (NEMA), and registration for discharge (NWSC), and all these work together to foster a working Public Private Partnership (PPP) arrangement for better service delivery (Laker, 2020).

Therefore, the objective of this study is to highlight the existing FS management practices, examine the level of involvement of the different stakeholders and their different roles, review the existing policies and institutional frameworks and explore the challenges and business opportunities that can be harnessed from FS.

It also discusses the possibilities of deriving various products out of FS to enhance the productivity of agricultural soils for food security.

2. METHODS

A systematic review of literature was done to inform innovative approaches in faecal sludge management. Relevant articles were identified, assessed, and their findings synthesized. Preliminary research ensured no duplication and sufficient literature availability. Inclusion criteria were based on study design and relevance, while exclusion criteria focused on unrelated or inaccessible articles.

Comprehensive searches across various databases such as Google Scholar, Web of Science, and Scopus was conducted. This methodological approach aimed to at establishing a robust foundation for faecal sludge management research, offering insights into advancing methodologies in this critical area.

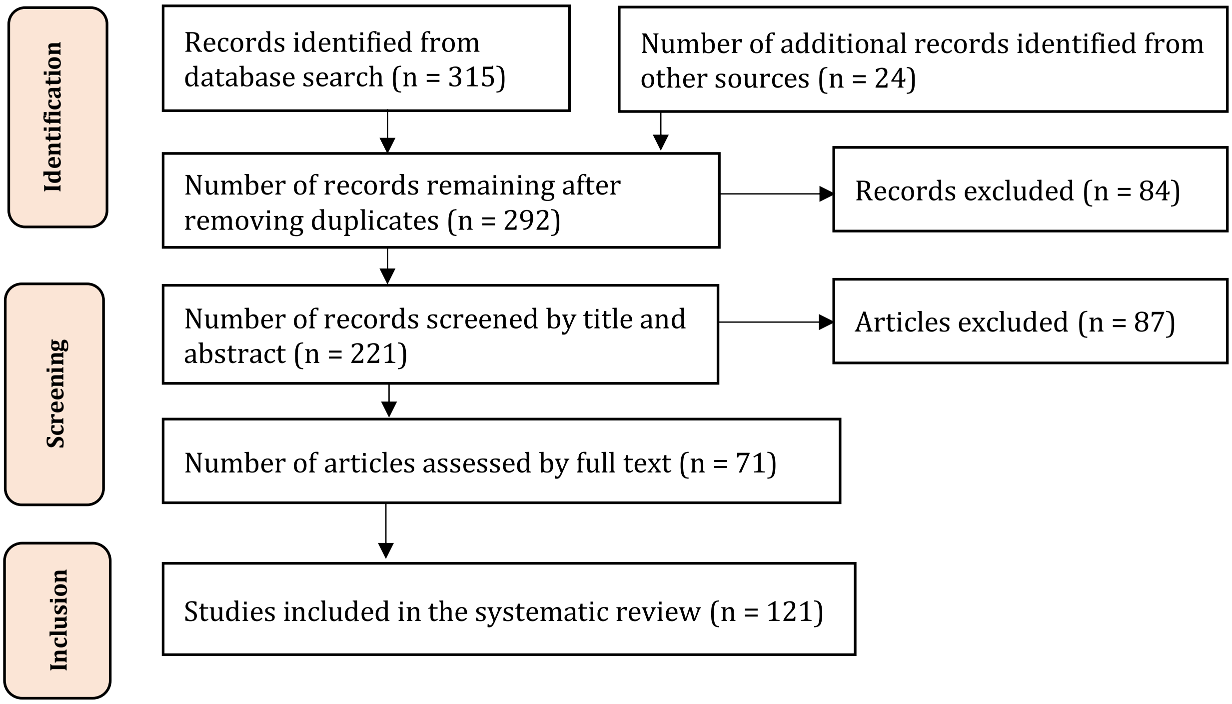

FIGURE 1: Systematic review Prisma.

3. FAECAL SLUDGE MANAGEMENT PRACTICES IN UGANDA

3.1 Overview of The Faecal Sludge Management

In Uganda, there are two main FS sludge treatment plants: the Bugoloobi treatment plant and the Lubigi treatment plant. The Bugolobi sewerage treatment plant was established in 1940 and expanded in the 1970s with a capacity to handle 33,000 m3/day of wastewater and 580 m3/Day of FS. However, it is not designed to treat FS (KCCA, 2020). The plant comprises conventional wastewater treatment processes such as preliminary and primary treatment through screens or grit removers, sedimentation tanks, biological trickling filters, and secondary sedimentation tanks before being discharged to the Nakivubo channel towards the Nakivubo wetland for tertiary treatment. The Lubigi Sewerage Treatment plant was commissioned in 2014 with a design capacity of 400 m 3 and 5000 m3 for FS and wastewater, respectively, daily. As a result of the establishment of the Lubigi treatment plant, there was a noticeable 20% increase in the dumping of FS, with 85% of the emptying activities carried out from informal settlements of Kampala (KCCA, 2018). Proper FS management entails safe containment, adequate and safe emptying of full onsite sanitation systems, safe transportation, proper treatment, and safe disposal or reuse, as shown in Figure 1 (Klingel et al., 2002, Medland et al., 2016).

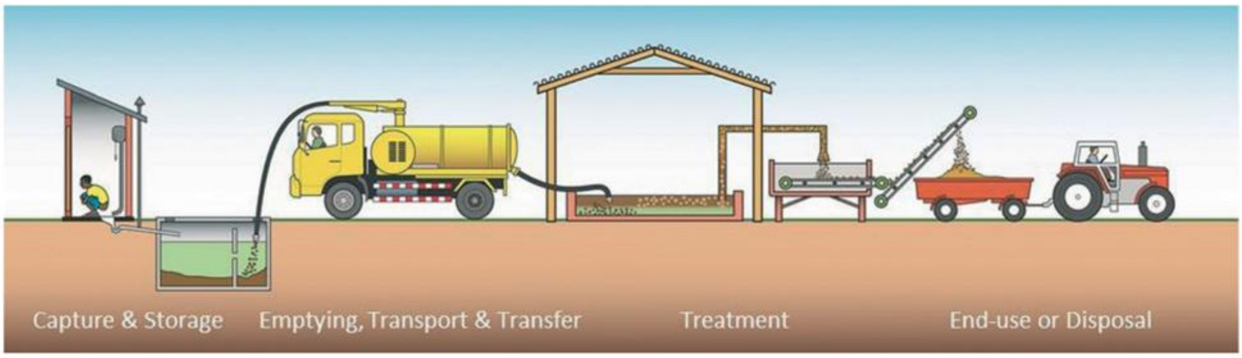

FIGURE 2: The sanitation service chain (Medland et al., 2016).

In Uganda, there are key players at all these different levels comprised of both public and private sectors hence the public-private partnership (PPP) to ensure quality and affordable FSM management services to all, with the public sector taking the leading role (Chowdhry and Kone, 2012) and the government authorities taking the sole responsibility of regulation. In addition, the regulation ensures that the environment is well protected (NEMA) and promotes public health and safety (Cairns-Smith et al., 2014).

Many private players are involved in the FS emptying and transportation segment. However, these operate informally and unregulated in various settings (Rao et al., 2016) with little or no supervision from the regulatory bodies fostering illegal dumping of FS.

3.2 FS Management Technologies

There are several technologies that are commonly used for the management of faecal sludge, including:

(1) Septage treatment: This involves the treatment of Septage, which is the solid and liquid material removed from septic tanks and similar onsite wastewater treatment systems. Septage treatment typically includes processes such as screening, dewatering, and stabilisation.

(2) Pit latrine emptying and transport: This involves the manual or mechanical emptying of pit latrines and the transport of the faecal sludge to a treatment facility (Thye et al., 2011).

(3) Vacuum truck: This truck is equipped with a vacuum system that can empty pit latrines and transport the faecal sludge to a treatment facility (Semiyaga et al., 2022a, Chipeta et al., 2017).

(4) Container-based sanitation: This involves using portable toilets serviced by a truck equipped with a vacuum system. The faecal sludge is transported to a treatment facility (Russel et al., 2019, Tilmans et al., 2015).

(5) Anaerobic digestion: This is a biological process in which microorganisms break down organic matter without oxygen. Anaerobic digestion can be used to treat faecal sludge and produce biogas as a by-product (Forbis-Stokes et al., 2016, Semiyaga et al., 2022b).

(6) Incineration: This thermal treatment process involves burning the faecal sludge at high temperatures, reducing its volume and destroying pathogens (Harada et al., 2016).

(7) Composting: Composting is a process of breaking down organic matter (faecal sludge in this case) into a humus-like substance that can be safely used as a fertiliser (Cofie et al., 2009, Mengistu et al., 2018).

3.2.1 Emptying technologies

The commonest emptying technologies across Asia and Africa are mechanised and semi-mechanised technologies (Chowdhry and Kone, 2012). The semi-mechanised technologies include; Manual Pit Emptying Technology (MAPET), Vacutug, and the Gulper (Mikhael et al., 2014, Thye et al., 2011). In several developing countries where people do not have the financial muscle to pay for mechanised emptying services, manual emptying is employed, which is informal and illegal in many developing countries. This mainly occurs in slum areas and other informal settlements that are sometimes inaccessible by mechanised emptying trucks.

FIGURE 3: Gulper emptying technology.

FIGURE 4: Vacutug emptying technology.

FIGURE 5: Cesspool trucks at offloading bay in Lubigi.

Other factors may include thickened FS due to delayed emptying that cannot be effectively emptied by mechanical means (Chowdhry and Kone, 2012, Medland et al., 2016, Strande et al., 2018, McConville et al., 2019). Emptying frequencies for households vary widely from 3 months to 3 years (Cairns-Smith et al., 2014, Chowdhry and Kone, 2012, Kulabako et al., 2010) depending on several factors which may include but are not limited to; the size of containment, number of users, groundwater table and percentage of solids in pit latrines (Lugali et al., 2016). By 2018, under the Kampala Faecal Sludge Management Project (KFSMP) funded by DFID and Bill and Melinda gates foundation, a survey revealed that there were 140 vacuum trucks varying in sizes from 2m3 to 15m3 and 15 sludge gulpers in total, which are privately owned. There were 15 trucks and 20 tricycles where 200-litre barrels were loaded and informal manual emptiers that KCCA did not legalise to operate (KCCA, 2018). Although these numbers have since increased in the past five years, the challenges have remained the same and are yet to be addressed due to a limited resource envelope for the regulatory bodies and the increasing poverty levels rendering client’s incapable of affording the proper sanitation services. In 2020 alone, the poverty levels raised by 10 percentage points due to the COVID-19 pandemic (D+C, 2021).

4. CHARACTERISTICS OF FAECAL SLUDGE

The characteristics of FS are determined by several factors, such as environmental, technical, socioeconomic, or cultural, as seen in Figure 5.

Environmental factors resulting from the nature of the location may be altered. An example is the sub-surface's hydrological properties that may determine to what extent water may sip or drain from the containment, as described by Graham and Polizzotto (2013). The technical aspects or factors may arise from the choice of sanitation technology that may determine whether the containment is sealed, which affects the water content and the design of the flow of materials, which may influence the fractions of excreta in the FS or whether conditioning material has been added to the sludge containment (Krueger, 2021). Socioeconomic and cultural aspects can be largely seen in the characteristics of FS from one region to another, locally and internationally. Basing on demographics, cities employ a lot of public toilets, which more people use, empty more often, and based on such, the FS from these facilities is less decomposed and compared to that in rural settings or sparsely populated areas (Strande and Brdjanovic, 2014, Strauss et al., 1997). Cultural norms like how anal cleansing is done, whether by wiping or washing, also determine whether water or wiping material is added to the sludge. The population's dietary habits greatly impact the amounts of undigested fibre in the faecal matter (Rose et al., 2015). The affordability of the various sanitation types in a community will also determine the kind of technology to be adopted, which also affects the nature of the sludge in the long run. In a study to determine the amount of solid waste in pit latrines in Zambia, James et al. (2019) found that FS contained between 20 to 55% solid waste, including menstrual hygiene products, condoms and diapers.

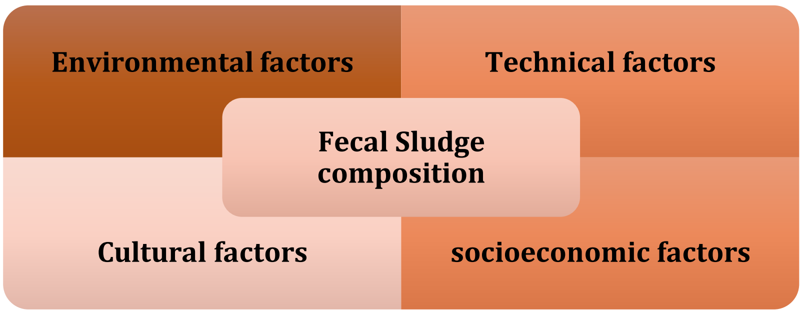

FIGURE 6: Factors influencing faecal sludge composition.

Generally, all the above factors determine the quantities of the major parameters that describe the nature of FS, and these include Total Solids (TS), Total Soluble Solids (TSS), pH, Electrical Conductivity (EC), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand and nutrients, which may also vary depending on the containment technology. In a study by Kimuli et al. (2016) to characterise the faecal sludge in pit latrines around the slums of Kampala, it was found that the COD decreases with the FS depth of the pit latrine. The sludge found at the bottom of the pit latrines also has fewer pathogens and odours than at the top (Kimuli et al., 2016).

5. POLICY ANALYSIS FOR FS REGULATION, MANAGEMENT, AND INSTITUTIONAL FRAMEWORK

For the sanitation and public health targets that are set both globally and locally to be achieved, a number of realistic, achievable and coherent policies and institutional frameworks for sanitation have to be put in place (Lerebours et al., 2021, Mumssen et al., 2018). The need for regulation of faecal sludge emptying and transportation services have been greatly emphasised by the international communities and several governing bodies, but there is minimal new information on the levels of implementation of the available regulatory frameworks and drivers for such implementation (Weststrate et al., 2019). In a study to analyse the regulatory frameworks and mechanisms of FS emptying and transportation that was carried out in 15 countries and 20 cities, including Uganda, Lerebours et al. (2021) indicated that sanitation governance varies across cities, with most being decentralised (74%) where it is the responsibility of the local government. Across countries, the regulator of sanitation services is local government alone, a national entity, or both, and this was observed at 35%, 20% and 45%, respectively, across cities. Among the cities in sub-Saharan Africa, only 24% started active faecal sludge regulation before 2000, while 54% was after 2010. Nevertheless, several regulatory mechanisms have been put in place in sub-Saharan Africa, and every country has at least one mechanism, as indicated by Lerebours et al. (2021). These include but are not limited to mandatory sites for disposal, licenses for operators, truck licenses, use of personal protective gear, use of specific emptying tools, tariffs, scheduled emptying, sanctions, fines, arrest, monitoring and control, inspections at disposal sites, customer satisfactory surveys, support and incentives, support for financial access, training on regulations, subsidies on building sanitation facilities, subsidies to empty the pits and septic tanks, formalisation of informal emptiers among other regulatory mechanisms.

In Uganda, the role of regulation is charged with several bodies, with the main actors being KCCA, town councils, municipal councils and NEMA under the Ministry of Water and Environment. These bodies enforce several intensive regulations and mechanisms regarding FS management through the environmental police section, including arresting and apprehending those who violate them. These include the KCCA Act, 2010; The National Environment (Waste Management) Regulations SI No 52/1999; The Public Health Act 1935 (Cap.281); The Local Government Act 1997 (Cap 243); The Public Private Partnership Act 2015 and The Local Government (Kampala City) bye Laws (Parliament, 2022). These laws regulate emptying services, enforce standards, engage the private sector, formulate specific by-laws, and lower urban councils and enable licensing and certification. The Kampala city council also passed the Kampala Capital City Authority (Sewerage and faecal sludge management) ordinance in 2019 to address challenges with the current laws and regulations (KCCA, 2019). This clearly outlines the minimum standards for FS transportation, onsite sanitation systems, and waste disposal.

6. FAECAL SLUDGE MANAGEMENT AS A BUSINESS ENTITY

In most developing countries, the FSM chain needs to be given more attention in terms of funding, which has predominantly left the services in the management of private players. This has been mainly realised in non-networked sanitation systems and offsite systems. Public funds have also been heavily invested in building sewer networks alongside domestic water networks in major urban areas, but this serves only a small group leaving the rest in the hands of private players. A case in point is Dar es Salaam, Tanzania, where only 10% of the population is connected to sewer networks, yet 99% of the public funds in this sector were used to finance these networks and sewerage treatment plants. This is the same situation in most sub-Saharan countries, including Uganda. Several business models have been developed to address the different challenges and help meet the demands of the critical stakeholders in the FS service chain.

These have majorly focused on the emptying and transportation of FS, offering different value propositions like; timely emptying to the various niches and environmental protection by ensuring safe disposal (Rao et al., 2016). In a study to assess the business models of FS transportation and emptying services in Kampala suburbs, Laker (2020) reported that in Kanyanya and Lukuli, most users were using onsite sanitation systems, and this accounted for 93% and 97%, respectively and the costs are all met by the owner of the sanitation facility. In Kampala alone, only 7.5% of the population has access to the sewerage network, with 91.5% relying entirely on onsite sanitation systems and 1% practising open defecation (McConville et al., 2019).

The cost and practicality of emptying septic tanks are affected by several factors, like disposing of solid wastes by tenants in pit latrines and septic tanks, as mentioned by one of the landlords among the households studied by Laker (2020) in her study, she quotes: "some of us who have tenants with children they keep throwing pampers in the toilets, and the ladies keep throwing pads in the toilets, even broken bottles, and this is very unfair to us these are some of the challenges we have faced". In one of the key informant interviews one landlord indicated that Quote "If there is solid waste, they charge more money if you are giving them 80,000= [referring to the client paying the cesspool emptiers 80,000=], they can ask you like 100,000 because of the garbage". Therefore, disposal of solid waste may be attributed to a lack of proper solid waste management systems on top of the untimely garbage collection and the need for more knowledge on waste management.

During her study, Laker (2020) revealed that clients pay from USD 5 to USD 8 per 200 litter barrel as emptying fees for gulping services and USD 22/per trip to USD 62/per trip for cesspool services. However, clients also revealed a known price of USD 5.4/m3 and USD 27/m3 for gulping and cesspool services, respectively, which all emptiers must stick to but do not for various reasons. Clients in these informal settlements claimed the charges were higher according to their income status, which was later confirmed in a study by KCCA (2018) and Strande et al. (2018). On analysis of the capital expenditures (CAPEX), operational expenditures (OPEX) and revenue projections over 10 years, it was observed that cesspool technologies, particularly the large trucks of 10m3 size, generated more revenue and medium trucks for gulping technologies, as shown. Revenues for the large cesspool trucks are attributed to the large amounts of FS collected vs the operational costs (personnel and fixed costs).

Various business models for cesspool and gulper technologies were studied, including franchise, scheduled desludging, licensing incentivised disposal, call centre, and non-franchised models. Laker (2020) Concluded that for the cesspool technology, the most suitable business models were scheduled desludging and the call centre models, while for gulper technology, it was the mobile transfer station model, scheduled desludging model and the call centre model (Kulabako et al., 2010, Rao et al., 2016).

7. CHALLENGES IN FS MANAGEMENT

Faecal sludge management in low-developing countries can be challenging due to a lack of infrastructure and resources. Some common challenges include: 1). Limited sanitation coverage: In many low-developing countries, access to basic sanitation facilities is limited, leading to the practice of open defecation and the accumulation of large amounts of faecal sludge. 2). lack of infrastructure: Many low-developing countries lack the infrastructure and resources needed to collect, transport and treat faecal sludge (Bassan, 2014). This can lead to the discharge of untreated faecal sludge into the environment, contaminating water sources and spreading disease (Harada et al., 2016). 3). Treatment facilities inadequacy: Many low-developing countries need access to appropriate treatment facilities for faecal sludge. This can lead to the use of inappropriate disposal methods such as open dumping or discharge into water bodies. 4). Limited technical capacity: Many low-developing countries need more technical capacity to design, construct and operate faecal sludge management systems (Vodounhessi, 2006). This can lead to the use of inappropriate technologies and the failure of systems. 5). Socioeconomic and cultural factors: Socioeconomic and cultural factors such as poverty, cultural taboos, and lack of education can also hinder the development and implementation of faecal sludge management systems in low-developing countries (Akumuntu et al., 2017).

8. EXISTING INTERVENTIONS

Several new and existing interventions have been implemented to manage FS and reduce its adverse environmental and public health effects. These range from the expansion of existing wastewater and faecal sludge treatment plants to new innovative waste-to-energy technologies, which may include but are not limited to pyrolysis (Krueger, 2021, Krueger et al., 2021), vermicomposting , thermal composting (Manga et al., 2021, Mengistu et al., 2018) and briquettes making (Kizito et al., 2022, Atwijukye et al., 2018). However, these interventions have yet to be explored enough to obtain lasting solutions for FS management, creating a knowledge gap; therefore, more studies need to be done to close this gap. Energy recovery from FS seems to be a very attractive venture due to the increasing energy demand for urban areas and slums (Chidumayo et al., 2002, Yonemitsu et al., 2014).

Although the amount of energy that can be harnessed depends largely on the heating value, organic content and degree of dewaterability (Chen et al., 2002, Elsaesser et al., 2009, Ronteltap et al., 2014), FS has a very high degree of stability which influences its dewatering through thickening, decanting and drying. The degree of dewaterability of FS can also be enhanced by stabilising the stabilised FS with the fresh one up to a specific ratio (Ronteltap et al., 2014). Despite the existence of these interventions, the profitability of utilising FS and its products has yet to be well known, which could also be the leading factor in improper disposal (Diener et al., 2014, Peal et al., 2014).

Furthermore, to address these challenges, various approaches have been proposed and implemented, such as:

(1) Community-led total sanitation: This approach focuses on community involvement in designing and implementing sanitation systems. Community members are trained to construct and maintain latrines and to collect and transport faecal sludge for treatment or safe disposal.

(2) Decentralised treatment systems: This approach involves the construction of small-scale treatment facilities in the community, such as septic tanks, to treat faecal sludge locally.

(3) Resource recovery and reuse: This approach focuses on recovering resources such as energy, fertiliser, and water from faecal sludge. This can help reduce faecal sludge management's cost and environmental impact.

(4) Financing and subsidies: Government and international organisations can provide financing and subsidies to low-developing countries to support the development and implementation of faecal sludge management systems.

(5) Technical assistance: International organisations and experts can provide technical assistance to low-developing countries to help them design, construct, and operate faecal sludge management systems.

(6) It is important to note that the approach to faecal sludge management will vary depending on each country's specific context and characteristics, and it is essential to consider the local context and culture to develop sustainable and effective solutions.

PYROLYSIS OF FAECAL SLUDGE

Pyrolysis is a thermal treatment process that involves heating organic material without oxygen to produce biochar, bio-oil, and gases. Pyrolysis of faecal sludge (FS) has been proposed as a sustainable way to treat and convert FS into valuable products, such as biochar and bio-oil while reducing the health and environmental risks associated with traditional FS disposal methods.

Several studies have investigated the pyrolysis of FS and its potential as a sustainable waste management and resource recovery option. For instance, a study by Gold et al. (2018) evaluated the pyrolysis characteristics of FS and found that the optimal pyrolysis temperature for maximum biochar yield was 500°C. The study also reported that the biochar produced from FS pyrolysis had a high carbon content and could be used as a soil amendment.

The thermal decomposition process of biomass during pyrolysis takes place in the absence of oxygen under an inert atmosphere comprised of either argon or nitrogen gas flow. The biomass can be organic, inorganic or a mixture, depending on where its obtained (Zaman et al., 2017). FS comprises a mixture of solid and liquid waste, which contains excreta from humans collected from onsite sanitation systems such as septic tanks and pit latrines. It also often contains garbage, sand or soil, and groundwater, growing water depending on the local conditions. The high organic matter composition in FS qualifies it highly as a feedstock for pyrolysis. However, the pyrolysis process is highly affected by the moisture levels of the feedstock, and therefore there is a need for pre-processing to desired temperatures before pyrolysis. High moisture levels increase the amount of H2 gas in a water-gas shift reaction which is favoured by a high steam partial pressure. In the process, CO is consumed, producing CO2 and H2, causing a decrease in CO and an increase in CO2 accordingly. The composition of CH4 and C2 decreases automatically as the water quantity increases due to the enhanced reforming reactions (Dong et al., 2016). Therefore, considering the balance.

The pyrolysis offers a safe and valuable alternative to illegal dumping and unsafe handling of FS by producing valuable products like biochar, improving the physiochemical soil properties and destroying pathogens due to high processing temperatures (Ward et al., 2014). Compared with other waste management processes like incineration and open burning, pyrolysis of FS is a more environmentally friendly procedure as it inhibits the formation of dioxins and volatilisation of Cu, Ni and Cr (Dong et al., 2016). When Ngo (2020) characterised the products from pyrolysis of FS at 300oC and 500oC, the yields were 55.6% and 48% for char, 33% and 26.7% for tar, 10.4% and 26.3% for gas, respectively, which indicated that higher temperatures yield more gases while the yields for char and tar reduce. It was also found that higher heating values for the faecal char were reduced with increasing pyrolysis temperatures (Ngo, 2020)

ACTIVATED CARBON

Activated carbon (AC) is a highly porous material that is widely used in various applications, including water and air purification, energy storage, and gas separation (Wong et al., 2018, Sevilla and Mokaya, 2014). The production of AC from waste materials, such as faecal sludge (FS), has gained significant attention due to its potential for sustainable waste management and resource recovery. Several studies have investigated the production of AC from FS using different pyrolysis and activation methods. For instance, a study by Ahmed et al. (2023) investigated wastewater pollutants remediation using FS-based activated carbon. Results showed significant removal efficiencies for heavy metals and microbial contaminants and showed no loss in removal efficiencies after large-scale applications.

In addition to steam and chemical activation, several studies have investigated the use of other activation methods, such as microwave and electrochemical activation, to produce AC from different biomass. For instance, in a study by Liu et al. (2010), the production of AC from bamboo using microwave activation showed that the resulting AC had a high surface area and pore volume, as well as a high carbon yield and high adsorption potential for organic pollutants.

Despite the potential benefits of using FS for AC production, several challenges need to be addressed, including the variability in FS composition, the presence of impurities, and the high ash content. The production of AC from FS has gained significant attention as a sustainable waste management and resource recovery option. Recent research has shown that different activation methods can be used to produce AC with high surface area, pore volume, and adsorption capacity. However, challenges related to FS variability and impurities need to be addressed. Further research is needed to optimise the production process and explore the potential applications of FS-derived AC.

CARBON NANOPARTICLES

Nanoparticles are particles with sizes of 1-100 nm, exhibiting unique properties due to their small size and high surface area (De Marchi et al., 2018). They have found applications in various fields, such as electronics, medicine, energy, and environmental remediation (Parvizi et al., 2019). Several types of nanoparticles are available, including metal, metal oxide, carbon-based, and polymer-based nanoparticles. Metal nanoparticles, such as gold, silver, and platinum, have been widely used in catalysis, sensing, and biomedicine. Metal oxides nanoparticles, such as titanium dioxide and zinc oxide, have applications in photocatalysis, energy storage, and water treatment (Thines et al., 2017, Zhang et al., 2016). Carbon-based nanoparticles, such as graphene and carbon nanotubes, have been used in electronics, energy storage, and biomedical applications (Boroumand Moghaddam et al., 2015). Polymer-based nanoparticles, such as polystyrene and polyethene glycol, have found applications in drug delivery and imaging (Wang et al., 2019). Recent advances in the synthesis and functionalisation of nanoparticles have opened up new opportunities for their use in various fields.

Carbon-based nanoparticles have been the subject of extensive research due to their unique properties and potential applications in various fields, such as electronics, energy, and biomedical sciences (Asadian et al., 2019). The discovery of carbon nanoparticles can be traced back to 1985 when Harold Kroto, Richard Smalley, and Robert Curl discovered the fullerene molecule, which consists of 60 carbon atoms arranged in a soccer ball-like structure. This discovery led to the development of various carbon nanoparticles, including carbon nanotubes and graphene, which have attracted significant research interest due to their unique properties.

Carbon nanoparticles have been extensively studied due to their unique properties, such as high surface area, mechanical strength, and electrical conductivity (Velmurugan et al., 2013). These properties make them suitable for various applications such as energy storage, catalysis, and drug delivery. Recent discoveries in the field of carbon nanoparticles include carbon dots which are small carbon-based nanoparticles with sizes less than 10 nm that exhibit strong fluorescence properties. They have been used for bioimaging, sensing, and drug delivery applications (Asadian et al., 2019). Carbon nanotubes which are cylindrical carbon-based nanoparticles with diameters in the nanometre range and lengths in the micrometre range. They have been used in various applications, such as water treatment, electronics, energy storage, and biomedical sciences. And graphene which is a two-dimensional carbon-based nanoparticle with a thickness of one atom. It exhibits unique mechanical, electrical, and optical properties, making it suitable for various electronics, energy, and biomedical sciences applications.

NANOPARTICLE SYNTHESIS

Several methods have been developed for synthesising carbon nanoparticles, including chemical vapour deposition (CVD), arc discharge, laser ablation, ball milling and sol-gel synthesis. Each method has advantages and disadvantages regarding the quality of the produced nanoparticles, scalability, and energy requirements.

NANOPARTICLES FOR WATER TREATMENT

In recent years, nanoparticles have found significant applications in water treatment, particularly in removing micro pollutants. Micro pollutants, including pesticides, pharmaceuticals, and personal care products, can pose a significant risk to human health and the environment if not properly removed from water sources (Bottoni et al., 2010, Kumar et al., 2022, Mohmood et al., 2013).

Nanoparticles include titanium dioxide, iron oxide, and carbon nanotubes (Khaydarov et al., 2010, Vatchalan, 2022, Okoli et al., 2014, Getahun et al., 2022) have been studied for their ability to remove micropollutants from water. For example, titanium dioxide nanoparticles effectively remove organic pollutants through photocatalytic degradation (Shaban et al., 2016, Banerjee et al., 2012). The photocatalytic process involves the activation of the nanoparticles by light, which then oxidises the organic pollutants into harmless by-products. The nanoparticles have a high surface area and reactivity, effectively allowing them to adsorb pollutants from water sources.

Recent research has focused on developing new and improved nanoparticles for removing micro-pollutants from water. For example, silver nanoparticles have been investigated for their ability to remove antibiotic-resistant bacteria from water sources (Khan et al., 2022, Zahoor et al., 2021, Kallman et al., 2011). Additionally, magnetic nanoparticles have been studied for their potential use in water treatment, as they can be easily separated from water using magnetic fields.

RESEARCH GAPS

Although the use of faecal sludge-based activated carbon (FSAC) for water treatment has shown promising results, several gaps still need to be addressed, particularly in its use in nanotechnology-based water treatment systems. Some of the critical gaps are discussed below:

Lack of standardised synthesis methods: There currently needs to be a standardised method for the synthesis of FSAC, which makes it difficult to compare the results of different studies. This lack of standardisation also makes it challenging to scale up the production of FSAC for large-scale water treatment systems.

Limited understanding of the adsorption mechanisms: While FSAC effectively removes contaminants from water, there still needs to be a greater understanding of the adsorption mechanisms that take place. This makes it challenging to optimise the performance of FSAC in water treatment systems.

Limited information on long-term stability: There needs to be more information on the long-term stability of FSAC, particularly in terms of its performance in real-world water treatment systems. This information is important for determining the lifespan of FSAC-based water treatment systems and ensuring their long-term sustainability.

Health and safety concerns: The use of FSAC for water treatment raises health and safety concerns, mainly due to the potential presence of pathogens and other harmful contaminants in the faecal sludge. Proper handling and treatment of the faecal sludge is necessary to ensure that the resulting FSAC is safe for use in water treatment systems.

Limited understanding of the impact on the environment: The impact of FSAC-based water treatment systems on the environment still needs to be better understood. There is a need for further research to determine the potential environmental impact of FSAC-based water treatment systems, particularly in terms of their long-term sustainability.

In conclusion, while the use of FSAC for water treatment has shown promising results, several gaps still need to be addressed, particularly in terms of its use in nanotechnology-based water treatment systems. Addressing these gaps will be important for optimising the performance of FSAC-based water treatment systems and ensuring their long-term sustainability.

SUSTAINABILITY PLAN FOR FS MANAGEMENT

The rate of urbanisation in around cities and municipalities is rapid, particularly for low and middle-income countries, which has escalated the sanitation challenges with regard to infrastructure, operation and maintenance of wastewater and faecal sludge treatment plants (Rydin et al., 2012). Kampala city and several municipalities around the country are characterised by ageing and overloaded wastewater treatment facilities serving a small population and inefficient faecal sludge collection from onsite facilities. Furthermore, pit latrines in slums are constructed without considering the possibility of emptying in the future, which poses a challenge (STILL et al., 2013). This is mainly faced in unplanned and densely populated parts of urban areas. As a result, the faecal sludge is sold off for soil amendment, and the effluent from the treatment plants carries a load of pathogens and unsafe elements, making it unsafe for disposal. Most rural areas lack designated faecal sludge disposal and treatment sites and are characterised mainly by onsite treatment facilities with limited desludging. In a study by Appiah-Effah et al. (2014) about faecal sludge management in low-income areas, it was found that only 3.7% of the respondents desludged their toilets, and 61% of those who desludged did not have any designated disposal sites. Therefore, a comprehensive mechanism encompassing social, economic, and environmental factors is needed. In their study, Mallory et al. (2019) found a very high potential for further expansion of FS reuse with a very high market in the agricultural sector and that a monthly permit system would enhance the revenue collections from FS damping as compared to per-visit fees. Furthermore, using the Agent-Based Model (ABM) for FS management, the illegal dumping of FS was significantly reduced through the existing fees, fines and regulatory structure (Mallory et al., 2019). There is also a need to explore the need to use Omni-processors in FS management as they provide a financially and environmentally viable solution for sustainably reducing the global sanitation gaps (Rowles et al., 2022, Vyas and Swami, 2021). Omni-processors are also a smart solution for resource recovery from FS through carbon sequestration. In fast pyrolysis, fly ash can be further used as a construction material (Gueye et al., 2022).

CONCLUSIONS

Therefore, we can conclude that the management of faecal sludge (FS) in urban and rural settings faces challenges due to socioeconomic and institutional issues. These challenges include a lack of sensitization, inadequate budgeting and resource allocation, and a knowledge gap in understanding the potential benefits of FS management. The government needs to partner with stakeholders, including academic institutions, to bridge this knowledge gap and achieve global sanitation goals. Recommendations include formalizing private sector involvement, providing support to private sector operators, continuing sensitization, integrating solid waste management with FS management, and engaging communities to create demand for FS management services. Additionally, there is a need for further research to address gaps in the use of FSAC-based water treatment systems, particularly in nanotechnology-based systems, to optimize performance and ensure long-term sustainability.

RECOMMENDATIONS

(1) The government needs to partner with stakeholders, including academic institutions, to address the knowledge gap in FS management.

(2) Formalize private sector participation in FS management and provide necessary support to improve service delivery.

(3) Continue sensitization and community engagements to create demand for FS management services.

(4) Integrate solid waste management and FS management to ease the process, especially in peri-urban areas where toilets are often full of solid waste.

(5) Explore the potential benefits that can be harnessed from faecal sludge, from collection to the reuse of dewatered sludge.

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