THE APPLICATION OF ANAEROBIC DIGESTION IN ADDRESSING THE UNSANITARY CONDITIONS OF LAVATORIES IN TERTIARY INSTITUTIONS OF NORTH-WESTERN NIGERIA: A REVIEW

ABSTRACT

North-Western Nigeria is a climate-vulnerable area characterized by seasonal rainfall and hot weather.The region is faced with various challenges, including inadequate water supply, making sanitation practice the topic of discussion among various stakeholders in the environmental and public health sectors. The objective of this paper is to review the applications of anaerobic digestion in addressing the sanitary issues in the tertiary institutions in North-Western Nigeria. Most important on this issue is the unsanitary conditions of lavatories at students' in these institutions.A report by the International Centre for Investigative Report posted it that "life in most tertiary institutions in North-Western Nigeria is quite unbearable for students, due to the level of discomfort and poor sanitary conditions of public toilets in their hostels. In view of this, it is suggested that various sanitation technologies that would prevent the spread of communicable diseases with less application of water should be considered in these institutions. Anaerobic digestion technology has been reported to play a significant role in addressing sanitary challenges and can also be integrated with other technologies such as urine-diverting flush toilet and waterless urinals, among others, to address the issue of inadequate water and energy supply, as well as sanitary conditions of students' lavatories in higher institutions in North-Western Nigeria.

Keywords: Sanitation technologies, Anaerobic digestion, lavatories, tertiary institutions, waterless urinals.

Introduction

Waste generation is a natural consequence of human life. The way these wastes are handled, stored, collected and disposed, can pose risks to the environment and to public health (Ross *et al*., 2022). The management of this waste is one of the major challenges worldwide and is an important concern in developing countries where waste management infrastructure and services are lagging behind the basic standards in terms of hygiene, efficient collection and disposal (Workman *et al*., 2021). When people do not have access to sanitation, their biological waste is left in the open, providing a means to transmit gastrointestinal disease (Nakamya *et al*. 2020; Cid *etal*., 2022). Untreated waste is responsible for several diseases like cholera, gastroenteritis, dysentery, typhoid, hepatitis A, and intestinal parasites, taking the life of millions of people each year and infects hundreds of millions more (Hossain *et al*., 2013). These conditions, overrepresented in developing countries, further hamper quality of life in populations that already lack sufficient food, clean water, and energy (Workman *et al*., 2021).

The World Health Organization (WHO) and United Nations Children's Fund (UNICEF) Joint Monitoring Programme (2019) estimated that there are more than 673 million people practicing open defecation in the world, especially in rural communities of developing countries (Ross *et al.*, 2022; Boyd *et al.*, 2022). In urban settings, the situation is more pronounced at the institutional level such as in prisons, students' hostels, among others. Water shortage is the main cause of unsanitary conditions of lavatories since adequate water needs to be used to flush the faecal waste down the sewer system; otherwise, the faeces remains floating on the water seal, covering the opening of the trapway (Hossain *et al.*, 2013).Sanitation is one the most serious problems facing the world today. Almost 40% of the world's population (about 2.6 billion people) does not have access to adequate sanitation; open defecation is their normal practice (WHO/UNICEF, 2019). This leads to increased transmission of intestinal parasites and various infectious diseases. On the current development trajectory, it is unlikely that the United Nations Sustainable Development Goals (SDGs), particularly goal 3 (good health and well-being), goal 6 (clean water and sanitation), goal 11 (sustainable cities and communities), be met (WHO/UNICEF, 2019). Sub-Saharan African countries are particularly at high risk of this sanitary challenges, where the effect of climate change and socioeconomic hardship are well-pronounced.

According to a recent observation by International Centre for Investigative Report (2021), life in most tertiary institutions in North-West Nigeria is quite unbearable for students, due to the level of discomfort and poor sanitary conditions of public toilets in their hostels.Modern toilets need a lot of water and septic systems; and to tackle this issue, the development of waterless toilet was found helping (Affam and Ezechi, 2021). However, waterless toilet also comes with its own challenges. These include the perception of odour from the system; cleaning and replacement of the broken parts are another challenges (Opidi, 2020). Other options include the use of septic tank and anaerobic digestion technology. These also come with their challenges as about 13 to 15 litres of water is required to flush the human excreta down the sewer system to the digester or septic tank.In order for such problems to be addressed, a holistic approach needs to be employed (Affam and Ezechi, 2021).

Some of the existing improved mechanisms to address challenges related to wastes from human excreta include ventilated improved pit latrines, compost toilets, toilets connected to the conventional septic tanks onsite, toilets linked to the public sewage system, among others (Affam and Ezechi, 2021).However, some of these systems have not performed to expectations due to intrinsic issues with respect to location, construction quality, as well as operation and maintenance (Orner and Mihelcic, 2018). However, there are obvious disadvantages associated with the use of pit latrine in addressing sanitary issues, some of which are contamination of surface and underground waters, as well as collapsing of the latrine, especially during the rainy season. In view of this, the use of natural treatment of the human excreta and other biodegradable waste through the application of bio-digester technology is given serious consideration (Almansa *et al.*, 2023).This is a technology that can be applied to household and institutions, as well as in industries and agricultural sector. This paper is a review on the application of anaerobic digestion in addressingunsanitary lavatories in developing countries.

Anaerobic Digestion Technology

There are about 50 tertiary institutions in North-Western Nigeria, with an estimated students and staff population of 225,000 (Hile, 2023). With variation of dietary intake of food, which determines the rate of defecation and quantity, an average of 128g of fecal waste per capita per day has been reported to be produced by a healthy person (Ross *et al.*, 2015; Shukla *et al.* (2023), with a range of 51g to 796 g/capita/day. According to the literature, one gram (1g) of human feces generates 0.04 – 0.05 cubic meter (40 - 50 liters) of biogas (Tilley*et al.*, 2014; Donacho*et al.*, 2023). With an average of five thousand (5000) students in the hostels, particularly in first and second generation universities in North-Western Nigeria, an estimated 640kg of human feces is generated on daily basis. Based on the data from Tilley*et al.* (2014), 32,000 liters of biogas can be generated daily using Anaerobic Digestion technology. The biogas produced can be used to generate electricity for the hostel (Barragan-Escandon *et al.*, 2020; Kabeyi and Olanrewaju, 2022; Kariyat and Janardhanan, 2023) and for water supply (Abdel-Galil *et al.*, 2008; Haryanto et al., 2019), and can also be used to supply students with cooking gas (Singh, 2012; Mgbachi*et al.*, 2021). Moreover, efficient biofertilizer is produced through anaerobic digestion, which can be used for cultivation of crops and other plants in the university (Owamah*et al.*, 2014; Kitessa*et al.*, 2022).

Anaerobic digestioninvolved a series of biochemical reactions where microorganisms such as bacteria and fungi breakdown the organic matters of any substrate into a gaseous mixture (CH_4, CO_2, H_2, H_2S, etc.) in the absence of free oxygen (Deng *et al.*, 2017; Bakkaloglu*et al.*, 2022). Some groups of microorganisms involved in the biodegradation of organic matter in an anaerobic digestion processes cannot survive in the presence of oxygen (Nakamya *et al.* 2020), thus anaerobic (oxygen-free) environment is required (Almansa *et al.*, 2023).Anaerobic digestion breakdown complex organic substrates such as animal waste, through a multi-step processes, involving various categories of microorganisms (Ferronato and Torretta, 2019). The process can be described in four various stages, including hydrolysis, acidogenesis, acetogenesis and methanogenesis (Bakkaloglu*et al.*, 2022). At hydrolytic stage, the complex organic compounds, such as carbohydrate, protein and lipid, are broken down by the action of microbial extracellular enzymes into simple monomeric and dimeric compounds such as single sugars, amino acids and long chain fatty acids, which can pass through the microbial cellular membrane(Boyd *et al.*, 2022). In the acidogenic stage, these simple compounds are anaerobically oxidized into alcohol, ammonia, and volatile fattyacids (VFA). Alcohols and VFAs are converted to acetic acid, hydrogen and carbon dioxide in the acetogenic stage. In methanogenesis, these products undergo various biochemical processes (hydrogenotrophic and acetocalystic pathways) for methane production (Almansa *et al.*, 2023).

Anaerobic digestion is considered as the most effective and desirable sanitation options (Deng *et al.*, 2017); it is the technology that offer on-site waste treatment, elimination of pathogen and recovery of resources such as biogas and efficient biofertilizer (Ferronato and Torretta, 2019; Almansa *et al.*, 2023). Biogas contains about 60% methane and 40% carbon dioxide, and is usually used in generating heat and electricity in large scale production plants, while at household level, it is for cooking and lighting (Boyd *et al.*, 2022). Anaerobic digestion can be employed in addressing various environmental challenges such as deforestation and indoor air pollution in developing countries through the provision of alternative source of energy for cookinginstead of firewood, which releases toxic gases due to its incomplete combustion when burning (Watabe*et al*., 2023; Malet *et al*., 2023).Anaerobic digestion also provides nutrients-rich biofertilizer, which can be applied in agriculture to improve soil fertility and boost food production (Watabe *et al*., 2023).

Anaerobic digestion has been described as an option for treatment of blackwater and kitchen waste within the sustainable sanitation concepts (Deng *et al*., 2017), and based on the experimental and simulation results, it was found that anaerobic digestion of combined blackwater and other waste play a crucial role in addressing sanitary and energy issues (Wells *et al*., 2022). In a study, van Eekert*et al*. (2019) evaluated the potential of anaerobic digestion processes with respect to rate and extent of degradation of the organic matter in the latrine using experimental procedures (Ferronato and Torretta, 2019). Based on the findings, the study concluded that pit latrine is the most suitable option for sanitation when it comes to the management of human excreta, particularly in the communities around the developing world; and that anaerobic digestion is the dominant pathway through which organic matter is broken down in the system(Watabe*et al*., 2023).

Different types of anaerobic digestion technologies have been widely implemented in addressing sanitary issues around the world (Wells *et al*., 2022) including the fixed dome digester, the floating drum and plug flow or tubular digester models (Almansa *et al*., 2023). For example, as at 2014, China had over 40 million household-scale biogas plants, which was expected to double in 2020, while India developed over 90 000 household-size biogas digesters between 2017 and 2021. In some countries around Asia, Africa and Latin America, moreover, financial incentives have been provided to households that connected their toilet to an anaerobic digestion system for energy and sanitary purposes (Watabe *et al*., 2023). Paliwal (2012) reported the construction of 100,000 bio-digester toilets by the Indian Central government to curb open defecation through total sanitation mission program.

In assessing the potentials of anaerobic digestion in addressing sanitary issues at institutional level, particularly schools, prisons and camps, Butare and Kimaro (2002) described the case of Cyangugu biogas pilot project in Rwanda, where a fixed-dome type of anaerobic digester was set up to manage the feacal waste at Cyangugu prison. The pilot project was implemented by the Kigali Institute of Science, Technology, and Management (KIST) between 2001 and 2002, after the wars and genocide in 1994, when the prisons in Rwanda accommodate inmates ten times more than their actual holding capacity, which resulted in excessive generation of feacal waste that was a threat to the sanitary conditions of the environment. According to Rao and Doshi (2018), the project was funded by the International Committee of Red Cross (ICRC) through its Institutional Biogas Sanitation System. Similar projects were also implemented in Nepal and Philippines by the ICRC. The Rwandan government also launched a program to install anaerobic digesters in schools and health facilities, as well as in organizations that have restaurants. About 86 organizational biogas digesters were built in prisons and high schools, and up to 10,647 residential biogas digesters of different sizes were constructed for households.

Zuo *et al.* (2021) investigated the applicability ofanaerobic digestion technology in recycling of dry toilet generated blackwater using biomethane potential test. It was found that anaerobic digestion processes is affected due to rise in the level (3673.3 mg/L) of total ammonium nitrogen (TAN). The biomethane potential of dry toilet blackwater obtained was 402.36 mLCH4/gVSafter 55 days retention time at a temperature of 38^{o}C0). Pseudomonas aeruginosa was found to keep multiplying in dry toilet blackwater fermentation broth during the first 8 days, and the growth stabilized thereafter.The study demonstrated the self-adjustment process and pathogen growth dynamics in the dry toilet blackwater during the anaerobic digestion processes. The study alsorevealed the significance of considering the characteristics of dry toilet blackwater when designing and maintaining the anaerobic digestion for sanitary treatment and reuse systems.

Osei-Marfo (2022) assessed the sanitary efficiency of three existing biogas plant at Mfantsipim Senior High School (Mfantsipim), University of Cape Coast (UCC), and Ankaful Maximum Security Prisons (Ankaful), through wastewater characterization and examination of effluent quality in Ghana. The results of the study indicated significant differences between effluent qualities from the three biohas plants, with most of the quality parameters falling within the Environmental Protection Agency (EPA) guidelines of Ghana. However, the study reported under-performance of the biogas plants, which was attributed to inadequate maintenance, design deficiencies, poor environmental conditions and voluminous in-put loads beyond the capacities of plants.

Anaerobic digestion system have great potential to improve sanitation in areas where water supply is not adequate (Almansa *et al*., 2023). This technologyplays a significant role in achieving some of the Sustainable Development Goals (SDGs) includingZero Hunger (SDG2) through the generation of efficient and sustainable fertilizer for food production; Good Health and Well-Being (SDG3) through the elimination of pathogensand other risk factors in wastewater treatment plants(Ross *et al*., 2022); Gender Equality (SDG5) by reducing the workload on women in water and energy (Malet *et al*., 2023); Clean Water and Sanitation (SDG 6) through the microbial degradation of faecal and other anthropogenic waste, reducing the contamination of surface and underground waters; and Climate Action (SDG13) through the generation of renewable energy source such as cooking gas and electricity, as well as biofertilizer to improve agricultural productivity, especially in climate-vulnerable areas around the world (Bakkaloglu*et al*., 2022).

Integration of Anaerobic Digestion with other Sanitation Technologies

There are various sanitation technologies that can be applied for safe management of human excreta coming from the toilet to prevent or reduce exposure of the community to communicable diseases (UNICEF, 2017; Wells *et al*., 2022). These sanitation technology options can be any available and feasible means related to use of facilities, conveyance of the human excreta, its treatment and disposal in the possible hygienic ways (Gros *et al*. 2020). The system can be onsite sanitation or offsite, depending on the population size and location, design option, land availability, operation and maintenance costs. The sanitation concepts in onsite systems are similar to that of offsite; only that the treatment is carried out at different location (Almansa *et al*., 2023).

Onsite sanitation options include single use toilet, in which the collection and storage of the human excreta are done in one place. The excreta and urine, as well as the washing water go directly into the storage tank (Tan *et al*., 2021).The issue with this system is that it is susceptible to permeation of leachate, which can percolate into the underground water and surrounding environment when full or densely loaded (Affam and Ezechi, 2021). In this case, anaerobic digestion technology can be employed to avoid percolation and contamination of the ground water with pathogenic microorganisms (Moerland*et al*., 2020). The generated biogas and efficient biofertilizer can also be recovered when anaerobic digestion technology is integrated in this system (Almansa *et al*., 2023). However, the biogas production processes can be affected by the amount of urine that go into the storage tank and form ammonia through the conversion of urea by the enzymes urease (Tan *et al*., 2021). This can be addressed by employing the use of urine-diverting flush toilet, in which the urine is separately collected without mixing with the feacal matter, or waterless urinals, in which no water is needed to flush the waste into the storage tank,while the urine is collected separately (Tilley *et al*., 2014; Affam and Ezechi, 2021). Several scientific studies have been conducted to assess waterless urinals and urine-diverting and flush toilets.

Noteworthy is the work of Francis *et al.* (2016), who assessed the sanitation practices of traders in Kuje market, Federal Capital Territory (FCT), Abuja. A novel toilet complex comprising of 8 toilet units (for males and females), with urine diversion, gender-segregated urinal, urine storage tank, used menstrual absorbents disposal facility for women, bathing facility and a composting chamber, was designed and developed. There is also a provision of small spray system for anal cleansing and another for hand-washing. Data collection was done using key informant interviews and focus group discussion as well as semi-structured questionnaire. Women made the majority (55.8%) of the respondents. It was reported in the study that the majority (80.7%) of the respondents prefer paying to use the newly built dry toilet in the market due to their good sanitary conditions.

The integration of anaerobic digestion with waterless urinals can be achieved using dry digestion technology, in which the system can tolerate atotal solid above 15% in the slurry, and without the need for dilution (Affam and Ezechi, 2021). However, in the integration of anaerobic digestion with urine-diverting flush toilet, wet digestion should be considered (Spuhler *et al*., 2018; Tan *et al*., 2021). A wet digester or low solids anaerobic digestion system generally processes feedstock with less than 15 percent solids content. The feedstocks for a wet digester are typically in slurry form and can be pumped. A dry digester or a high solids anaerobic digestion system generally processes feedstock with greater than 15 percent solids content. The feedstocks for a dry digester are often described as stackable (Almansa *et al*., 2023).

Conclusion

Anaerobic digestion is a very important technology that can be applied, especially when integrated with other related technologies, to address various sanitary issues that affect lavatories in students' hostels in higher institutions, particularly in North-Western Nigeria. The unsanitary conditions are the result of inadequate water supply that make the lavatories unbearable, leading to open defecation and spread of infectious diseases. Integration of anaerobic digestion with urine-diverting flush toilet or waterless urinals will also address energy issue to certain level, in addition to saving more water for sanitation.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of themanuscript.

Acknowledgement

The authors appreciate the financial support from the Nigerian Tertiary Education Truat Fund (TETFund) through the Directorate of Research, Innovation and Partnership (DRIP), Bayero University, Kano, Nigeria.

References

Abdel-Galil, A., Mostafa, M.M., Elnono, M.A. and Mohamed, M.F. (2008). Biogas Utilization for Powering Water Irrigation Pump. *Misr J. Ag. Eng.*, 25(4): 1438-1453

AffamA.C. and Ezechi, H.E. (2021). Sanitation Systems and Technology Options, Clean Water and Sanitation, Encyclopedia of the UN Sustainable Development Goals. *Springer Nature Switzerland AG*. https://doi.org/10.1007/978-3-319-70061-8_129-1

Almansa, X.F., Starostka, R., Raskin, L., Zeeman, G., Reyes, F.D., Waechter, J., Yeh, D. and Radu, T. (2023). Anaerobic Digestion as a Core Technology in Addressing the Global Sanitation Crisis: Challenges and Opportunities. *Environmental Science & Technology*, 57, 19078−19087

Bakkaloglu, S.; Cooper, J.; Hawkes, A. (2022). Methane Emissions along Biomethane and Biogas Supply Chains Are Underestimated. *One Earth*, *5* (6), 724−736.

Barragan-Escandon A., Olmedo, R.J.M., Curillo, T.J.D., Zalamea-Leon, E.F. (2020). Assessment of power generation using biogas from landfills in an equatorial tropical context. Sustainability, 12(7):2669.

Boyd Williams, N.; Quilliam, R. S.; Campbell, B.; Raha, D.; Baruah, D. C.; Clarke, M. L.; Sarma, R.; Haque, C.; Borah, T.; Dickie, J. (2022). Challenging Perceptions of Socio-Cultural Rejection of a Taboo Technology: Narratives of Imagined Transitions to Domestic Toilet-Linked Biogas in India. *Energy Res. Soc. Sci.*, *92*, No. 102802.

Butare, A. and Kimaro, A. (2002). Anaerobic technology for toilet wastes management: the case study of the Cyangugu pilot project. *World Transactions on Engineering and Technology Education*, 1(1): 147 – 151.

Cid, C. A.; Abiola, F.; Starkl, M. (2022). Can International Nonsewered Sanitation Standards Help Solve the Global Sanitation Crisis? *Environ. Sci. Technol.*, *56* (2), 699−706.

Deng, L.; Liu, Y.; Zheng, D.; Wang, L.; Pu, X.; Song, L.; Wang, Z.; Lei, Y.; Chen, Z.; Long, Y. Application and Development of Biogas Technology for the Treatment of Waste in China. *Renewable and Sustainable Energy Reviews* 2017, *70*, 845−851.

Donacho, D.O., Tucho, G.T., Olani, D.D., Kabtiyimer, H.E., Hailu, A.B. and Wolde, A.D. (2023). Experimental Evaluation of Fresh Human Feces Biogas and Compost Potential: Evidence fro Circular Economy from Waste Streams in Ethiopia. *Heliyon*, 9(12): e22494.

Feachem R, Michael Mcgary and Duncan Mara (1977) Water, ***Waste and Health in hot climates***, John Wiley and Sons Inc.

Ferronato, N. and Torretta, V. (2019). Waste Mismanagement in Developing Countries: A Review of Global Issues. *International Journal of Environmental R3search and Public Health*, 15, 1060.

Francis, E.A., Hammed, T.B., Sridhar, M.K.C. and Aluko, O.O. (2016). Evaluation of Sanitary Conditions in Kuje Market in Abuja, Nigeria with Diverse Cultural Practices and Provision of a Dry Ecological Toilet System. *Sociology and Anthropology*, 4(11): 1011-1019

Gros, M., Ahrens L. and Level, L. (2020) Pharmaceuticals in source separated sanitation systems: fecal sludge and blackwater treatment. *Sci Total Environ*, 703:135530.

Haryanto, A., Nindhia, T.G.T., Rahmawati, W., Hasanudin, U., Saputra, T.W., Santosa, A.B., Tamrin and Triyono, S. (2019). Effect of load on the performance of a family scale biogasfuelled electricity generator, The 3rd International Symposium on Agricultural and Biosystem Engineering, *IOP Conf. Series: Earth and Environmental Science*, 355: 01207.

Hile, M. (2023). The burden of university funding shifts to students. Financial Nigeria Magazine, 16th October, 2023.

Hossain, M.L., Das, S.R., Rubaiyat, A., Salam, M.A. Uddin, M.K. and Hossain, M.K. (2013) Characteristics and Management of Institutional Solid Waste of Jamalkhan Ward, Chittagong, Bangladesh. *International Journal of Research in Management*, 2(3): 155-162.

Kabeyi, M.J.B. and Olanrewaju, O.A. (2022). Technologies for biogas to electricity conversion; 7th International Conference on Advances on Clean Energy Research, ICACER 2022 April 20–22, Barcelona, Spain. Energy Reports 8 (2022) 774–786

Kariyat, V.K.P. and Janardhanan, J.J. (2023). Design and development of biogas electrical power generation with an adaptive control mechanism for rural electrification. *Indonesian Journal of Electrical Engineering and Computer Science*, 31(2): 658~668.

Kitessa, W.M., Feyessa, F.F. and Abera, D. (2022). Biogas Production and Biofertilizer Estimation from Anaerobic Co-Digestion of Blends of Wastewater and Microalgae. International Journal of Chemical Engineering, 3: 1-10.

Malet, N., Pellerin, S., Girault, R. and Nesme, T.(2023). Does anaerobic digestion really help to reduce greenhouse gas emissions? A nuanced case study based on 30 cogeneration plants in France. *J. Clean. Prod*. 384, 135578.

Mgbachi, C.A.C., Omeni, C.C., Obiorah, K. and Eneh, I.I. (2021).Developmental Study on Biogas Digester for Cooking and as an Alternative Fuel for Petrol Generators. *International Journal of Engineering and Environmental Sciences*, 4(1): 1-10.

Moerland, M.J.; Borneman, A.; Chatzopoulos, P.; Fraile, A.G.; van Eekert, M.H.A.; Zeeman, G. and Buisman, C.J.N. (2020). Increased (Antibiotic-Resistant) Pathogen Indicator Organism Removal during (Hyper-)Thermophilic Anaerobic Digestion of Concentrated Black Water for Safe Nutrient Recovery. *Sustainability, 12* (22), 9336.

Nakamya, J.; Tumuhairwe, J. B.; Sabiiti, E. N.; Strachan, N. J. C.; Avery, L. M.; Smith, J. Influence of Biogas Digesters on Faecal Indicator Organisms in Digestate and around Homesteads in Ethiopia. *Biomass Bioenergy* 2020, *142*, No. 105746.

Opidi, A. (2020). Waterless Toilet: The Most Common Problems with Waterless Toilets. Retrieved on 3/06/2024 from: https://www.waterless-toilet.com/the-most-common-problems-with-waterless-toilets/

Osei-Marfo, M. (2022). *Sustainable sanitation system in Ghana: a biogas approach*. [Doctoral Thesis, Maastricht University]. ProefschriftMaken. https://doi.org/10.26481/dis.20220329mo

Owamah, H.I., Dahunsi, S.O., Oranusi, U.S. and Alfa, M.I. (2014). Fertilizer and sanitary quality of digestate biofertilizer from the co-digestion of food waste and human excreta. *Waste Management* 34, 747–752

Ross, I.; Greco, G.; Opondo, C.; Adriano, Z.; Nala, R.; Brown, J.; Dreibelbis, R.; Cumming, O. (2022). Measuring and Valuing Broader Impacts in Public Health: Development of a Sanitation-related Quality of Life Instrument in Maputo. *Mozambique. Health Econ., 31* (3), 466−480.

Shukla, A., Patwa, A., Parde, D. and Vijay, R. (2023). A review on generation, characterization, containment, transport and treatment of fecal sludge and septage with resource recovery-oriented sanitation, Environmental Research, Vol.216, Part 1: 114389, ISSN 0013-9351, https://doi.org/10.1016/j.envres.2022.114389.

Singh, I. (2012). Use of Biogas for Cooking Purpose in a TechnicalInstitute: A View Point. *Proceedings of the National Conference on Trends and Advances in Mechanical Engineering*, YMCA University of Science & Technology, Faridabad, Haryana, Oct 19-20, 2012.

Spuhler, D., Scheidegger, A., Maurer, M. (2018). Generation of sanitation system options for urban planning considering novel technologies. *Water Res* 145:259–278

Tan, L.; Zhang, C.; Liu, F.; Chen, P.; Wei, X.; Li, H.; Yi, G.; Xu, Y.; Zheng, X. Three-Compartment Septic Tanks as Sustainable on-Site Treatment Facilities? Watch out for the Potential Dissemination of Human-Associated Pathogens and Antibiotic Resistance. *J. Environ. Manage* 2021, *300*, No. 113709.

Tilley E, Ulrich L, Lüthi C, Reymond P, Schertenleib R, and Zurbrügg C (2014). *Compendium of Sanitation Systems and Technologies. 2nd Revised Edition.* Swiss Federal Institute of Aquatic Science and Technology (Eawag).

United Nation Children Educational Fund (UNICEF) Water, Sanitation and Hygiene (2017) Update and SDG baselines, Geneva. https://washdata.org/report/jmp-2017-report-final.

van Eekert, M.H.A., Gibson, W.T., Torondel, B., Abilahi, F., Liseki, B. Schuman, E., Sumpter, C. and Ensink, J.H.J. (2019). Anaerobic digestion is the dominant pathway for pit latrine decomposition and is limited by intrinsic factors. *Water Science & Technology*,

Watabe, S.; Lohman, H.A.C.; Li, Y.; Morgan, V.L.; Rowles, L.S.; Stephen, T.; Shyu, H.-Y.; Bair, R.A.; Castro, C.J.; Cusick, R.D.; Yeh, D.H.; Guest, J.S. (2023). Advancing the Economic and Environmental Sustainability of the NEWgeneratorNonsewered Sanitation System. *ACS Environmental Au, 3* (4), 209−222.

Wells, E. C.; Vidmar, A. M.; Webb, W. A.; Ferguson, A. C.; Verbyla, M. E.; de los Reyes, F. L.; Zhang, Q.; Mihelcic, J. R. Meeting the Water and Sanitation Challenges of Underbounded Communities in the U.S. *Environ. Sci. Technol.* 2022, *56* (16), 11180−11188.

Wendland, C. (2008). Anerobic Digestion of Blackwater and Kitchen Refuse. Vom Promotionsausschuss der Technischen Universität Hamburg-Harburg zur Erlangung des akademischen Grades

Workman, C. L.; Cairns, M. R.; de los Reyes, F. L.; Verbyla, M. E. (2021). Global Water, Sanitation, and Hygiene Approaches: Anthropological Contributions and Future Directions for Engineering. *Environ. Eng. Sci.*, *38* (5), 402−417.

Zuo, S.; Zhou, X.; Li, Z.;Wang, X.; Yu, L. (2021). Investigation on Recycling Dry Toilet Generated Blackwater by Anaerobic Digestion:From Energy Recovery to Sanitation. *Sustainability*, 13, 4090. https://doi.org/10.3390/su13084090