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Suitability of treated FS using *Jatropha curcas* on unplanted sand drying beds for agricultural use in Dar es Salaam, Tanzania

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ABSTRACT

The huge amount of water in faecal sludge (FS) has been presented as one of the major faecal sludge management (FSM) challenges and concerns. *Jatropha curcas* (JC) has been adopted as a dewatering and disinfection solution for FS treatment. However, very little is known about the agricultural suitability of their physical–chemical characteristics, nutrient and pathogen levels. The agricultural suitability of by-products from the unplanted sand drying beds was investigated by assessing the physical–chemical parametric indices, Wilcox diagram and pathogen removal rate. The qualitative method was adopted for both untreated and treated FS samples. A total of 60 samples for dry sludge and 70 samples for both leachates from control and JC chambers were analyzed for three months. Its agricultural suitability was judged by the level of salinity and sodium hazard in leachate and pathogen levels. The results showed that the salinity level of leachate from the JC chamber falls under medium- and low-risk levels. The removal efficiency of *Escherichia coli* by JC in leachate was from $7 \pm 2 \times 10^9$ CFU/g to $6 \pm 1 \times 10^2$ CFU/100 mL. Treating FS with JC is suitable for reducing salinity and sodium hazards in leachate hence favourable for irrigation. Further treatment of dry sludge is required before being used for agriculture.

Key words: agricultural suitability, Dar es Salaam, faecal sludge, *Jatropha curcas*, unplanted sand drying beds

HIGHLIGHTS

- Agricultural suitability of treated faecal sludge.
- Potentiality of treating faecal sludge using *Jatropha curcas*.
- Enhancement of FS treatment on unplanted sand beds using *Jatropha curcas*.
- The efficiency of *Jatropha curcas* in the treatment of faecal sludge for agricultural use.
- The potential of *Jatropha curcas* for small farmers in Dar es Salaam.

1. INTRODUCTION

The world was seriously off track in meeting the United Nations Global Sustainable Development Goal (SDG) sanitation-related target. The available data estimated that globally about 600 million people are using improved sanitation services, while more than 2.3 billion people still lack basic sanitation services (WHO & UNICEF 2017). Thus, they either practice open defecation or use unimproved facilities (WHO & UNICEF 2017). Communities in low- and middle-income countries are grappling to meet SDG 6. Whereby, over 80% of the Sub-Saharan African population relies on onsite sanitation systems; and in Tanzania, about 90% of the people depend on it (Strande *et al.* 2014). These systems are among the poor sanitation facilities where faecal sludge (FS) is produced, treated and disposed of in the same place. The systems are likely to remain dominant soon due to massive rural–urban migration, economic inequality and high capital costs of sewer systems (Cross & Coombes 2014). Produced FS has been reported to offer a good resource to enhance soil productivity for sustainable food–water–energy security by reusing it for agriculture and energy production (Seck *et al.* 2019).

Recently, studies have indicated that small-scale farmers in Dar es Salaam used untreated FS for vegetable fertilization (Kayombo & Mayo 2018). This unsafe practice exposes farmers and consumers to pathogens and poses a great risk to public health, water resources and challenges caused by both Gram-positive and Gram-negative bacteria in the soil (Seck *et al.* 2019). The reason behind this is due to a large number of pathogens that may cause health hazards. Therefore, FS must be disinfected before agricultural use. Dewatering of FS is the first key element in the treatment process and is normally achieved using sand-drying bed technology with either conventional or local conditioners (Benjamin *et al.* 2021).

Nevertheless, conventional conditioners like aluminium sulphate are relatively costly for developing countries and a high concentration of their ion in the sludge may increase toxicity in the soil (Gold *et al.* 2016). Studies have shown that natural disinfectants like *Jatropha curcas* (JC) seeds contain proteins and glucosinolate 4 alpha-L-rhamnosyloxy benzyl isothiocyanate which enhances dewaterability and antibacterial activity against bacteria in FS (Gold *et al.* 2016; Ngandjui *et al.* 2018). The resulting by-products (dry sludge and leachate) are environmental- and agricultural-friendly. However, very little is known about the agricultural suitability of their physical–chemical characteristics, nutrient and pathogen levels. This study assesses the agricultural suitability of FS treated by JC on sand-drying beds for soil conditioning.

2. MATERIALS AND METHODS

2.1. Study approach

In this study, the qualitative method was adopted whereby untreated and treated samples were analyzed at the University of Dar es Salaam laboratories. A total of 60 samples for dry sludge and 70 samples for both leachates from control and JC chambers were analyzed for three months.

2.2. Experimental setup

The experimental setup of the field and FS sample collection campaigns were conducted at the adopted FS dewatering research pilot facility which was designed and installed at the University of Dar es Salaam (Figure 1). The plant consists of six unplanted sand-drying beds. The beds had 30-cm filter media as recommended by Cofie *et al.* (2006). The facility was modified whereby collected FS from onsite sanitation containments were disposed of straight to the mixing tank instead of settling thickener to avoid bacterial die-off. Dosing of the local disinfectant was done at the mixing unit and agitated by a pump to attain thorough mixing (homogenized sludge). The homogenized sludge was pumped to the unplanted sand drying beds for drying. The drying period varied from 14 to 20 days for control (without disinfectant) and that dosed with JC took 4–5 days.

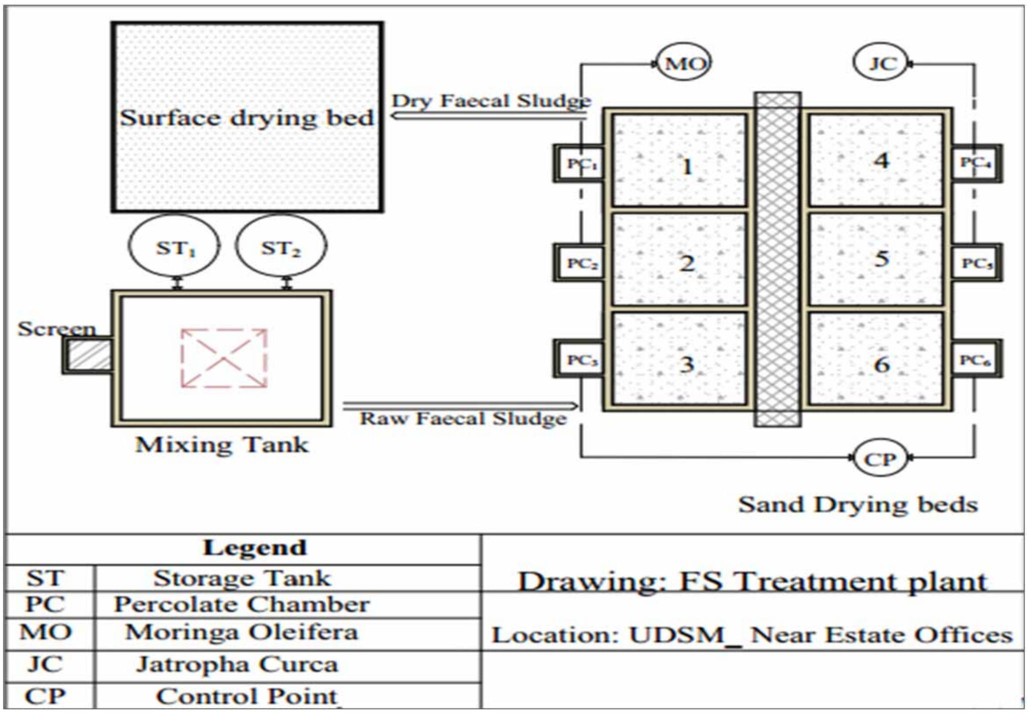

Figure 1 | Modified pilot plant of unplanted sand drying beds.

2.3. Sampling campaign

Sampling was undertaken according to the standard method for examining water and wastewater (APHA *et al.* 2017). A sampling of leachate was done on daily basis (every 24 h) every 8.00 am morning to avoid the killing of the pathogen. The samples were taken at the ejecting percolate pipe and not from the percolating chamber to avoid mixing the samples. Samples of dry FS were taken after the total dryness sludge was removed from surface drying beds. Raw FS samples were collected from trucks that were discharging the sludge to the mixing tank (second unit of the piloted FS dewatering plant). To ensure no bacterial die-off in the samples, the collected samples were protected as recommended by the standard method of examining water and wastewater (APHA *et al.* 2017).

2.4. Analysis of agricultural suitability of treated FS

The agricultural suitability of FS by-products was analyzed using three tests; the first test was the classification of physical–chemical parameters of treated products and compared it with WHO agricultural guidelines and Tanzanian agricultural standards. The second test is the analysis of salinity and sodium hazard test (Wilcox diagram) and the last is a test of physical–chemical parametric indexes. A final decision on suitability for agricultural use of treated products was judged by the level and class of salinity and sodium hazard to which the treated leachate belongs and pathogen levels (Wilcox diagram).

2.4.1. Agricultural suitability of treated FS leachate using physical–chemical indexes

The pH and temperature of the FS were measured *in situ* using a digital pH measuring kit with a probe (pH meter PT-15), while EC was measured with a Metrohm E587 conductivity meter. The classification of the agricultural suitability of leachates was based on physical–chemical parametric indexes of leachate. These indexes are sodium adsorption ratio (*SAR*), soluble sodium percentage (*SSP*), permeability index (*PI*) and magnesium adsorption ratio (*MAR*).

The recommended SAR of treated wastewater ranges from 4.5 to 7.9 (Hussain & Sheriff 2015) and was calculated by Equation (1):

$$\mathrm{SAR} = \frac{[\mathrm{Na}]}{\sqrt{([\mathrm{Ca}] + [\mathrm{Mg}])/2}} \tag{1}$$

The required SSP of treated effluent was calculated by Equation (2) Khandouzi *et al.* (2015):

$$\mathrm{Na}\ (\%) = \frac{[\mathrm{Na}] + [\mathrm{K}]}{[\mathrm{Ca}] + [\mathrm{Mg}] + [\mathrm{Na}] + [\mathrm{K}]} \times 100 \tag{2}$$

The PI of treated effluent was calculated using Equation (3) Muyen *et al.* (2011):

$$\mathrm{PI} = \frac{[\mathrm{Na}] + \sqrt{[\mathrm{HCO_3}]^-}}{[\mathrm{Ca}] + [\mathrm{Mg}] + [\mathrm{Na}]} \tag{3}$$

The MAR of treated effluent was calculated using Equation (4) and recommended that the values above 50 were considered as risk index (Khandouzi *et al.* 2015):

$$\mathrm{MAR} = \frac{[\mathrm{Mg}]}{[\mathrm{Ca}] + [\mathrm{Mg}]} \times 100 \tag{4}$$

2.4.2. Agricultural suitability of leachate using salinity and sodium hazards (Wilcox diagram)

The agriculture suitability of leachate salinity was assessed by classifying it based on salinity and sodium hazards (Wilcox diagram) (Figure 2). The diagram classified the treated effluent into 16 classes as low, medium, high and very high, respectively, on each axis and the suitability class of the treated effluent from the drying bed was obtained.

2.4.3. Agricultural suitability of treated products for nutrients and pathogens

The leachate quality of FS from the unplanted sand drying beds was analyzed for nitrogen and phosphorous nutrients. Also, the pathogens analyzed are total coliform, *Escherichia coli* and helminths. The helminthics eggs are analyzed in this study because they are the causative organisms of the very common intestinal diseases affecting the developing countries especially Tanzania. Moreover, if FS was allowed to be used in agriculture, these eggs

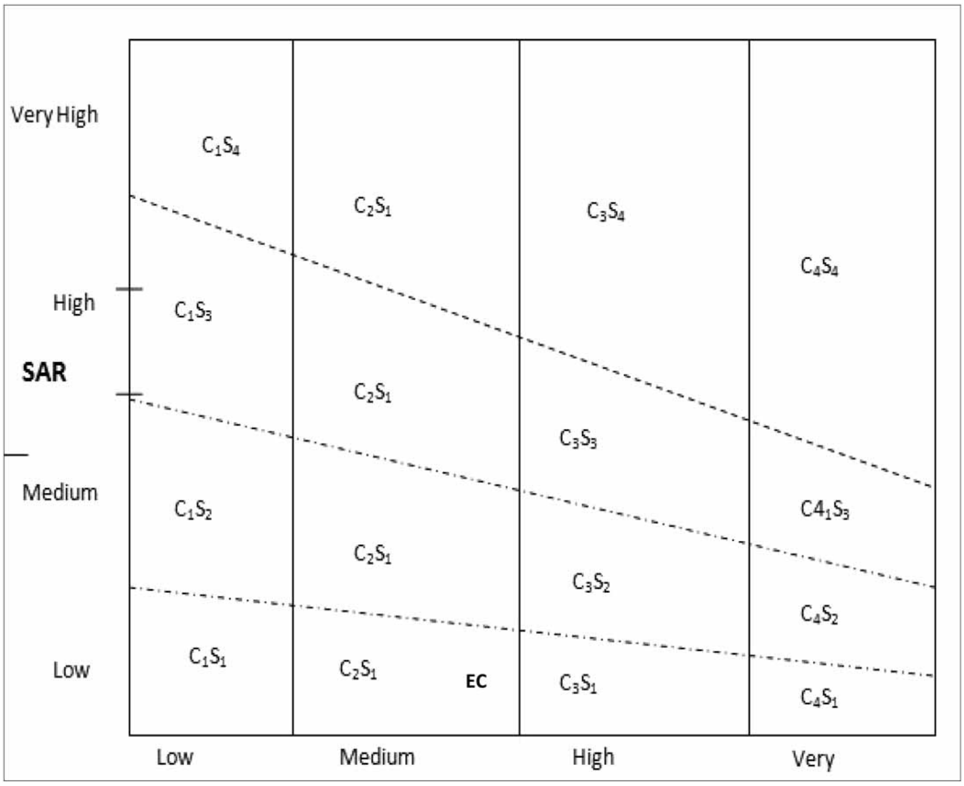

Figure 2 | Wilcox diagram for treated percolate. *Source*: Wilcox (1955). EC, electrical conductivity; S, sodium adsorption ratio (SAR).

can survive in soil for more than five years and can cause serious health and environmental problems. The analysis was conducted following the standard method for water and wastewater (APHA *et al.* 2017). The obtained results were compared with the nutrient and pathogen levels required for agriculture as provided by TBS/AFDC (2017) and WHO (2006).

2.4.3.1. Nutrient levels in leachate and dry FS. Untreated and treated FS samples were analyzed for nutrients that affect plant growth. These parameters include organic nitrogen and organic phosphorus. Amount of organic phosphorus in both treated and untreated FS was determined using the digestion method, specifically the ascorbic acidic method (Figure 3(a)) followed by Equation (5). Organic nitrogen was determined using the semi-micro-Kjeldahl method (Figure 3(b)) followed by Equation (6) as instructed by APHA *et al.* (2017). The results were compared by agricultural guidance and standard of TBS/AFDC (2017) and FAO/WHO (2006):

$$P_{org} = P_{total} - (P_{hydrolyzed} + P) \quad (5)$$

where P_{org} indicates organic phosphorus, P_{total} indicates total phosphorus, $P_{\mathrm{hydrolyzed}}$ indicates hydrolyzed phosphorus and P indicates phosphate:

$$\mathrm{N_{org}(mg/L) = TKN - ((NH_4 - N) + NO_3 - N)} \quad (6)$$

where N_{org} indicates organic nitrogen, TKN indicates total Kjeldahl nitrogen, NH_4-N indicates ammonium nitrogen and NO_3-N indicates nitrate nitrogen.

2.4.3.2. Pathogen levels in leachate and dry FS. Concentrations of pathogens analyzed were *E. coli*, total coliform and helminthic eggs. *E. coli* and total coliform were analyzed by the pour-plate method (Figure 4(a)) and the concentration of helminthic eggs was determined by the modified Bailenger method (Figure 4(b)) (APHA *et al.* 2017).

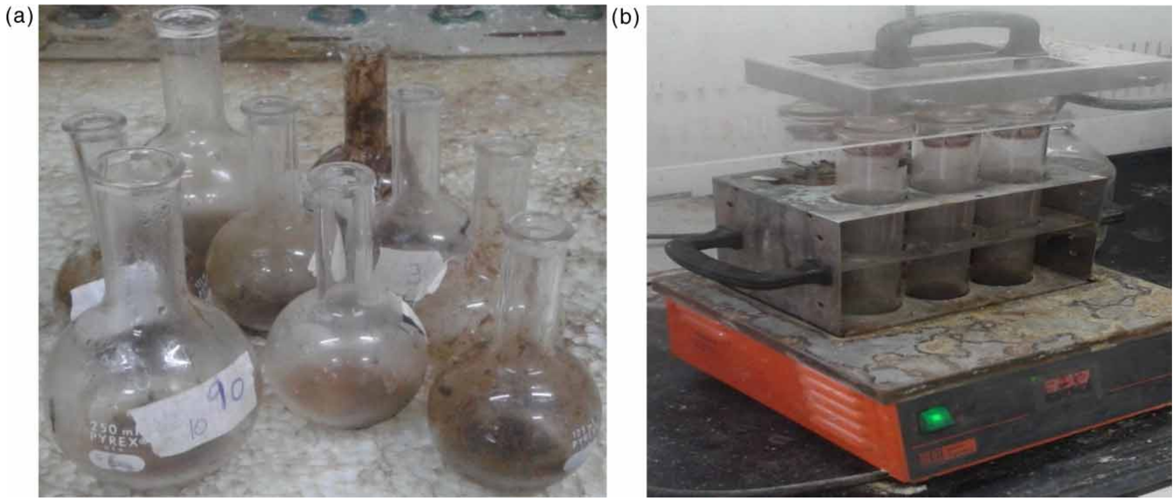

Figure 3 | Determination of nutrients. (a) Measurement of organic phosphorous and (b) measurement of organic nitrogen.

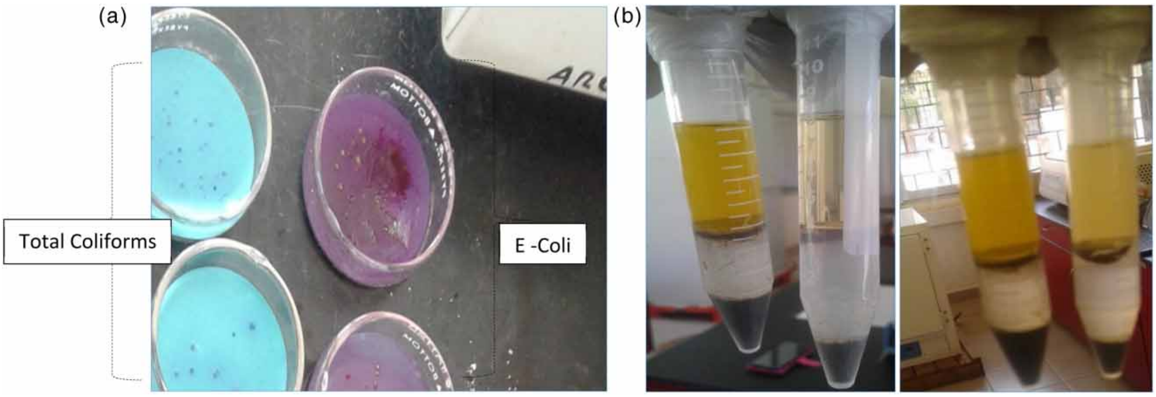

Figure 4 | Determination of pathogen levels in treated and untreated FS. (a) *Escherichia coli* and total coliforms (CFU/100 g) and (b) separation of helminthic eggs from the FS sample.

2.5. Source and preparation of JC seeds

The used JC seeds were purchased from natural products company located in Arusha, Tanzania and brought to the water quality laboratory at the UDSM. The seeds were deshelled manually to get clean seeds (Figure 5(a)), then dried in the oven at 45 °C (model DHG 916A, Germany) for 48 h to allow total dryness (Ndabigengesere *et al.* 1995). The dry seeds were blended by using a kitchen blender to make seed powder (Figure 5(b)). Then, the oil that hinders the treatment is extracted from seed powder using the Soxhlet method (APHA *et al.* 2017). The cake was dried at room temperature for 15 min to allow total dryness (Figure 5(d)). The cake was crushed to obtain the fine particles sieved at a size of 0.58 mm (Figure 5(e)).

2.6. Preparation of the conditioner stock solution

The JC stock solution was prepared using the salting method (0.6 M of NaCl). The salting effect was used to improve the extraction process by eluting a higher amount of disinfectant agents from yield (JC*)* seed powder (Ndabigengesere *et al.* 1995). The stock solution is made by dissolving 5 g of seed powder in 100 ml of NaCl solution.

2.7. Data analysis

Normality distribution of some of the physical–chemical parameters data of untreated FS were tested using histogram, deviation, skewness and kurtosis values. Due to data lacking normality, a decision on the use of different non-parametric tests for FS data analysis was opted (Figure 1). A statistically significant difference between

Figure 5 | Preparation of JC seed powder. (a) JC seeds; (b) oil JC powder; (c) the Soxhlet method for oil extraction; and (d) 0.58-mm sieved fine particles.

treated and untreated FS products was analyzed using Mann–Whitney (Wilcoxon Rank Sum) (Mendenhall & Sincich 2012). Parametric indices, comparison and Wilcox diagram test were used to test salinity and sodium hazard of treated FS by-products.

3. RESULTS AND DISCUSSION

3.1. Normality distribution for parameters of raw FS

The collected data for raw FS parameters indicated that they lack normal distribution (Figure 6). Similar observations of normality tests on FS characteristics were reported by Awere *et al.* (2020) and Ward *et al.* (2019) The FS characteristics analyzed were physio-chemical, biological and nutrient parameters.

3.2. Agricultural suitability of leachates

The major factors that judge the agricultural suitability of treated FS products were the different physical–chemical parameters of the treated FS in supporting plant growth and human health.

3.2.1. Agricultural suitability of physical–chemical parameters for leachate

The pH and EC (μS/cm) results were analyzed for raw FS, control (leachate without conditioner) and leachate treated with JC. No pH shift was found for the leachate from the control showing that the unplanted sand drying bed does not have any impact on the pH of the raw FS. However, a slight reduction of pH was observed with 7.4 ± 0.3 for JC. The difference was statistically insignificant for both conditioners with $p = 0.07$ at $\alpha = 0.05$. The pH values were within the allowable agricultural standards for irrigation which are 6.5–8.5 and 6.5–8.4 for Tanzanian standards and WHO standards, respectively, as presented in Table 1. Moreover, a significant reduction of EC was found at both control and JC leachate, with a reduction from $2,851.6 \pm 1.3$ to $1,751.6 \pm 1.7$and 240.7 ± 5.6 (μS/cm)

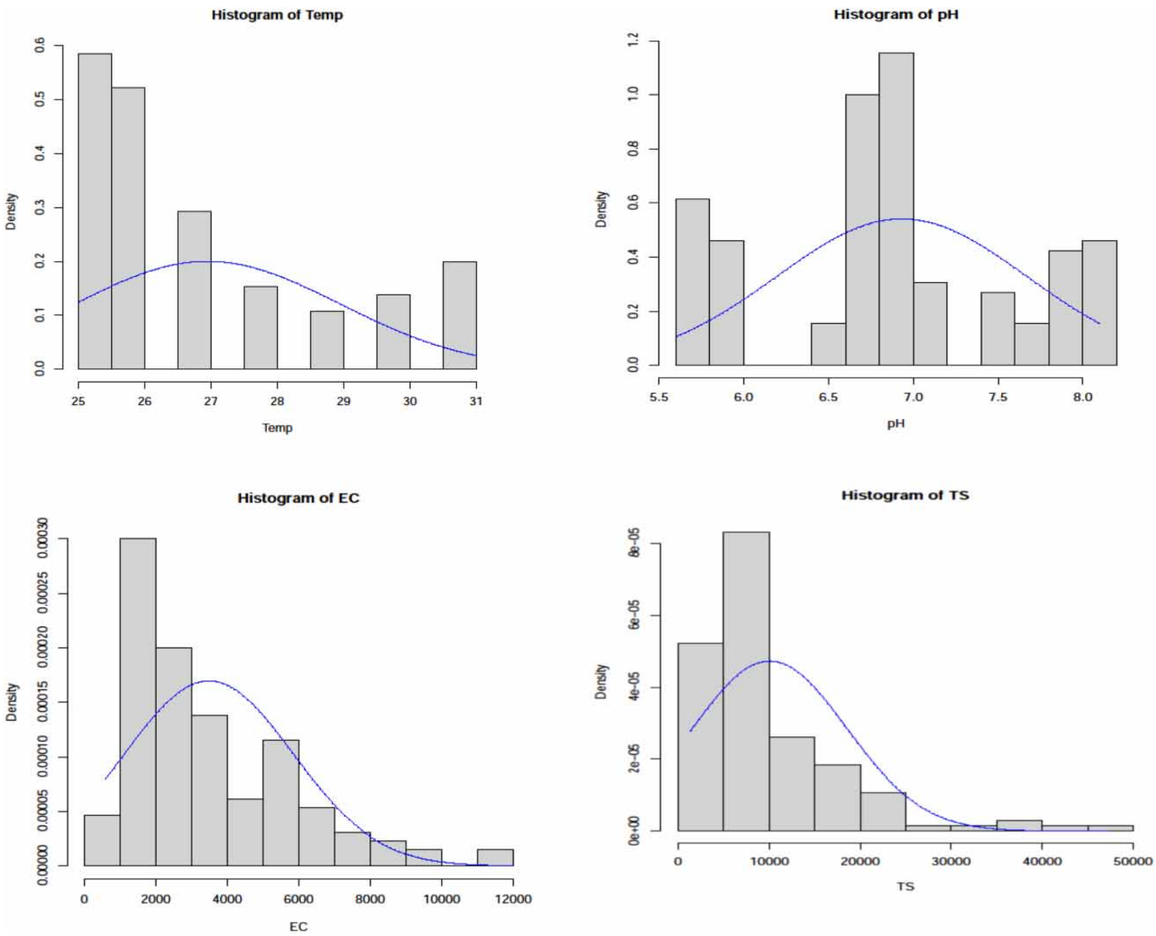

Figure 6 | The normality test of some analyzed FS parameters.

Table 1 | Agricultural suitability of physical–chemical parameters of treated percolate

Parameters: Group	Parameters: Specific	Raw	Control	JC	Tanzanian standards (organic fertilizer specifications)	FAO/WHO irrigation water quality
Physical–chemical	pH	7.6 ± 0.3	7.6 ± 0.3	7.4 ± 0.3	6.5–8.5	6.5–8.4
	EC	2851.6 ± 1.3	1751.6 ± 1.7	240.7 ± 5.6	–	250–3000

respectively. The differences were statistically different with $p = 0.02$ and $p = 0.001$ at $\alpha = 0.05$ for control and JC, respectively. The values from raw FS to the leachates were within the allowable range for agriculture by FAO/WHO which is 250–3000 (μS/cm) (Table 1).

The leachate pH influences the soil pH where the leachate would be used for irrigation, depending on the nature of the plants. Some plants prefer slightly acidic pH while others prefer slightly basic or neutral, in a range of (6.5–8.4). According to WHO (2006), leachate with either higher or lower pH levels than the recommended range have an impact on growing plants. It causes the plants to suffer from nutrient deficiencies and insufficient availability of trace elements results in plant toxicity. Thus, the pH values from this study are favourable for agricultural use since they fall within the allowable range.

The EC values exhibit the hazard level of the leachate in agricultural applications, and it is among the most important water guideline on crop production (Yu *et al.* 2021). The leachate with higher EC values is toxic to plants and poses a salinity hazard (Qu *et al.* 2021). The values have been classified depending on the level of suitability for agricultural production, whereby, values greater than 30,000 μS/cm are referred to as fair, the range from 700 to 3000 μS/cm is referred to as good, and the values below 700 μS/cm is referred as excellent (WHO 2006). From the classification, the EC values for raw FS and control percolate are classified as good for agricultural use. While the EC values for JC percolates are classified as excellent for agricultural use. This means that the usability of JC in treating FS has a high potential of improving the suitability of raw FS from good to excellent in agricultural use. Moreover, the agricultural suitability of physical–chemical parameters of treated percolate was further tested by parametric indices. The results for all parametric indices are presented in Table 2.

Table 2 | Agricultural suitability of percolate using parametric indices

				Classification		
Parametric indices	**Raw**	**Control**	**JC**	**Range**	**Class**	**Description**
SAR	13 ± 0.1	12.8 ± 0.04	3.5 ± 0.2	0–10	1	Low
				10–18	2	Moderate
				18–26	3	Intensive
				26–30	4	Very Intensive
SSP	90%	89%	54%	>60%	–	Unsuitable
MAR	44%	43.9%	36%	>50%	–	Risk Index
RSC	131 ± 0.8	121 ± 0.9	36 ± 0.7	<66.25 mg/L	–	Safe
				66.25–132.5 mg/L	–	Doubted
				>132.5 mg/L	–	Unsuitable
PI	53%	47%	23%	<25%	3	Suitable
				25–75%	2	Doubtful
				>75%	1	Unsuitable
KR	1.7	1.3	0.5	<1	–	Suitable
				1 < KR < 2	–	Marginal
				>2	–	Unsuitable

3.2.2. Agricultural suitability for salinity and sodium hazard using Wilcox diagram

The sodium amount in leachate has a significant impact when used for crop irrigation. The large sodium amount poses a sodium hazard to soil (Muyen *et al.* 2011). The SAR values for raw FS and leachate from the control chamber posed a moderate sodium effect, hence are not considered suitable for long-term irrigation (Table 2). However, treating the raw FS with JC has a significant impact on reducing the sodium effect in FS. Thus, it is considered suitable for irrigation purposes. According to WHO (2006), the excellent suitable leachate for irrigation should have values ranging from 0 to 10. Moreover, the values ranging from 10 to 18 are considered good, but not recommended for irrigation in a long term. The salinity (EC) levels of raw FS and leachate from control and JC chambers were classified to be very high-, high-, medium- and low-risk levels for agricultural use as shown here.

3.2.2.1. Raw FS. The EC values of raw FS from onsite containments fall under a very high- and high-risk level for agricultural use (Figure 7). Very high and high-risk levels from the classification of raw FS samples are due to the high concentration of dissolved solids. The high EC values classified as very high and high risks for agriculture have effects on crop growth. The risk levels lead to distortion of the soil structure and its ability to transfer water and air. Thus, the raw sludge can only be suitable for non-sensitive plants with EC ranging from 5 to 8 dS/m (FAO/WHO 2006).

3.2.2.2. Leachate from the control chamber. The EC values in leachate from the control chamber fall under very high-, high- and medium-risk levels for agricultural use (Figure 8). The high and very high levels from the classification of leachate from control chamber samples are due to the high concentration of dissolved solids. However, the medium class was probably due to the attachments of a small fraction of dissolved solids in the filter media. The higher values of EC classified as high and very high risks for agriculture have effects on crop growth. The levels lead to distortion of the soil structure and its ability to transfer water and air. Thus, the raw sludge can only be suitable for non-sensitive plants with EC ranging from 5 to 8 dS/m (FAO/WHO 2006).

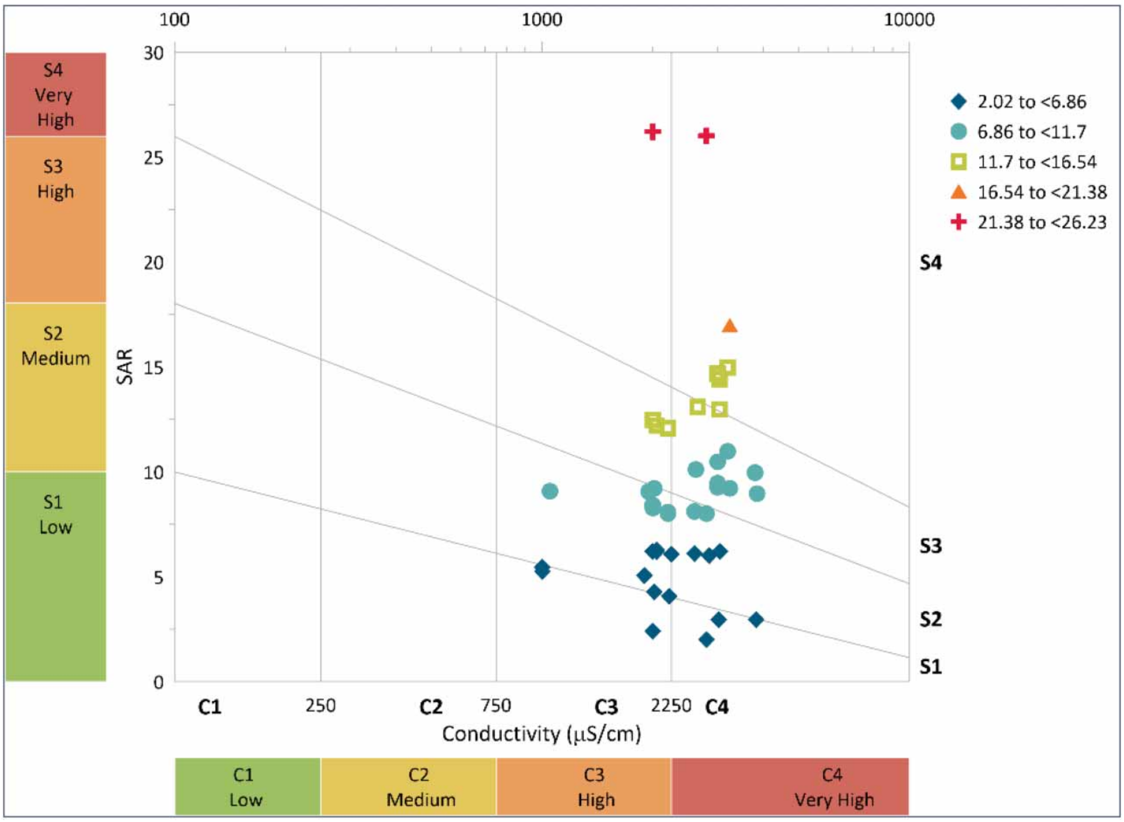

Figure 7 | Salinity risk classification of raw FS for irrigation.

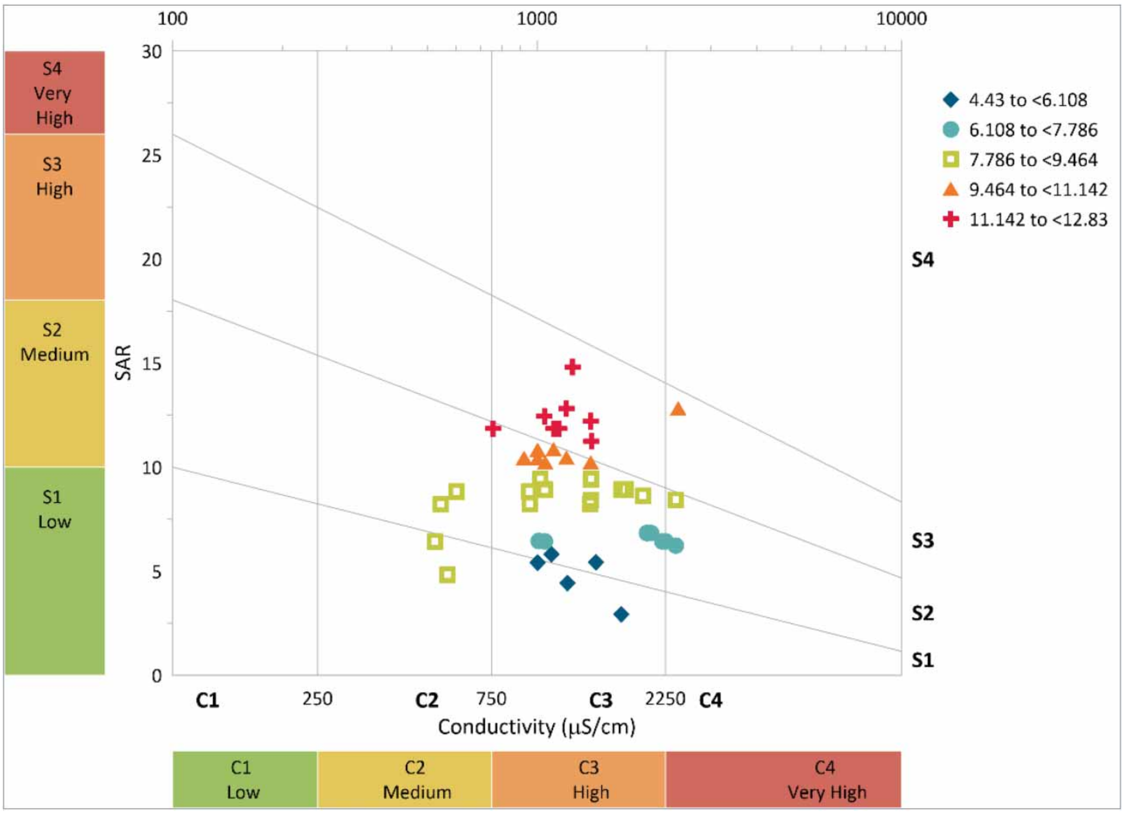

Figure 8 | Salinity risk classification of leachate from the control chamber for irrigation.

3.2.2.3. Leachate from the JC chamber. The EC values of leachate from the JC chamber fall under medium- and low-risk levels for agricultural use (Figure 9). The medium- and low-risk levels of the samples were due to the effect of the JC that caused the trapping of the dissolved solids which are retained on the surface of the filter media. The good levels of EC have fringe effects on crop growth, hence it does not distort the soil structure and its ability to transfer water and air. Therefore, leachate from the JC chamber can be used for both sensitive and non-sensitive plants (FAO/WHO 2006).

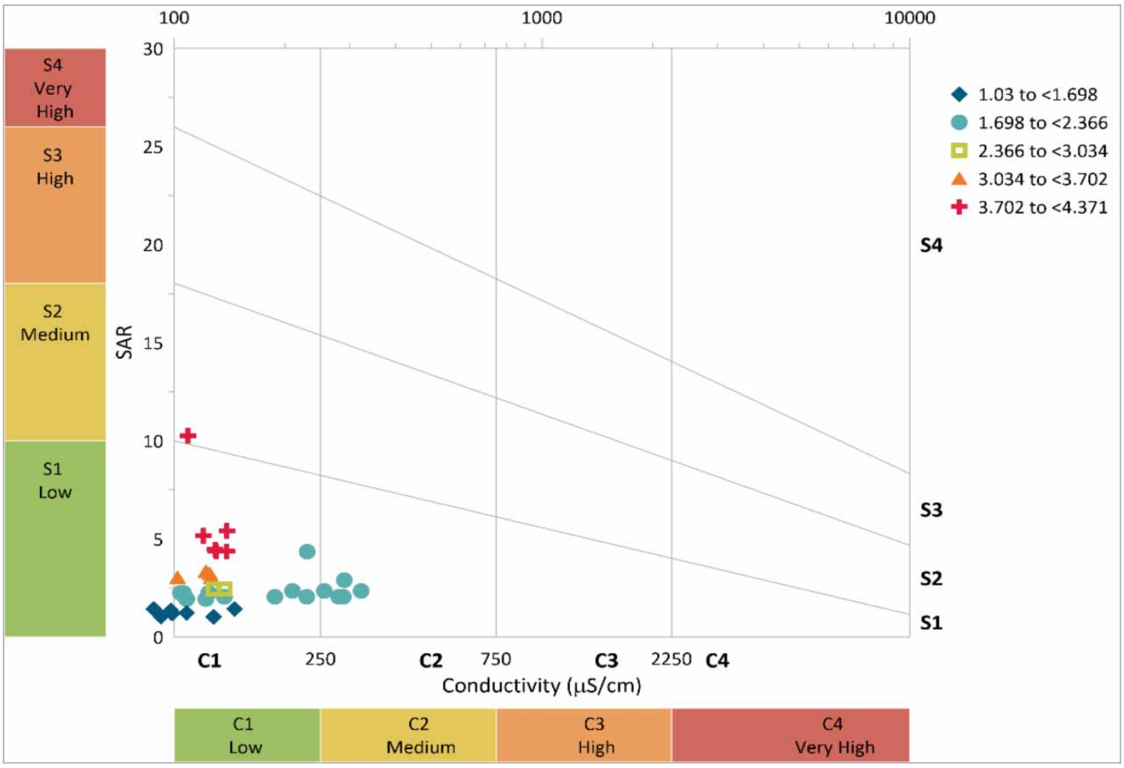

Figure 9 | Salinity risk classification of leachate from the JC chamber for irrigation.

3.2.3. Agricultural suitability of leachates using PI

3.2.3.1. Permeability index. The PI for raw FS (53%) and the control leachate (47%) were found to be within the doubtful range of 25–75% (Seck *et al.* 2019). However, the PI for the leachate from the JC chamber was 23% and was found to be suitable for irrigation. According to Seck *et al.* (2019), PI of either wastewater or leachate with PI values less than 25% is considered suitable for agricultural use.

3.2.3.2. Magnesium adsorption ratio. Both the raw FS, leachate on control and JC beds were found to be suitable for irrigation as they both have MAR values of 44, 43.9 and 36%, respectively, which are less than the risk index level (>50%). Because according to Khandouzi *et al.* (2015), the high values for MAR greater than 50% cause adverse effects on crop yield, as they shift the soil pH to more alkaline. The results in this study suggest that the JC have no significant impact on soil pH, hence does not have any influence on altering the pH to alkaline and is suitable for agricultural use.

3.2.3.3. Soluble sodium percentage. The raw FS and leachate from the control bed were unsuitable for irrigation of crops, as they have higher values SSP of 90 and 89%, respectively. However, treating the raw FS with either JC was found to lower the SSP values from 90 to 54%, respectively. According to WHO (2006), the percolate or FS with an SSP value greater than 60% results in sodium accumulation that causes a breakdown in soil's physical properties, hence reducing its permeability. So, using the JC disinfectant in unplanted sand beds results in the formation of percolate that is safe for irrigational use of crops. The JC leachate was found to have values that are statistically and significantly different from the limiting value (60%) with $p = 0.03$ at $\alpha = 0.05$.

3.2.3.4. Residual sodium carbonate content. The results for the raw FS and control percolate were doubted to be suited for irrigation of crops as they had RSC values of 131 ± 0.8 and 121 ± 0.9, respectively. However, the percolate treated by JC was found to be suitable for crop irrigation as it had RSC values of 36 ± 0.7. According to WHO (2006), the percolate or FS with RSC values less than 66.25 mg/L are considered safe for use in crop irrigation while the values ranging from 66.25 to 132.5 mg/L are doubted to be used for irrigation of crops. For this study, it has been found that treating raw FS with JC turns the sludge into percolate to be used for irrigation of crops, without any doubt, and hence considered suitable for agriculture.

3.2.4. Agricultural suitability of leachates using cations and anions

The ions determined from the raw FS and percolates from the control and JC beds fall within allowable limits by WHO (2006), except for the bi-carbonate parameters from the raw FS that were found to be higher than the allowable limits (Table 3). Moreover, JC was found to significantly reduce the ion concentration of raw FS, except for calcium ions and magnesium ions, which increase with the dosing of JC because it has calcium and magnesium compositions. The JC has the potential of reducing almost three times the sodium concentration of raw FS (Table 3). Moreover, JC reduces almost six times the bicarbonate ion concentration in raw FS (Table 3). The JC tends to double the calcium concentrations from raw FS to treated percolates because JC has calcium concentrations in its composition that eventually contributes to the addition of the ions. Also, the JC was found to increase the magnesium ion concentrations from 8.3 ± 0.4 to 13.3 ± 0.2 (mg/L).

Table 3 | Ion levels suitable for irrigation purposes

Parameters						
Group	Specific	Raw (mg/L)	Control (mg/L)	JC (mg/L)	Tanzanian standards (organic fertilizer specifications)	FAO/WHO irrigation water quality
Ions	Na^{+1}	135.4 ± 0.3	120 ± 0.7	55.5 ± 0.01	N/A	<460
	Ca^{+1}	10.7 ± 0.3	10.7 ± 0.3	23.5 ± 0.2	N/A	<400
	Mg^{+2}	8.3 ± 0.4	8.3 ± 0.4	13.3 ± 0.2	N/A	<61
	HCO_3^{-1}	694.3 ± 0.3	584.2 ± 0.3	105.9 ± 1.3	N/A	<610

Sodium ion is considered a micronutrient that aid in the metabolism and synthesis of chlorophyll. However, when the sodium is higher exceeding the allowable limit of <460, it leads to slowing down the movement of water from the soil to the roots, and when the sodium concentration is higher in the root cells of plants, the soil draws water from them, hence wilting the plant and killing it (FAO/WHO 2006). Moreover, the excessive calcium uptake by plants greater than <400 leads to disturbances in ion balance, as it leads to changes in cytosol pH and decrease the solubility of other ions (Lea & Miflin 2018). Furthermore, the excessive magnesium ions more than the limit value of <61 inhibit the uptake of calcium; hence, the plant exhibits the symptoms of excess salts such as stunted growth and dark-coloured vegetation (FAO/WHO 2006). Also, the excessive levels of bi-carbonate lead to the precipitation of calcium when the soils are dry and produce calcium carbonate ($CaCO_3$). This causes the alkalizing effect and hence increases the level of pH. Hence, it can be concluded that the high pH levels in percolate are an indication of high bicarbonate concentrations, which are toxic to roots, reduces the shoot growth and reduces the phosphorous uptake by plants (Geilfus *et al.* 2018). Hence for this study, both the percolates from the control where JC fall within the allowable maximum limits, meaning that they are suitable for irrigation purposes.

3.2.5. Agricultural suitability of leachates using the nutrient level

The essential nutrients for plant growth are nitrogen (ammonium-N, nitrate-N and organic nitrogen), phosphate and potassium (Lea & Miflin 2018). From this study, the ammonium-N concentration levels are 214.9 ± 2 and 74.4 ± 2 mg/L for percolate from the control and JC, respectively, and are higher than the allowable limits of <5 mg/L by FAO (2016). Also, the nitrate-N (NO_3-N) levels are 4.9 ± 0.1, 5.6 ± 0.3and 7.02 ± 0.2 mg/L for raw FS, percolate from control and JC, respectively, and are also above the allowable limits of <10 mg/L by WHO (2006) (Table 4). From the results, it was found that the ammonium-N concentrations were significantly reduced by the JC from raw FS, whereby the reduction was from 214.9 ± 2 to 74.4 ± 2 mg/L, respectively. However, the reduction was not enough to reduce the concentrations to the allowable limits by WHO (2006).

Table 4 | Nutrient levels suitable for leachate for irrigation purposes

Parameters	Raw (mg/g)	Control (mg/L)	JC (mg/L)	FAO/WHO irrigation water quality
TKN	425.9 ± 6	374.8 ± 13	390.9 ± 5	–
Ammonium-N (NH_4-N)	214.9 ± 2	123.6 ± 2	74.4 ± 2	<5
Nitrite-N (NO_2-N)	0.04 ± 0.006	0.01 ± 0.005	0.16 ± 0.06	–
Nitrate-N (NO_3-N)	4.9 ± 0.1	5.6 ± 0.3	7.02 ± 0.2	<10
Organic Nitrogen (N-org)	206.1 ± 5.5	245.6 ± 13	308.9 ± 5.7	–
Phosphate (PO_4^{-3})	1.7 ± 0.1	0.7 ± 0.1	1.6 ± 0.1	<2
Orthophosphate (P_2O_5)	3.17 ± 3.1	1.7 ± 0.1	2.8 ± 0.1	–
Total phosphorous (PT)	6.08 ± 0.2	7.9 ± 0.2	9 ± 0.7	–
Organic Phosphorous (P-org)	1.2 ± 0.3	1.6 ± 0.4	4.7 ± 0.7	–
Potassium (K)	35.7 ± 0.4	26.4 ± 1.2	10.6 ± 0.5	<2

On the other hand, the nitrate-N concentrations were found to increase with the dosing of JC, due to oxidation of the percolate. Moreover, the phosphate concentration was found to be within the allowable limit by WHO (2006). For both the raw FS and percolate from the control and JC, the JC has no significant impact on levelling the phosphate of raw FS. Furthermore, the JC had an impact on reducing the potassium levels of raw FS, whereby the decrease as a result of dosing JC(10.6 ± 0.5 mg/L) was a statistical difference from that of the control (26.4 ± 1.2 mg/L) with $p = 0.0001$ at $\alpha = 0.05$. Also, the reduction was significant as the JC reduced the nutrient level more than three times that of the raw FS.

Nitrogen is an essential nutrient for plant growth as it facilitates food processing (metabolism) and the creation of chlorophyll, limited amount of nitrogen leads to yellowish plant leaves. However, excessive nitrogen leads to excessive biomass production and less root structure growth (FAO/WHO 2006). Moreover, phosphorous is essential for complex energy transformation (formation). However, excessive phosphorous leads to a reduction of the plant's ability to take up required micronutrients, particularly iron and zinc (Qu *et al.* 2021). Also, excessive potassium is unhealthy for plants as it affects the soil absorption level of other nutrients (FAO/WHO 2006). The nutrient levels from this study are within the allowable limits, hence both, the raw FS and percolate from control and JC are considered suitable for irrigation purposes.

3.2.6. Agricultural suitability of leachates based on pathogen

The pathogen levels of raw FS were found to be reduced significantly by JC. The removal of *E. coli* by JC was from $7 \pm 2 \times 10^9$ CFU/g to $6 \pm 1 \times 10^2$ CFU/100 mL. This removal level is less than the allowable limit (<1000 CFU/100 mL), therefore treated leached is suitable for irrigation purposes (Table 5). The reason behind this is due to the high amount of antibiotic compounds (*glucosinolate 4 alpha-L-rhamnosyloxy benzyl isothiocyanate)* in JC (Ngandjui *et al.* 2018). On the other hand, JC was found to reduce the helminthic eggs to fit within a non-tolerance limit (0 CFU/100 mL). However, dewatering FS without dosing disinfectant (control) was found to have 1 CFU/100 mL, which is above the allowed limit (0 CFU/100 mL). This means that to eliminate helminthic eggs in FS, dosing of JC disinfectant is essential during the treatment process.

Table 5 | Pathogen levels for percolates suitable for irrigation purposes

Parameters	Raw	Control	JC	Tanzanian standards (organic fertilizer specifications)	FAO/WHO irrigation water quality
E. coli	$7 \pm 2 \times 10^9$ CFU/g	$5 \pm 1 \times 10^7$ CFU/100 mL	$6 \pm 1 \times 10^2$ CFU/100 mL	<1000	<1000
Total coliforms	$13 \pm 2 \times 10^{11}$ CFU/g	$10 \pm 3 \times 10^8$ CFU/100 mL	$9 \pm 2 \times 10^4$ CFU/100 mL	–	–
Helminthic eggs	11 ± 2	1	0	Nil	0

The helminthic eggs are considered non-tolerant as they are hard to kill in an ordinary environment so when the percolate with helminthic eggs is used for irrigation it transfers the eggs to the soil. The helminthic eggs mutate to the plants where the percolate has been applied. In this case, using the JC for FS treatment eliminates the potential harm by the helminthic eggs and hence making the percolate suitable for irrigation purposes. Moreover, the JC is conducive to reduce the number of *E. coli* to the allowable limit levels, so JC should be considered a suitable option for treating FS.

3.3. Agricultural suitability of dried sludge

3.3.1. Agricultural suitability of treated dry sludge based on nutrients

A higher amount of total nitrogen (TKN) was found in the dry sludge from the JC chamber (156.2 $\pm$ 2.5 mg/L) than that from the control chamber (98.4 $\pm$ 0.8 mg/L). This difference between nutrient levels from the JC chamber and the control is statistically significant with $p = 0.0027$ at $\alpha = 0.05$ for JC. The difference is due to the ability of JC to form flocs with embedded nutrients that are retained on the surface of sand media and hence remain as part of the dry sludge. The concentrations of TKN are within the allowable TZS 1015 and TZS 11108, Tanzania agricultural standards (Table 6). Furthermore, the organic nitrogen concentration levels were 7.8 $\pm$ 0.5 and 14.7 $\pm$ 1.7 mg/L for the control and JC, respectively. Moreover, the organic phosphorous concentrations in sludge were 0.4 $\pm$ 0.2 and 3.6 $\pm$ 0.4 mg/L for the control and JC, respectively. The summation of values was found below the limits of 50,000 mg/L by the TZS 1015 and 11108 Tanzania fertilizer standards (Table 6). The difference in the summation of the organic nitrogen and organic phosphorous was found to vary significantly at $p = 0.01 \times 10^{-6}$ with $\alpha = 0.05$.

Table 6 | Nutrient levels suitable for agricultural purposes

Parameters	Raw (mg/L)	Control (mg/L)	JC (mg/L)	TZS 1015, TZS 11108 Tanzanian Organic Fertilizer Standards (mg/L)
TKN	425.9 $\pm$ 6	98.4 $\pm$ 0.8	156.2 $\pm$ 2.5	10,000
Ammonium-N (NH_4-N)	214.9 $\pm$ 2	90.5 $\pm$ 0.7	140.4 $\pm$ 1.1	–
Nitrate-N (NO_3-N)	4.9 $\pm$ 0.1	0.1 $\pm$ 0.05	1.1 $\pm$ 0.1	–
Organic nitrogen (N-org)	206.1 $\pm$ 5.5	7.8 $\pm$ 0.5	14.7 $\pm$ 1.7	$\leq$ 50,000
Organic phosphorous (P-org)	1.2 $\pm$ 0.3	0.4 $\pm$ 0.2	3.6 $\pm$ 0.4	
Total phosphorous (PT)	6.08 $\pm$ 0.2	3.1 $\pm$ 0.1	7.4 $\pm$ 0.5	–

According to WHO (2006) organic nitrogen and organic phosphorous are key elements for increasing crop yield and improving the ion-buffering capacity of soils. However, extreme levels of nutrients above 50,000 mg/L have negative impacts on crop growth whereby it leads to yellowish colouration and retardation of crop growth (FAO/WHO 2006). The organic nitrogen and organic phosphorous levels of dry sludge obtained in this study are within the allowable limits, however, they are too small, meaning that the sludge might be suitable for crops requiring lower levels of nutrients.

3.3.2. Agricultural suitability of dried sludge-based pathogens

About 3.5 $\pm$ 1 $\times$ 10^8 and 9.1 $\pm$ 1 $\times$ 10^8 CFU/100 mL of *E. coli* were retained on sludge found in the control and JC chamber; thus, the reduction is significant since the raw sludge had pathogens level of 7 $\pm$ 2 $\times$ 10^9 CFU/100 g. Even with such tremendous reduction of pathogens, the sludge is not fit for use as a soil conditioner since it exceeds both the national (TZS 1015 and TZS 11108) and international standards (FAO/WHO 2006) for agriculture which is as follows: nil (0) and $<$1000 respectively. Furthermore, the sludge had both higher total coliforms and helminthic eggs. It was 6.2 $\pm$ 5 $\times$ 10^9 and 11 $\pm$ 3 $\times$ 10^9 CFU/100 g of total coliforms for the control and JC dry sludge, respectively. Also, it has 10 CFU/100 g and 11 CFU/100 g for the control and JC sludge, respectively. Both values for total coliforms and helminthic eggs are above the standards since the standards prohibit their presence (nil) in soil fertilizer (Table 7).

The results imply that further treatment of dry FS is required to completely remove the *E. coli*, total coliforms and helminthic eggs, and hence make the sludge fully fit for agricultural use.

Table 7 | Pathogen levels for dry sludge suitable for agricultural purposes

Parameter	Raw	Control	JC	Tanzanian standards (organic fertilizer specifications)	FAO/WHO irrigation water quality
E. coli	$7 \pm 2 \times 10^9$ CFU/g	$3.5 \pm 1 \times 10^8$ CFU/100 g	$9.1 \pm 1 \times 10^8$CFU/100 g	Absent	<1000
TCs	$13 \pm 2 \times 10^{11}$ CFU/g	$6.2 \pm 5 \times 10^9$ CFU/100 g	$11 \pm 3 \times 10^9$ CFU/100 g	Absent	–
Helminthic eggs	11 CFU/100 g	10 CFU/100 g	11 CFU/100 g	Nil	Nil

4. CONCLUSION AND RECOMMENDATION

The study also found that the leachates from treated FS by JC are suitable for agricultural application. This is because most parameters such as salinity and sodium hazard are classified as a low class for JC which are suitable for agricultural applications. Moreover, the removal of *E. coli* by JC was from $7 \pm 2 \times 10^9$ CFU/g to $6 \pm 1 \times 10^2$ CFU/100 mL, which meets WHO agricultural standard application.

It was concluded that the treated dry sludge had a higher amount of both *E. coli* and helminthic eggs, where the number of helminthic eggs was 10 CFU/100 g and 11 CFU/100 g for control and JC sludge, respectively. Yet, the treated dry sludge is not fit for use as a soil conditioner.

Treating FS with JC is suitable for reducing salinity and sodium hazards in leachate. Hence, it is favourable for irrigation. Further treatment of dry sludge is required before being used for agriculture.

The research on how to treat FS using JC and other simple technology such as upflow anaerobic sludge blanket (UASB) reactor or thermal treatment using JC should be conducted.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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