

Comparative Technical Assessment of the Treatment Schemes for Faecal Sludge Handling and Management using Geotube and Jute Tube Technology

Sakkubai Lakavathu

JNTUH CEH: Jawaharlal Nehru Technological University Hyderabad College of Engineering

Vamshi Krishna Reddy

JNTUH CEH: Jawaharlal Nehru Technological University Hyderabad College of Engineering

Neha Singh

Banka BioLoo Limited

Pramod Kamble

University of Rajasthan

Jayesh Jadhav

Savitribai Phule Pune University

Atun Roy Choudhury

BITS Hyderabad: Birla Institute of Technology & Science Pilani - Hyderabad Campus

Sankar Ganesh Palani (✉ sangan@hyderabad.bits-pilani.ac.in)

Birla Institute of Technology & Science Pilani - Hyderabad Campus <https://orcid.org/0000-0002-9278-8514>

Research Article

Keywords: Faecal sludge, Coagulation, Flocculation, Dewatering, Disinfection, Economic Viability

Posted Date: April 25th, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-2586008/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on November 11th, 2023. See the published version at <https://doi.org/10.1007/s11356-023-30746-8>.

Abstract

Faecal sludge (FS) or septage collected from an onsite containment system such as septic tanks, pit latrines, bio-digester etc., is handled in sewage treatment facilities with the help of a co-treatment unit or tackled individually at faecal sludge treatment plants (FSTPs). Treatment of faecal sludge in FSTPs is a generally cumbersome, energy-intensive, and expensive process. Enhancing the size of the solid particle, dewatering, and disinfection are essential unit operations that contribute to a significant portion of the operational expenditure. Therefore, the present study took up the task of investigating and yielding a natural alternative to each of the above-delineated unit operations. Crushed seed powders of Moringa, Guilandina bonduc, Nirmali, Tamarind, Soap nut, Nutmeg, Jackfruit, and Custard apple seed powder experimented as natural coagulants. At the same time, a double-stitched cow dung-lined jute tube was utilized as the media for solid-liquid separation. Finally, Neem and Custard Apple seed and leaf powder were considered herbal disinfectants for the separated liquid and solid fractions, respectively. The findings of the physicochemical and biological analysis of the above unit operations were compared with a conventional polymer-based Geotube driven treatment scheme. The natural alternatives registered some promising outcomes. However, the combined treatment efficacy of 78.94% for pollutant removal and disinfection could not exceed the value of 99.01% offered by the conventional method. Moreover, herbal alternatives are scarce, expensive, and slow reacting. Therefore, the authors recommend further research to overcome the persisting issues with herbal alternatives for their field-scale adaptation.

Introduction

In onsite sanitation systems, a mixture of human excreta, anal cleansing products, urine, flush water, and solid wastes (such as toilet paper and menstrual hygiene products) is called FS. The terms FS and septage are often used in a similar sense, but they differ in terms of origin and degree of digestion. Septage is a category FS that is partially digested onsite in septic tanks. FS and septage are far more concentrated in total solids than sewage and are a far more nuisance to the environment; for instance, the biochemical oxygen demand (BOD) value of septage is roughly 100 to 200 times more concentrated than that of sewage (Wanda et al. 2021).

Generally, septage and FS are dumped in open conditions without prior treatment. These illegal disposals and emptying of the FS into nearby water bodies lead to various diseases and trigger local pollution. Therefore, the ablest faecal sludge management is the need of the hour. Typically, FS and septage management incorporate all components of the sanitation value chain, such as collection, emptying, transport, treatment, disposal, and reuse (Dirix et al. 2021).

As per the guideline issued by the ministry of housing and urban affairs, the urban local bodies (ULBs) are advised to maintain a database on the onsite sanitation systems and create annual city plans once every two to three years.

The sludge undergoes several unit operations since the reception at the sewage treatment plant (STP) or FSTP. Mostly, domestic sewage and septage are often preferred to be treated in combination due to the ease of operation and reduced cost of treatment. An appropriate proportion of septage is diluted with sewage before treatment since it has a higher concentration of organics. This mechanism is termed co-treatment (Mamera et al. 2022).

In the absence of a sewerage network, the localities situated in the vicinity of the existing STPs are served through co-treatment. While standalone FSTPs are mostly preferred for remote locations, including a series of primary, secondary, and tertiary operations. The overall performance of the FSTPs is primarily influenced by the degree of solid-liquid separation. Chemical processes such as coagulation and/or flocculation are practiced to attain better separation efficacy during the dewatering process. Coagulation destabilizes the colloidal particles, while flocculation aids in agglomerating the destabilized colloidal particles to form macro flocs. These chemical precipitation processes help attain rapid agglomeration, thereby separating and settling large flocs (Samal et al. 2022).

After-chemical precipitation, sludge undergoes a stringent straining process using a physical media or cyclonic action. Membrane-based mechanisms such as screw press, filter press, belt filter press, Geotube etc., are popular alternatives to physical straining. In contrast, cyclonic process such as centrifuge relies on density-based separation. Several dewatering mechanisms such as Geotube, mechanical presses, solar, planted, and unplanted drying beds are commercially used as proven solutions for FS treatment in India and abroad. However, the application of Geotube has recently captured the unparallel limelight due to its minimal footprint, the ability to handle shock loads, and the inexpensive nature of the operation (Banka et al. 2020).

Disinfection, the final step, involves eliminating or controlling many harmful organisms. Generally, the variation in the presence and concentration of the “indicator organism” is ascertained to map the disinfection efficiency. Total coliform is one of the most trusted indicator organisms, widely used for water and wastewater-related research. Both aerobic and anaerobic treatment processes reduce pathogens, but the reduction efficacy is typically limited in both cases. Chlorination/dichlorination, ozonation, and UV light application are the pronounced methods used to disinfect treated wastewater (Septien et al. 2020).

In addition to traditional procedures, natural options for coagulation/flocculation, dewatering, and disinfection should be investigated in FSSM. Natural substitutes offer several benefits over synthetic ones, including being organic and biodegradable, widely and regionally accessible across the nation, and reasonably priced.

Additionally, they benefit regional small-scale farmers and business owners and don't offer any hazard of secondary pollution in by-products. Due to their natural and environmentally benign nature, natural alternatives are more appealing than conventional methods. However, the products may have several drawbacks without discounting the fact that it is natural. The following are the most prominent issues encountered during the present study: limited polymerization efficacy, compromised durability and

comparatively larger pore size of the dewatering media, feeble disinfection, prolonged reaction time, etc. (Mishuk et al. 2020).

The study was designed to evaluate the techno-commercial feasibility of using an alternative local FS management system against the conventional approach. Factors including the type and amount of coagulants used, the time required for effective flocculation and the floc size, the pore size and durability of the dewatering material employed, and the effectiveness of the disinfectant in reducing pathogens were the key decision-making factors.

Materials And Method

Study area

Boduppal FSTP is located in the Chengicherla area under Boduppal Municipal Corporation, Telangana. The tentative coordinate of the site is 17.4139° N and 78.5783° E. The above-delineated FSTP was the primary source for sludge sampling and collection. the major research work was conducted at Chadwick's FSM Lab, Banka Bio Limited.

Sludge

The semi-digested (dark brown to black hue) samples used in the current study were repeatedly obtained from the stated place and were thoroughly characterized.

Fabrication of jute tube

Jute fibre was used to make stitched jute tubes. Jute tube was fabricated as a more affordable, easily accessible, and can be utilized for filtration and dewatering. In general, filtration is not considered a treatment process, and it is a process that separates the solids particles from the liquid through a membrane. The jute tube was employed in place of the Geotube to facilitate solid-liquid separation. Cow dung was used as a liner material in a double-layered Jute tube, which helped to reduce the pore size further and, in turn, indirectly lowered the pathogenic content and odour from the separated effluent.

Screening of natural coagulants

Natural coagulants/flocculants like Moringa, Guilandina bonduc, Nirmali, Tamarind, Soap nut, Nutmeg, Jackfruit, and Custard apple seed powder were investigated and experimented with. All these seeds were initially collected and pulverized into fine powders. Initially, all the seed powders are coagulated with the raw sludge and are allowed to settle. Post-settling, the efficiency of the seed powder as a coagulant was determined by ascertaining the floc size and stability, turbidity of the separated effluent, and settling period.

Preparation of natural disinfectants

Natural disinfectants were made from the leaves and seeds of *Azadirachta indica* (Neem) and *Annona squamosa* (Custard Apple). Neem offers exceptional therapeutic benefits and lowers microbial activity. Custard Apple seed and leaf generally contain medicinal properties and health advantages, and it is well known for cleansing pollutants. The seeds and leaves were dried and pulverized into a fine powder for further application in the semi-treated effluent and sludge cake.

Dosages optimization

The dosages of selected natural seed powders with coagulation/flocculation qualities were refined through numerous tests, starting with the lowest amount of 0.1 gm/100 ml that was feasible. It was decided to use the dose at which the appropriate size of floc (0.75 to 7 mm) formed with apparent solid-liquid separation. Similar to this, different dosages of powdered *Azadirachta indica* and *Annona squamosa* seeds and leaves were applied to filtrate and biosolids for disinfection, and the pathogen reduction was maximized.

Physico-chemical analysis

Both types of filtrates from, Geotube and Jute tube were subjected to physicochemical analysis, including pH, Electrical Conductivity (EC), Total Solids (TS), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Kjeldahl Nitrogen (TKN), and Total Phosphorus (TP) for comparison.

Using the standard approach outlined in the 23rd edition of the American Public Health Association's (APHA) authorized standard methodologies for testing Water and Wastewater. All values were obtained in mg/L or PPM.

pH was measured using ELICO LI 617 model, and the meter was calibrated with standard buffer solutions of 7.0 and 10.01. EC was performed on the ELICO EC/TDS meter of model CM-183, and the instrument was calibrated with 1412 $\mu\text{S}/\text{Cm}$. Total Solids and Total Suspended Solids were performed at 105 degrees Celsius for 2 hours with duplicates, while Total Dissolved Solids were performed after filtration of the sample at 180 degrees Celsius. For COD, digestion was done at 150 degrees Celsius for 2 hours, Potassium Hydrogen Phthalate (KHP) was kept as a check standard and titrated against 0.25 N of Ferrous Ammonium Sulfate (FAS). BOD was performed for 5 days at 20 degrees Celsius. TKN was performed using a setup for digestion and distillation with the instrument called KjelTRON Nitrogen, having a model KDIGB 6M, KjelDIST EA & KjelSCRB. TP was performed using the Vanadomolybdophosphoric acid method with a UV-Vis Spectrophotometer with a model UV-1900.

pH and conductivity values were analyzed for both biosolids extracted from a Geotube and Jute tube after making the 1:5 extract with double distilled water. Total organic carbon was calculated using the Walkley-Black method by applying 0.5 N of FAS. Total nitrogen was calculated with 0.5 gm of dry solid in the Kjeltron Nitrogen system.

Microbiological analysis

Both types of filtrate were examined for pathogenicity using Total Coliform, Fecal coliform, E.coli, and Salmonella tests. Multiple-tube fermentation method was used to determine the concentration of total and faecal coliforms. The experiments were performed in an incubator at 35 and 44 degrees Celsius for 48 and 24 hours, respectively. Both the parameters were evaluated using method 9221B APHA 23rd edition, 2017. The positive aliquot was submitted to the E. coli phase at 44 degrees Celsius for 24 hours in the incubator following the confirmation phase of faecal coliform. Salmonella was tested utilizing filtration, pre-enrichment, and enrichment procedures. The method utilized for counting the observed results was 9260 B APHA, and the results were expressed as colony-forming units/ml. The 10% extract was removed from both forms of biosolid using distilled water and peptone, and the same pathogenicity tests were conducted on both types to estimate comparative reduction efficacy.

Result And Discussion

The comparative flocculation, dewatering, and disinfection efficacies were ascertained between the conventional system and experimental setup. The results obtained were encouraging for the experimental setup. However, they were inferior compared to the traditional approach (Singh et al., 2017). Further, detailed findings associated with each unit operation are delineated below.

Comparative flocculation and filtration efficacy

Citing the reaction time and efficacy, Moringa and Guilandina bonduc were selected to conduct additional experiments. The findings were compared to the outcome of the synthetic coagulation (i.e., performed with the help of medium molecular cationic polymer (MMCP)) process. The comprehensive analytical result of the physicochemical experiments is portrayed in Table 1 (Semiyaga et al. 2015; Choudhury et al. 2018; Banka et al. 2020; Seleman et al. 2021; Osei et al. 2022).

Table 1: Results of tests conducted on the filtrate produced by passing flocculated sludge through the Geotube and jute tube

Sl. No.	Parameters	UOM	Raw Sludge	Geotube Filtrate (synthetic polymer)	Jute Tube Filtrate (Moringa)	Jute Tube Filtrate (Guilandina bonduc)	CPCB Guidelines for Expected Effluent
1	pH @ 25°C	-	7.99	7.97	7.95	7.96	5.5-9.0
2	EC	µS/cm	24826	1042	7745	8245	-
3	TS	mg/L	25546	802	6948	7042	-
4	TDS	mg/L	14896	625	4677	4582	-
5	TSS	mg/L	12846	141	2220	2468	≤50
6	COD	mg/L	23845	210	3512	3782	≤100
7	BOD	mg/L	13542	94	1740	1802	≤30
8	TKN	mg/L	1208	13	709	725	≤10
9	TP	mg/L	115	2.5	82	88	≤1.0

Table 1 depicts the correlation between the effectiveness of the flocculation process and floc trapping efficacy. This has a direct impact on the reduction of the TSS. The right size of the floc ensures no solids escape, lowering the pollution concentration in the separated effluent, which provides a reduced burden on the subsequent treatment units. Since lowering other biological parameters is greatly influenced by the concentration of TSS, flocculation becomes a deciding factor and impacts the filtrate's overall quality (Jain et al. 2022). The secondary factor that eventually determines the removal of flocs is the pore size of the Geotube and jute tube. The cow dung coating covering the jute tube's surface was not firm since it eventually began to dissolve during prolonged use. The same causes the jute tube's pores to open further, allowing more suspended matter to escape into the filtrate. The comparative removal efficacy of various pollutant concentrations in the semi-treated effluents resulting from the flocculation and dewatering is portrayed in Figure 2 (Appiah-Effah et al. 2020).

The above figure clearly depicts that the combination of synthetic flocculant with Geotube as the filtration media results in the most significant reduction percentage of the quality metrics. There is a maximum of 96.8, 95.8, 98.9, 99.1, 99.3, 98.9, and 97.8% reduction in TS, TSS, TDS, COD, BOD, TKN, and TP values, respectively, with MMCP and Geotube treatment combination (Chandana and Rao 2021; Mishuk et al. 2022). While the combination of Guilandina bonduc and jute tube-based dewatering yields 72.4, 62.9, 80.8, 71.5, 84.1, 39.9, and 23.5% reduction in TS, TSS, TDS, COD, BOD, TKN, and TP values respectively. Mishuk et al., 2020 also reported a similar degree of treatment. It is apparent from the comparison of the illustrated data MMCP outperforms the other two natural coagulants. At the same time, Moringa has demonstrated the best efficacy among the natural coagulant powders used.

Comparative efficacy of natural and artificial disinfectant in the filtrate

Applying 2.5% concentrated sodium hypochlorite (NaOCl) solution (@ 2.0 ppm dosage) helps attain complete pasteurization of the final treated effluent in the conventional approach. While the alternate method involved disinfecting jute tube filtrate with Neem seed powder (NSP) and Custard Apple seed powder (CASP) at a similar level of 2.0 ppm (Akumuntu et al. 2017; Butte et al. 2021). Post-dewatering, the semi-treated effluent is further purified with the help of bio-digestion and multiple stages of filtration. Subsequent lowering of the concentration of TSS indirectly helps attain better disinfection. The effectiveness of disinfection was evaluated based on the decline in widely recognized pathogens identified in faecal sludge (Simanjuntak et al. 2020; Singh et al. 2020). Table 2 comprehends the reduction in the concentration of the most common pathogens present in faecal sludge due to the application of chemical and herbal disinfectants.

Table 2: Pathogens reduction test results following disinfection using different disinfectant

Sl. No.	Parameters	UOM	Raw Sludge	Sodium Hypochlorite	Neem seed powder	Custard apple seed powder	CPCB ENVIS Guidelines for Expected Effluent
1	Total Coliform	MPN/100 mL	46×10^6	7900	79×10^5	17×10^6	<10000
2	Faecal Coliform	MPN/100 mL	38×10^6	450	33×10^5	94×10^5	<1000
3	E. coli	CFU/100 mL	2.4×10^5	58	22×10^3	38×10^3	-
4	Salmonella	CFU/100 mL	31×10^3	ND	ND	468	-

(‘ND’ Not detected or below detection level)

The efficiency of the disinfectant is directly proportional to the decline in the number of pathogens, as shown in Table 2. The filtrate yielded from the combined flocculation and dewatering operation performed with the help of Moringa and jute tube was considered for disinfection experiment. A comparative assessment was performed between the natural and chemical disinfectants. The results are portrayed in Figure 3.

Figure 3 shows that the percentage reduction with NaOCl is approximately 99.9%; it effectively denatured protein in bacterial biofilm matrices and simultaneously inhibited their enzymes. With 82.8, 91.3, 90.8, and 100% reduction rates for Total coliform, Faecal coliform, *E. coli*, and Salmonella, respectively, NSP

was shown to be more effective than CASP, respectively. At the same time, CASP was found to be the least effective of all.

Comparative efficacy of disinfection in the biosolid

Post-filtration, the trapped biosolid was pasteurized using experimental disinfectants. The biosolid trapped in the jute tube was dosed with disinfectants composed of leaf powders, while the slurry segregated in Geotube was dealt solely with the self-composting method. The Geotube with the specified polypropylene fibre, large surface area, and advantage of higher heat absorption (i.e., due to its black colour) supports elevating the temperature within the tube quite efficiently. The sealed bag was exposed to direct sunlight for around 60 days for inherent composting and drying. This exothermic process helps attain pasteurization. The average daytime temperature inside the bag reaches 65⁰ C (Krueger et al. 2021; Zhong et al. 2023).

On the contrary, the jute tube biosolid was dosed with neem and custard apple leaf powders (@ 2.5% by the weight of the biosolid) and sun-dried for 60 days. The temperature profile of the bag almost remained constant during the experimental tenure with a mean temperature of 45⁰ C during the daytime. The degree of reduction in the pathogenicity is depicted in Table 3 (Getahun et al. 2020).

Table 3: Pathogens test results for the biosolid

Sl. No.	Parameters	UOM	Geotube Biosolid	Jute tube Biosolid	
				Neem leaf powder	Custard Apple leaf powder
1.	Total Coliform	MPN/gm	160	192	324
2.	Faecal Coliform	MPN/gm	98	130	218
3.	<i>E.Coli</i>	CFU/gm	ND	05	12
4.	<i>Salmonella</i>	CFU/gm	ND	ND	Present
5.	Helminth ova	CFU/gm	ND	ND	ND

(‘ND’ Not detected or below detection level)

It is evident from the findings of the pathogens test that the Geotube-derived biosolid has demonstrated a lower number of pathogens than leaf powder disinfection. It has 51% lower Total Coliform than Custard Apple leaf powder and 17% less than Neem. Similarly, it is 25% and 55% more effective than neem and custard apple leaf powder for faecal coliform. Further, both types of disinfecting leaf powder were ineffective against E. coli. However, Neem leaf powder was successful at getting rid of Salmonella.

Financial comparison of the treatment schemes

Besides the technical capabilities of both treatment schemes, it is utterly necessary to understand the economic feasibility of large-scale adaptation. Table 4 portrays the economic difference between both treatment schemes for treating a batch of 10 KL of FS (Shahinur et al. 2022; Alim et al. 2022).

Table 4: Financial comparison of Geotube and jute tube treatment schemes for processing a 10 KL batch

No.	Parameter	Agent	Cost of Treatment (USD)	
			Jute Tube Scheme	Geotube Scheme
1	Coagulation/ flocculation	Moringa	~12.16	N.A.
		MMCP	N.A.	~0.7
2	Dewatering	Cow dung-lined jute fibre stitched bags	~8.5	N.A.
		Polypropylene grade-V bag	N.A.	~6.7
3	Disinfection of treated water	NSP	~3.0	N.A.
		NaOCl	N.A.	~0.55
4	Disinfection of biosolid (@ 4% dry solid in raw sludge)	Neem leaf powder	~3.65	N.A.
		No additional agents	N.A.	—
Total (USD)			27.31	7.95

The estimated cost for treating 10 KL may differ for other geographic locations. The final value depicts that the alternate treatment scheme with herbal agents is three times more expensive when compared to the conventional scheme. The large variation in the cost is most influenced by the present medicinal usage of agents such as Moringa and Neem leaf and seed powder (Nishi et al. 2012; Smith et al. 2020). At the same time, jute fibre has high demand and commercial value in the supply chain market (Kumari et al. 2020). The cost may depreciate up to a specific margin for bulk purchases of the agents. However, the margin of depreciation is difficult to predict at present. Due to an established market, bulk scale production, and ease of local availability, the cost of treatment agents involved in the conventional scheme is non-comparable to its herbal alternate. Therefore, the economic feasibility of the conventional scheme provides it with an edge over the investigated herbal technique.

Conclusion

The outcome of the feasibility analysis of using natural coagulants, followed by the dewatering with the help of the jute tube and natural disinfectants, is not significantly encouraging. The organic coagulants and disinfectants are expensive, scarce, and recorded a below-average to moderate performance. While the cow dung-lined jute tube is suitable only for a single dewatering application. This increases the

expenditure and hampers the ease of operation. However, in terms of efficacy, Moringa and Guilandina bonduc seed powder have outperformed other experimental coagulants. Moringa seed powder was superior among the natural coagulants to yield the most stable and largest flocs. However, the efficacy of MMCP was foremost among all the agglomeration agents. The screened wastewater samples derived from the naturally and chemically flocculated sludge portrayed a comprehensive pollutant (i.e., TS, TDS, TSS, COD, BOD, and TKN) removal efficacy of 66.66, 63.1, and 98.1% for Moringa, Bondac, and MMCP respectively with jute tube and Geotube screening. Further, the observed efficacy of disinfection was 99.925, 91.225, and 80.25%, respectively, for NaOCl, NSP, and CASP, respectively, at 2.0 ppm constant dosage. Therefore, owing to scarce availability, high operational expenditure, inconvenience of operation, and limited efficacy, the natural alternative has nothing to offer over the established treatment scheme.

Declarations

Acknowledgment

Banka Bio Limited supported the present research. The authors thank the organization for extending access to FSTP and laboratory facilities.

Ethical Approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

Not applicable

Authors Contributions

All authors contributed to the study's conception and design. Sakkubai Lakavathu, Neha Singh, and Jayesh Jadhav performed material preparation, data collection, and analysis. The first draft of the manuscript was written by Atun Roy Choudhury, Sankar Ganesh Palani, Pramod Kamble, Vamshi Krishna Reddy. All authors commented on the subsequent versions of the manuscript. All authors read and approved the final manuscript.

Funding

No funding was received to assist with the preparation of this manuscript.

Competing Interests

Authors have no conflicts of interest to declare relevant to this article's content.

Availability of data and materials

The datasets generated during and analyzed during the current study are available from the corresponding author upon reasonable request.

References

1. Akumuntu JB, Wehn U, Mulenga M, Brdjanovic D (2017) Enabling the sustainable Faecal Sludge Management service delivery chain—A case study of dense settlements in Kigali, Rwanda. *International journal of hygiene and environmental health* 220(6):960-973. <https://doi.org/10.1016/j.ijheh.2017.05.001>
2. Alim MA, Moniruzzaman M, Hossain MM, Repon MR, Hossain I, Jalil MA (2022) Manufacturing and compatibilization of binary blends of superheated steam treated jute and poly (lactic acid) biocomposites by melt-blending technique. *Heliyon* 8(8):e09923. <https://doi.org/10.1016/j.heliyon.2022.e09923>
3. Appiah-Effah E, Duku GA, Dwumfour-Asare B, Manu I, Nyarko KB (2020) Toilet chemical additives and their effect on faecal sludge characteristics. *Heliyon* 6(9):e04998. <https://doi.org/10.1016/j.heliyon.2020.e04998>
4. Banka N, Lanke M, Roy Choudhury A, Sarkar J, Anandapu SC, Banerjee R (2020) Evaluation of the Functionality of GeoTube® based Physicochemical Faecal Sludge Treatment: A Cursory Alternate. *International Journal of Plant and Environment* 6(2):122-128. <https://doi.org/10.18811/ijpen.v6i02.05>
5. Butte G, Niwagaba C, Nordin A (2021) Assessing the microbial risk of faecal sludge use in Ugandan agriculture by comparing field and theoretical model output. *Water research* 197:117068. <https://doi.org/10.1016/j.watres.2021.117068>
6. Chandana N, Rao B (2021) Assessing inter and intra-variation in the characteristics of faecal sludge from Vadgaon Maval, Maharashtra: For better faecal sludge management in India. *Journal of environmental management* 300:113634. <https://doi.org/10.1016/j.jenvman.2021.113634>
7. Choudhury AR, Ashok KN, Srinivas K, Arutchelvan V, Thota KR, Ravi SN, Dugyala SK, Goutham RM (2018) Black soldier fly larvae, a viable opportunity for entrepreneurship. *Acta Sci. Agric* 2(9):11-20.
8. Dirix D, Rossi F, Hoek, H (2021) Faecal sludge management in Toamasina, Madagascar: Emptying - Transport - Treatment. *Journal of environmental management* 281:111808. <https://doi.org/10.1016/j.jenvman.2020.111808>
9. Getahun S, Septien S, Mata J, Somorin T, Mabbett I, Buckley C (2020) Drying characteristics of faecal sludge from different onsite sanitation facilities. *Journal of environmental management* 261:110267. <https://doi.org/10.1016/j.jenvman.2020.110267>
10. Jain M, Upadhyay M, Gupta AK, Ghosal PS (2022) A review on the treatment of septage and faecal sludge management: A special emphasis on constructed wetlands. *Journal of environmental management* 315:115143. <https://doi.org/10.1016/j.jenvman.2022.115143>

11. Krueger BC, Fowler GD, Templeton MR, Septien S (2021) Faecal sludge pyrolysis: understanding the relationships between organic composition and thermal decomposition. *Journal of Environmental Management* 298:113456. <https://doi.org/10.1016/j.jenvman.2021.113456>
12. Kumari K, Singh PK, Kumari S, Singh KM (2020) Dynamics of Jute Export in India. *Int. J. Curr. Microbiol. Appl. Sci* 9:3769-3774. <https://doi.org/10.20546/ijcmas.2020.906.xx>
13. Mamera M, van Tol JJ, Aghoghovwia, MP (2022) Treatment of faecal sludge and sewage effluent by pinewood biochar to reduce wastewater bacteria and inorganic contaminants leaching. *Water research* 221:118775. <https://doi.org/10.1016/j.watres.2022.118775>
14. Mishuk MH, Islam SMT, Alamgir M (2020) Comparison of the efficiency of Deebag and jute made bag for faecal sludge management and wastewater treatment. *PLOS ONE* 15(11):e0241046. <https://doi.org/10.1371/journal.pone.0241046>
15. Mishuk MH, Janee JF, Islam ST, Alamgir M (2022) Assessment of treatment efficiency by non-energy consuming aeration system for faecal sludge management in an emergency human settlement in Bangladesh. *Groundwater for Sustainable Development* 19:100807. <https://doi.org/10.17632/w6h39xdj6c.1>
16. Nishi L, Vieira AS, Vieira MF, Bongiovani M, Camacho FP, Bergamasco R (2012) Hybrid process of coagulation/flocculation with *Moringa oleifera* followed by ultrafiltration to remove *Microcystis* sp. cells from water supply. *Procedia Engineering* 42:865-872. <https://doi.org/10.1016/j.proeng.2012.07.479>
17. Osei RA, Abagale FK, Konate Y (2022) Exploitation of indigenous bamboo macrophyte species and bamboo biochar for faecal sludge treatment with constructed wetland technology in the Sudano-Sahelian ecological zone. *Heliyon* 8(12):e12386. <https://doi.org/10.1016/j.heliyon.2022.e12386>
18. Samal K, Moulick S, Mohapatra BG, Samanta S, Sasidharan S, Prakash B, Sarangi S (2022) Design of faecal sludge treatment plant (FSTP) and availability of its treatment technologies. *Energy Nexus* 100091. <https://doi.org/10.1016/j.nexus.2022.100091>
19. Seleman A, Gabrielsson S, Kimwaga R (2021) Faecal sludge containment characteristics and their implications on safe desludging in unplanned settlements of Dar es Salaam, Tanzania. *Journal of environmental management* 295:112924. <https://doi.org/10.1016/j.jenvman.2021.112924>
20. Semiyaga S, Okure MA, Niwagaba CB, Katukiza AY, Kansiime F (2015) Decentralized options for faecal sludge management in urban slum areas of Sub-Saharan Africa: A review of technologies, practices and end-uses. *Resources, Conservation and Recycling* 104:109-119. <https://doi.org/10.1016/j.resconrec.2015.09.001>
21. Septien S, Mirara SW, Makununika BSN, Singh A, Pocock J, Velkushanova K, Buckley CA (2020) Effect of drying on the physical and chemical properties of faecal sludge for its reuse. *Journal of environmental chemical engineering* 8(1):103652. <https://doi.org/10.1016/j.jece.2019.103652>
22. Shahinur S, Sayeed MA, Hasan M, Sayem ASM, Haider J, Ura S (2022) Current development and future perspective on natural jute fibers and their biocomposites. *Polymers* 14(7):1445. <https://doi.org/10.3390/polym14071445>

23. Simanjuntak S, Soesilo TEB, Hartono DM, Amqam H (2020) An environmentally safe level of faecal sludge management and socio-economic demographic analysis. *Enfermeria Clinica* 30:398-402. <https://doi.org/10.1016/j.enfcli.2019.11.007>
24. Singh S, Mohan RR, Rath S, Raju NJ (2017) Technology options for faecal sludge management in developing countries: Benefits and revenue from reuse. *Environmental Technology & Innovation* 7:203-218. <https://doi.org/10.1016/j.eti.2017.02.004>
25. Singh S, Hariteja N, Prasad TR, Raju NJ, Ramakrishna C (2020) Impact assessment of faecal sludge on groundwater and river water quality in Lucknow environs, Uttar Pradesh, India. *Groundwater for Sustainable Development* 11:100461. <https://doi.org/10.1016/j.gsd.2020.100461>
26. Smith BA, Eudoxie G, Stein R, Ramnarine R, Raghavan V (2020) Effect of neem leaf inclusion rates on compost physico-chemical, thermal and spectroscopic stability. *Waste Management* 114:136-147. <https://doi.org/10.1016/j.wasman.2020.06.026>
27. Wanda C, Kengne ES, Wafo GVD, Nzouebet WAL, Nbandah P, Ngandjui YAT, Zapfack L, Noumsi IMK (2021) Quantification and characterisation of faecal sludge from onsite sanitation systems prior the design of a treatment plant in Bangangte, West Region of Cameroon. *Environmental Challenges* 5:100236. <https://doi.org/10.1016/j.envc.2021.100236>
28. Zhong L, Wu T, Ding J, Xu W, Yuan F, Liu BF, Zhao L, Li Y, Ren NQ, Yang SS (2023) Co-composting of faecal sludge and carbon-rich wastes in the earthworm's synergistic cooperation system: Performance, global warming potential and key microbiome. *Science of The Total Environment* 857:159311. <https://doi.org/10.1016/j.scitotenv.2022.159311>

Figures

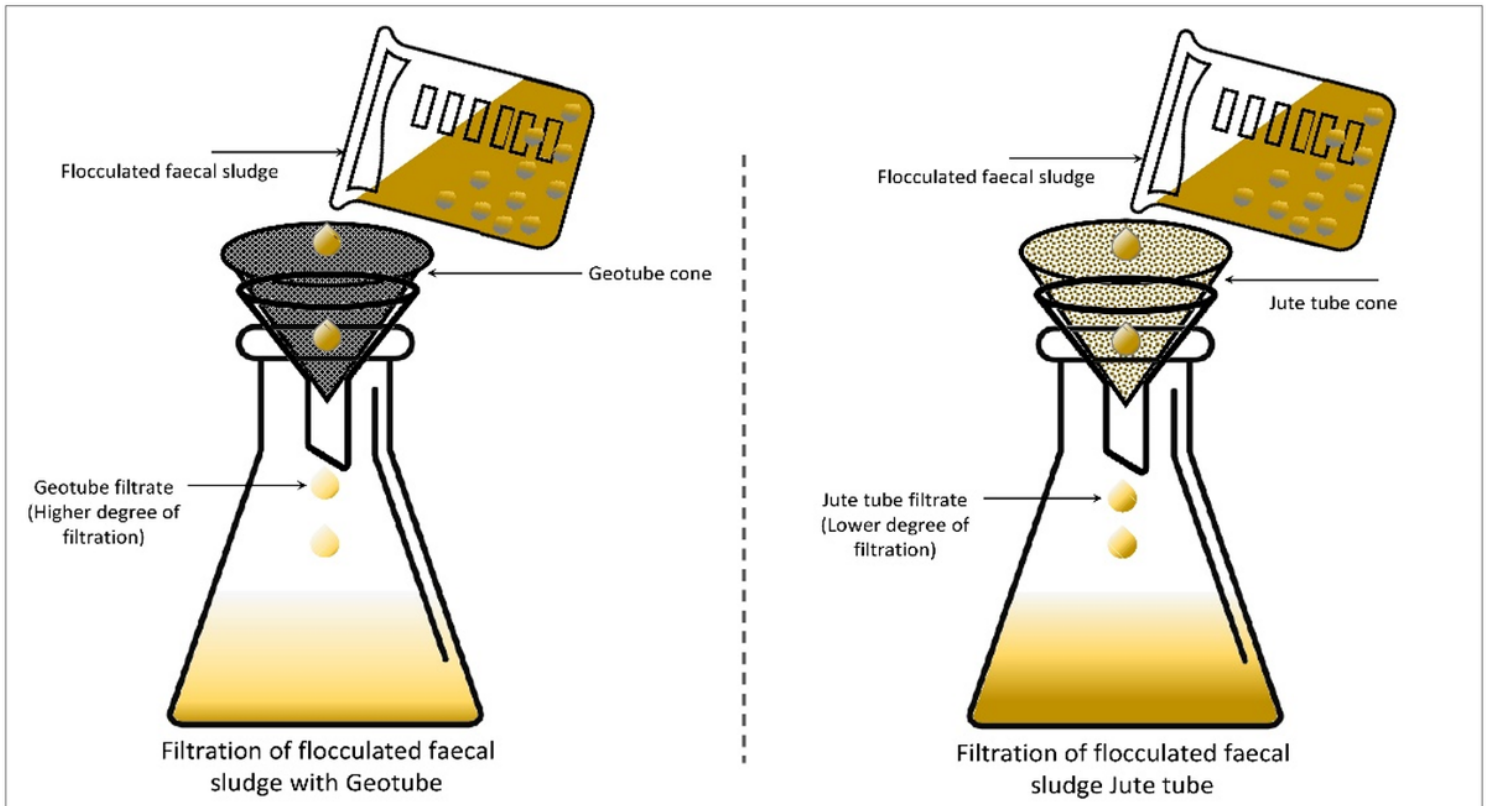


Figure 1

Comparative dewatering experiment with Geotube and jute tube post coagulation/ flocculation

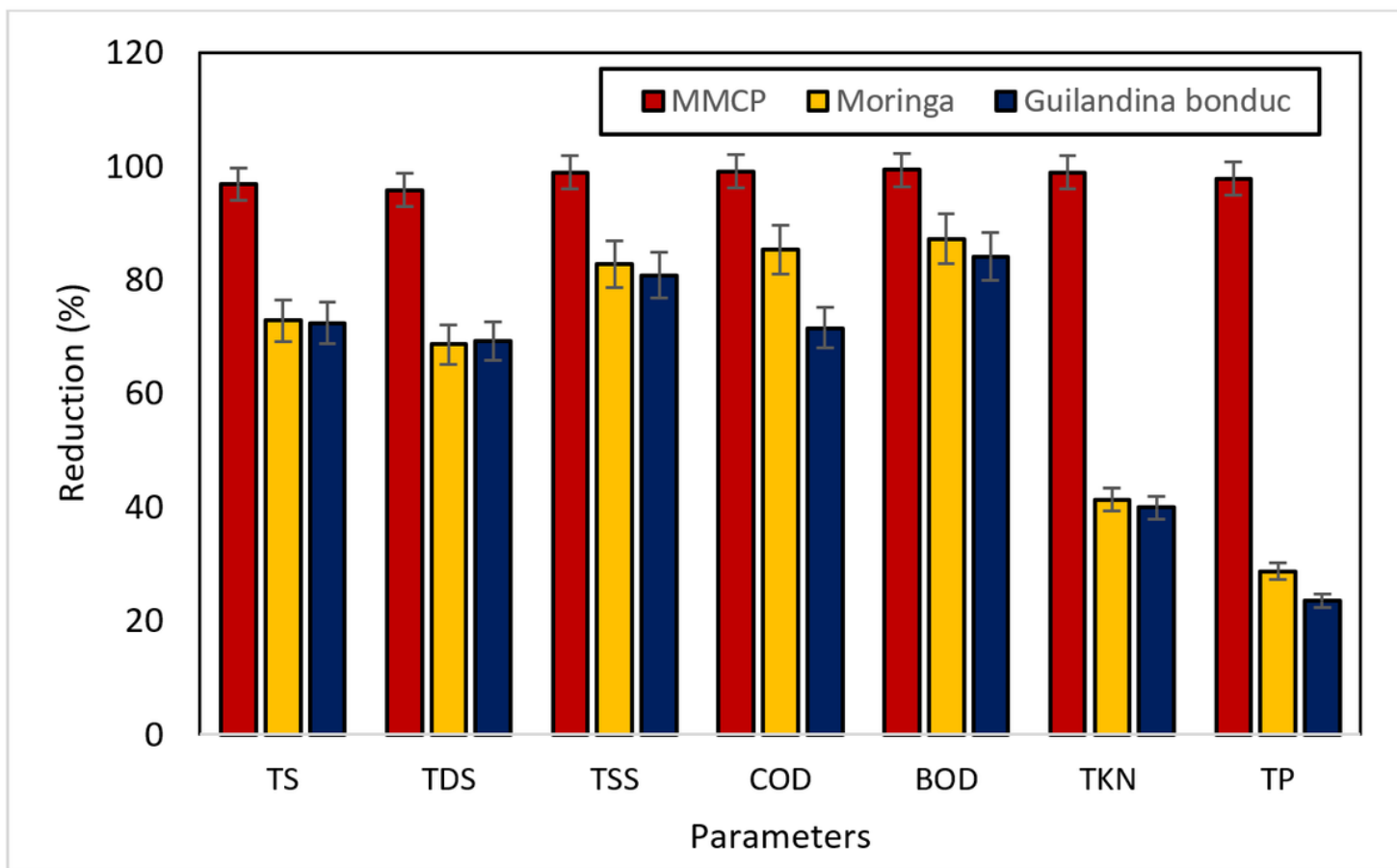


Figure 2

Efficacy of different coagulants towards the reduction of existing pollution concentration

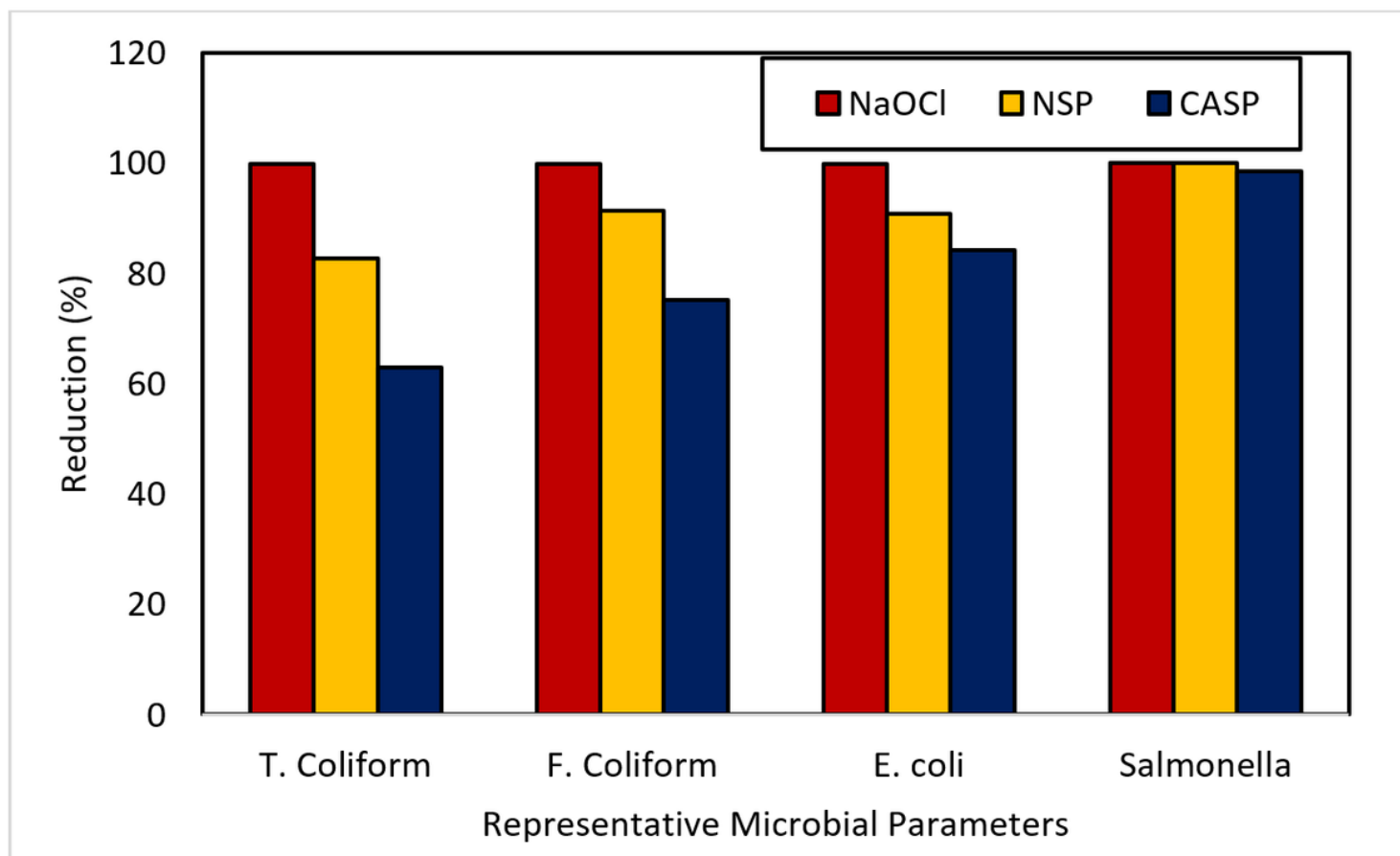


Figure 3

Efficacy of different disinfectants on the reduction of pathogens