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Efficacy Assessment of Decentralized Wastewater Treatment Systems in treating Faecal Sludge within Dar es Salaam City

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ABSTRACT

Dar es Salaam Water and Sewerage Authority (DAWASA) considers DEWATS as effective system for faecal sludge management especially from unplanned settlements. No study has been done in Tanzania to assess the treatment efficiency, adoptability and sustainability of the systems. That being the case, this study aimed at assessing the treatment efficiency of the Decentralized Treatment Systems installed within the city. Kigamboni and Mburahati DEWATS were selected as case study areas for the study whereby, quantitative method was used for data collection. The collected results showed that most of the physical parameters were within the allowable range specified by Tanzanian Standards for municipal wastewater discharge (TZS 860:2006). Nitrate and Phosphate levels were within the allowable range at both treatment plants. The BOD_5 and COD for Kigamboni DEWATS were four times higher than the maximum allowable safe limit for each. Both Kigamboni and Mburahati DEWATS failed to lower the coliform levels of faecal sludge to meet the maximum allowable discharge standard (10,000 cfu/100 ml) by having the effluent quality of 115,000 cfu/ 100 ml and 22,875,000 cfu/100 ml respectively. Addition of dosing chamber between the gravel filter and polishing dosed at 6mg/l of chlorine remediated the state.

Keywords: decentralized wastewater treatment systems (DEWATS); sanitation; faecal sludge

HIGHLIGHTS

- This study assessed the efficiency of Decentralized Wastewater Treatment Systems (DEWATS) in treating faecal sludge within Dar es Salaam City.
- The study utilized the quantitative methods of data collection and analysis, whereby the laboratory measurements and analysis were the key method utilized.
- Tungi and Mburahati DEWATS found within unplanned settlements in Dar es Salaam city, Tanzania were selected as case studies, since they are among of the few fully operating DEWATS within the city.
- The study found out that DEWATS are performing well in lowering the physical and nutrient parameters of faecal sludge as they lower the levels to fit the allowable discharge limits. However, they are not suitable in lowering the BOD_5, COD and total coliform concentration levels. Hence modification of the system should be thought to improve their efficiencies.

INTRODUCTION

Sanitation is the term derived to express the protection of public health by safely managing the human excreta [14]. Sustainable development goal (SDG) 6, target 6.2 calls upon ensuring availability and sustainable management of water and sanitation for all by 2030 [20]. However, the provision of safely managed sanitation is lagging behind so as supply of safe drinking water in both urban and rural settings of developing countries. The situation is more critical for urban than the rural areas due to high population density and unplanned settlement patterns of the areas [4, 16, 17].

Moreover, sanitation management refers to practice of promoting safely handling of faecal sludge (FS) and wastewater (WW), from generation to the disposal or recycling stage [12, 15, 23]. The Faecal sludge and wastewater are terminologies that mostly are used interchangeably, but the key difference between them is the viscous level of the faecal matter, whereby the viscous if referred as FS, while the watery faecal matter as Wastewater [10, 11, 15], however for this study the term faecal sludge has been adopted for use to mean the faecal matter/waste from onsite containment origins.

With an increasing demand of safely handling the generated WW in urban centers of developing countries like Tanzania, the Decentralized Wastwater Treatment Systems (DEWATS) has been adopted. The systems have been adopted in Dar es Salaam city, since they are suitable for small scale generation areas like; community households and institutions. Also, they are commonly installed within households from unplanned settlements and offers options for resource recovery [1, 4, 7, 8].

Despite the existing construction and operation manual of the DEWATS, and the adoption emphasis by the Dar es Salaam Water and Sanitation Authority (DAWASA), yet, several observational doubts has been claimed regarding the treatment efficiency of the systems [4, 8, 10, 22], which is thought to compromise the discharge standards set by the [21].

This study aimed at filling the gap by assessing the efficiency of the DEWATS in treating faecal sludge within Dar es Salaam city.

METHODS

Description of Study Area

This study was conducted Dar es Salaam city which lies at Latitude 6° 48' 8.4708'' S and longitude 39° 16' 46.4016'' E. The city is in the eastern coast shore of Tanzania and is considered the largest commercial center of the country. It is 1,393 km^2 by size and have a population of more than five (5) million people with growth rate of 5.6% in which 51.3% are male and 48.7% are female [13]. The rapid urbanization of the city led to an average of 75% people dwelling in unplanned settlements with more than half living a low life of less than US$ 1 a day [5, 19]. With that situation DEWATS has been introduced as pilots in some areas of the city. The Tungi and Mburahati wards (Figure 1) has been selected as case study areas to represent others for this study.

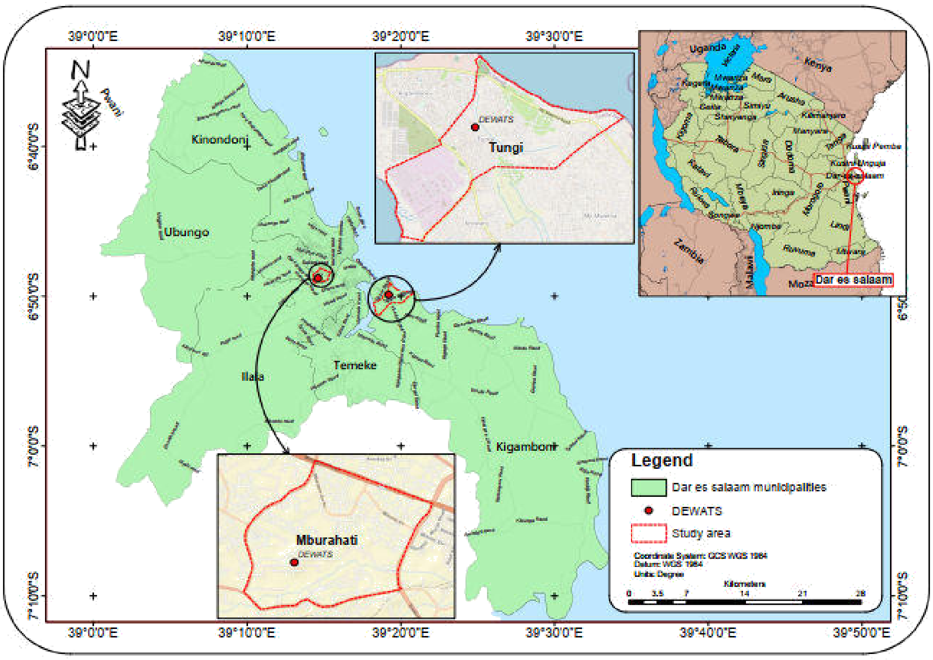

FIGURE 1: Location of study area
(Modified from google maps and Census shapefiles, 2012)

Study design

The study utilized both the quantitative and qualitative methods of data collection, however the quantitative method was the major method employed for the study. The laboratory analysis was used to analyze the FS loaded to the inlet chamber of the DEWATS, the intermediate FS qualities of the system and the effluent. The analysis assisted in establishing the treatment ability of the system. This method is considered the quantitative one, since it involves the manipulation and description of numerical data. The obtained data were compared with the provided treatment manual values of the system and the discharge standards provided by the United republic of Tanzania. Thereafter the treatment efficiency of the system was determined and discussed. On the other hand, the factors leading to either failure or success of the system were assessed by a qualitative tool called key informant interview with the systems operators. The laboratory data collected were statistically analyzed using the Microsoft excel version 2019, with XLSTAT plugin. While those form the key informant, interviews were analyzed using the SPSS version 20.

Field sampling

Sampling of the faecal sludge for both field and laboratory measurements were done at Tungi and Mburahati DEWATS. The field sampling and analysis was done for Temperature, dissolved oxygen, pH and Electrical conductivity parameters using dissolve oxygen meter equipped with thermometer, pH meter and electrical conductivity meter, respectively.

Sampling of the FS for laboratory measurements were done at the six sampling locations for Tungi (Figure 2), and Mburahati (Figure 3), using a one litre transparent sampling bottles. The samples were collected in such a way that a homogeneous representative sample were collected. The samples were stored in the cool box, whereby they were transported to the water quality laboratory at the Department of Water Resources Engineering.

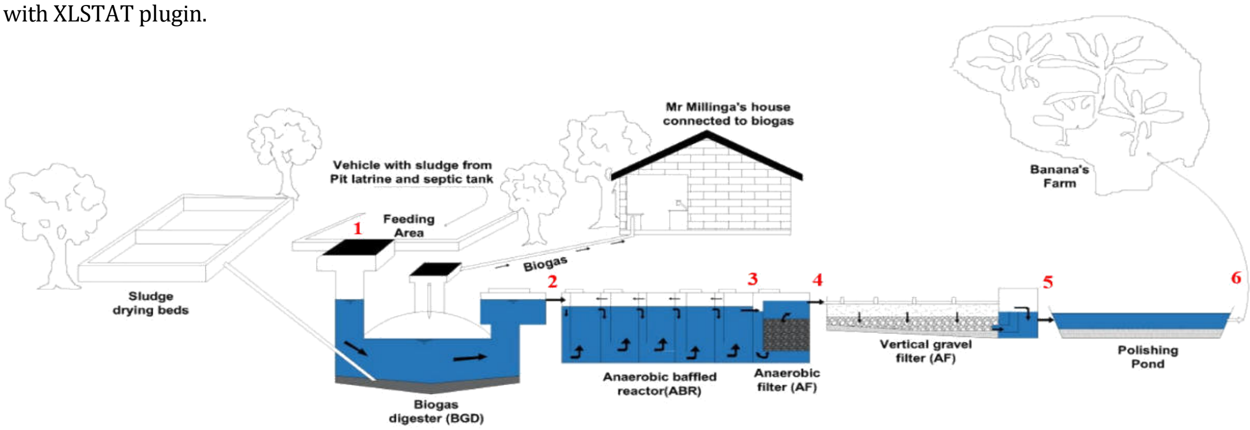

FIGURE 2: Faecal sludge sampling locations at Tungi DEWATS

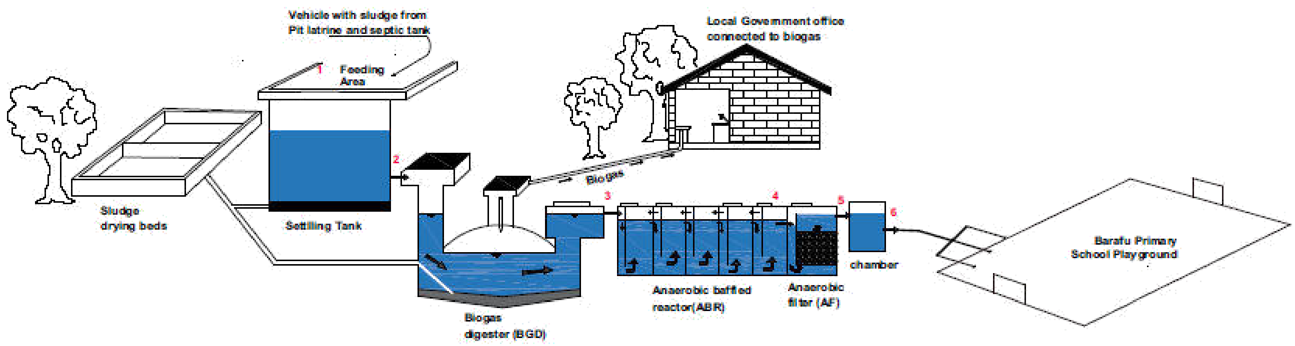

FIGURE 3: Faecal sludge sampling locations at Mburahati DEWATS

Laboratory measurements

The laboratory measurements were initiated started within four to six hours after sampling. The measurements were carried out based on the Standard methods for analysis of water and faecal sludge (Table 1).

TABLE 1: Standard methods for analysis of faecal sludge/faecal sludge

S/N	Parameter	Units	Standard Method [2]
1	DO, Temperature, EC, pH	Mg/l, ^0C, µS/cm	DO and Portable EC meters (insitu parameters)
2	Faecal indicating organisms	cfu/100ml	Membrane filtration
3	Total solids	(mg/L)	Gravimetric
4	BOD_5	mg/L	OXITOP Method
5	COD	mg/L	Closed Reflux Method
6	Nitrate (NO_3^-)	mg/L	Ultraviolet Spectrophotometric Method
7	(NH_4^+-N)	mg/L	Total Kjeldahl Nitrogen (TKN)
8	Organic Phosphorus	mg P/L	Colorimetric Method

Data analysis

The data collected were analyzed using the Microsoft excel version 2019 which is equipped with EXLSTAT version 2021 plugin. whereby the correlation of events was analyzed and presented using graphs and tables. Moreover, the SPSS version 20, was used to transcribe the data collected on the key informant interviews with the DEWATS operators. The interview guide questions were structured to gather information on the reasons leading to the over-served performance of the system.

Ethical Considerations

An introductory letter was granted by the University of Dar es Salaam, introducing the researcher to the operators of Tungi and Mburahati DEWATS. The researcher made the purpose of data collection open that the collected data were only for research purpose and that no data collected would be used against the subject offering them. Furthermore, the key informants were willing to withdraw from the interview session at any time if they feel uncomfortable or unwilling to offer data. This was done in order to ensure credibility and reliability of the data collected.

RESULTS AND DISCUSSIONS

Treatment potential of faecal sludge using DEWATS

The faecal sludge at Tungi and Mburahati ward is originating from the onsite containments, whereby the distribution of the source is that the 53% and 52% of the Tungi and Mburahati residents respectively rely on improved pit latrines for their sanitation needs. Also, about 37% and 43% of the Tungi and Mburahati residents respectively rely on the septic tanks. Since the whole population is not served by sewerage networks and the settlements are unplanned, then the dominance of onsite containments is expected for near future. This strengthen the need for DEWATS at the respective sites. Figure 4 shows the source of faecal sludge at Tungi and Mburahati wards.

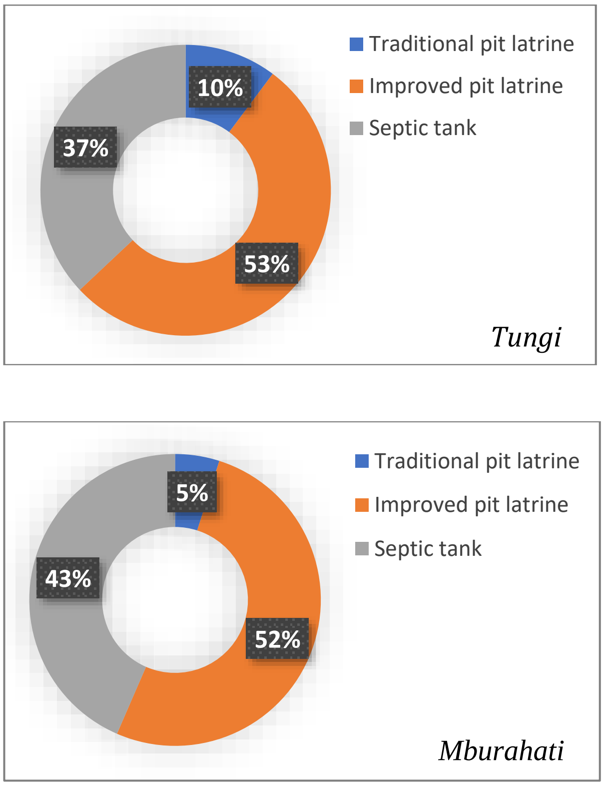

FIGURE 4: Sources of faecal sludge loaded the DEWATS

The source of faecal sludge has prediction on the quality, whereby that from septic tanks is claimed to have less parameters than that from the pit latrine [2,12]. This is due to the fact that the septic tanks are sealed and don't allow for water percolations, hence the faecal sludge is waterier than that from the pit latrines that are slurry, due to percolation of water on the pit walls and bottom unless if the pit is lined. However, for this study the faecal sludge collected were mixed at the inlet/feeding area, because it is not possible to treat faecal sludge as discrete from sources but as mixture. So, the quality characterization results are based on the mixed faecal sludge.

Physical Parameters

The physical parameters under analysis includes the pH, Temperature (0C) and Electrical Conductivity (EC) (µs/cm). The pH plays a significant role in faecal sludge treatment systems whereby there is a marginal range of pH for microorganisms to function well. The microbial faecal sludge treatment is accomplished in a pH range of 6.5 to 8.5, where most microbial thrives [6, 9, 18]. The pH levels for both the Tungi and Mburahati DEWATS were within the allowable limits. This signifies that the processes were altered by the pH variations and also that the effluent quality were within the allowable limits.

Both the Tungi and Mburahati DEWATS operate within the allowable temperature ranges i.e., 20 to 35 0C. The temperature variations affect the reduction in COD within the system, whereby the decrease in temperature decreases the systems efficiency to reduce the COD [6]. The DEWATS anaerobic processes are very sensitive to temperature variations so having reasonable values imply that the system operates as required [3, 6, 18].

The Tungi DEWATS effluent EC concentration is 1.5 times higher than the allowable TZS 860:2006 limit which is 2700 µS/cm. This means that the effluent has high concentration of ions, that when discharges or reused may cause health harm to users. The Mburahati DEWATS have EC 90 µS/cm higher than the allowable limit, this is tolerable as it has less health effects to users.

BOD^5 and COD

The mean effluent BOD_5 recorded at Tungi DEWATS was higher (129 mg/l) than the recommended value (30 mg/l). The reading is 4 times higher than the standard value by TZS 860:2006 (30 mg/l).

On the other hand, the mean effluent BOD_5 at Mburahati is 47 mg/l. The values signify that the Mburahati has better capacity of reducing BOD_5 than the Tungi DEWATS. In this sense there is no harmony in treatment between two systems.

The mean effluent COD at Tungi DEWATS was found to be 235 mg/l which is 4 times the allowable limit (60 mg/l). On the other hand, the mean COD value for Mburahati was 94 mg/l which is lower than that of Tungi but higher than the allowed limit. According to BORDA, (2017), COD is a good indicator of breakdown of biological matter in DEWATS process. The results show that there is poor breakdown of biological matter in both treatments, though the situation much worse for Tungi than Mburahati system.

Nutrients

The nutriens for this section include the nitrate and phosphate. The mean nitrate effluent concentrations for both Tungi and Mburahati DEWATS were within the allowable maximum limit (20 mg/l). The mean values are 17 mg/l and 32 mg/l for Tungi and Mburahati DEWATS respectively. The higher nitrates concentration levels have significant impacts on the receiving water bodies where as it promotes the eutrophication.

The phosphate concentration levels have the same effect as nitrate when in excess. The Tungi DEWATS have a mean concentration of 12 mg/l which is 2 mg/l above the allowable maximum limit. However, the excess concentration level has no effect since the effluent is utilized for agriculture. On the other hand, the mean effluent phosphate concentration at Mburahati DEWATS (7 mg/l) was 3 mg/l below the allowable maximum limit. This signifies that the system has ability of reducing the nutrients levels to suit both discharge and re-use options.

Total coliforms

The mean total coliform concentration levels for Tungi and Mburahati were 115,000 cfu/100 ml and 22,875,000 cfu/100 ml respectively. The values are way higher than the allowable maximum discharge limits of 10,000 cfu/100 ml. Since the mean values are 12 and 2288 times higher than the allowable maximum limits (Figure 5 and 6), then it can be claimed that DEWATS might be suitable for lowering other faecal sludge parameters but not faecal indicating pathogens (Total coliforms).

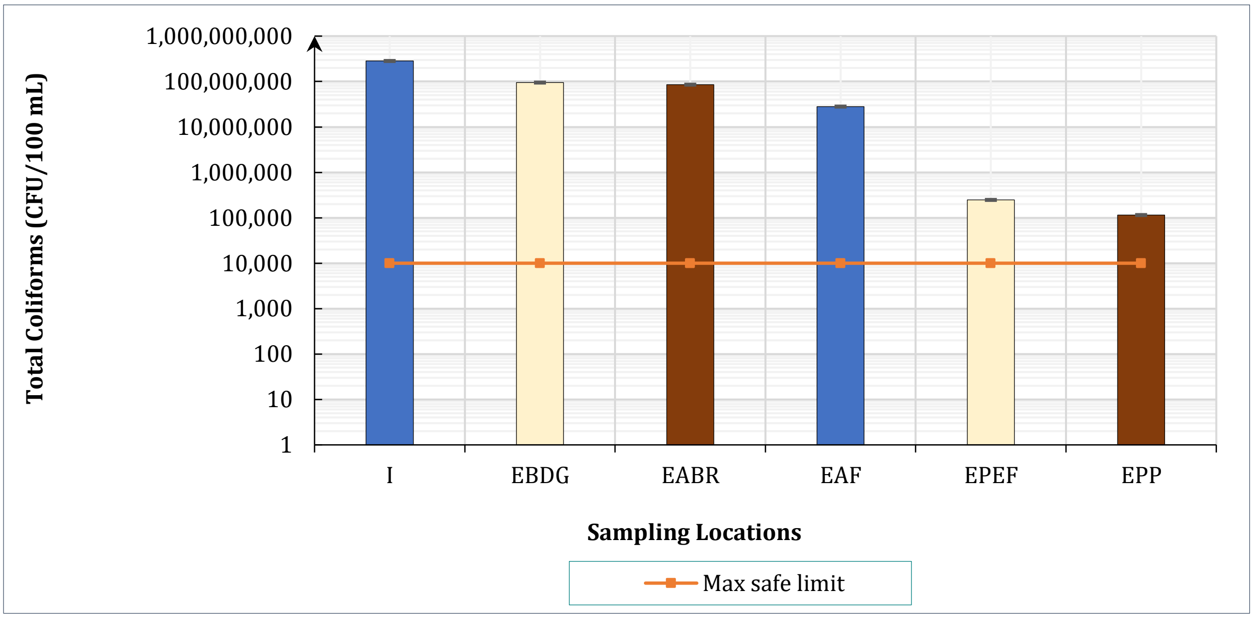

FIGURE 5: Total Coliforms trend for treatment compartments at Kigamboni

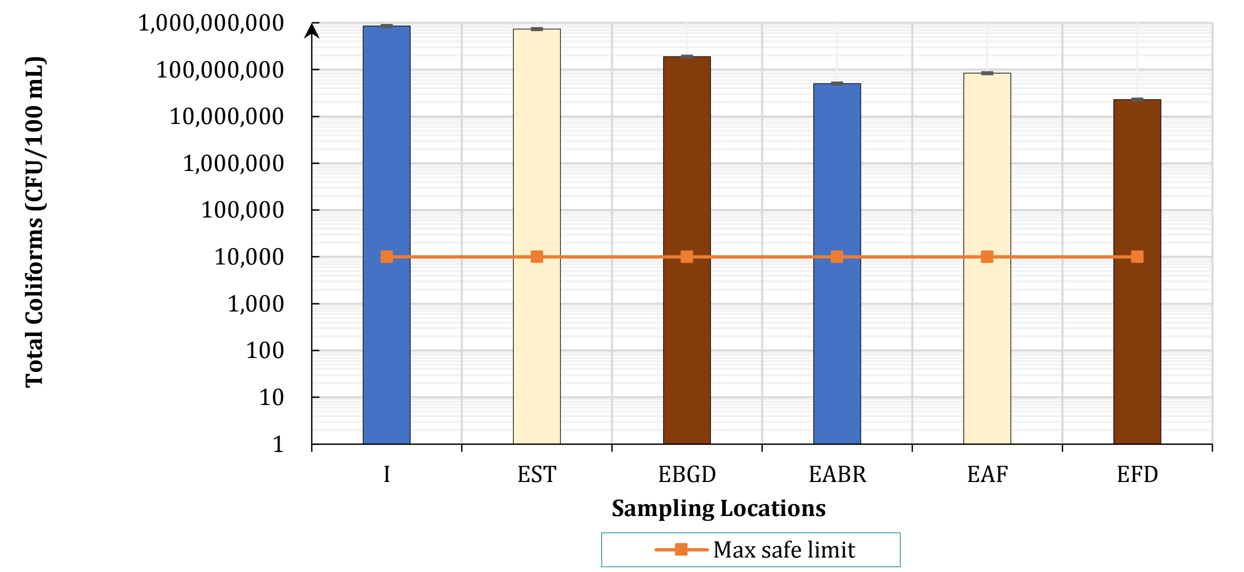

FIGURE 6: Total Coliforms trend for treatment compartments at Mburahati

Figure 5 and 6 signifies that the systems failed to lower the coliforms to safe limits, hence allows for receptor pollution where the effluent is discharged or consumed. Hence, they pose health threat to users of the effluent.

The results from the key informant interviews revealed that the failure of the system to operate as required is suspected to be due to poor technology knowhow on operations of the systems as they are overloaded. However, this might not be the standing reason for the failure, because even during the low inflow of the faecal sludge, yet the mean concentration levels were recorded to be above the allowable maximum limits.

Faecal sludge treatment efficiency of DEWATS

DEWATSS are designed to remove 90% of BOD_5 at the Anaerobic Baffled Reactors, and 75 to 90% of the remaining at the Gravel filters. Also, the over 95 of total coliforms are expected to be removed by Anaerobic Baffled Reactor and 40 to 75% by gravel filters [3]. Tungi DEWATS is operating way below the design expectations, whereby, the Anaerobic Baffled Reactors removes only 49% and 10% of BOD_5 and total coliforms, instead of 90% and >95%, respectively. Also, the gravel filters only reduce the total coliforms (50%) while the design is 40 to 75% (Table 2).

TABLE 2: Treatment efficiency of Tungi DEWATS

S/N	Parameter	Treatment compartment	Designed removal efficiency (%)	Actual removal efficiency (%)	Final Effluent quality	Required Standard (TZS 860:2006)
1	BOD_5	Anaerobic Baffled Reactor	90	49	129 mg/l	30 mg/l
		Gravel filters	75 - 90	50		
2	Total coliforms	Anaerobic Baffled Reactor	> 95	10	115,000 Cfu/100 ml	10,000 Cfu/100 ml
		Gravel filters	40 – 75	50		

On the other hand, the Anaerobic Baffled Reactors at Mburahati DEWATS also failed to meet treatment standards whereby it only reduces 6% instead of 90% BOD5.

Unlike Tungi DEWATS the Mburahati DEWATS significantly reduced the total coliform concentration levels to 73% which is within the provided design. However, the influent faecal sludge was of very high strength, as a result the reduction efficacy seemed ineffective (Table 3).

TABLE 3: Treatment efficiency of Mburahati DEWATS

S/N	Parameter	Treatment compartment	Designed removal efficiency (%)	Actual removal efficiency (%)	Final Effluent quality	Required Standard (TZS 860:2006)
1	BOD_5	Anaerobic Baffled Reactor	90	6	47 mg/l	30 mg/l
		Gravel filters	75 - 90	87		
2	Total coliforms	Anaerobic Baffled Reactor	> 95	73	22,875,000 Cfu/100 ml	10,000 Cfu/100 ml
		Gravel filters	40 – 75	73		

That being the case, an additional unit is proposed to be installed within the DEWATS to lower the total coliform levels. The unit proposed is called the dosing chamber that should be installed between the gravel filter and the polishing pond. From a serial dossing batch experiment, it was revealed that an optimal 6mg/l dose of chlorine is sufficient remediate the state by lowering the levels to the allowable limits (10,000 cfu/100ml).

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

About 63% of the Tungi residents rely on pit latrines while the remaining 37% rely on septic tanks. Moreover, about 57% and 43% of the Mburahati residents rely on pit and septic tank tanks respectively. These are considered as onsite sanitation systems that generate domestic faecal sludge. The generated faecal sludge is treated using DEWATS at each respective area. The DEWATS is suitable for lowering the physical parameters of faecal sludge as it lowers the concentration to the acceptable discharge standards, which are; 6.5 to 8.5, 20 to 35 0C and 2700 µS/cm, for pH, temperature and Electronic conductivity respectively. The system was found to perform well also on lowering the nutrients concentrations, as it lowered them to fit the allowable standards which are; 20 mg/l and 10 mg/l for nitrate and phosphate respectively.

However, the system was found not to perform well in lowering the BOD5, COD and Total coliforms of the faecal sludge. The mean effluent BOD5 and COD were both 4 times higher than the allowable discharge standards. Moreover, the mean effluent total coliforms for Tungi and Mburahati DEWATS were 12 times higher and 2288 times higher than the allowable standard (10,000 mg/l). So, it can be concluded that DEWATS are not suitable for lowering the BOD5, COD and Total coliforms of the domestic faecal sludge, unless additional dosing chamber is installed between the gravel filter and polishing pond of the system.

Recommendations

More studies should be done to determine the rout cause of DEWATS failure in lowering the BOD5, COD and total coliforms. Because the results reported under this study revealed that even though systems operators' faults are sources as the key factor for the phenomenon, yet the effect of varying hydraulic loading rates of the DEWATS should be studded.

ACKNOWLEDGEMENT

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DATA AVAILABILITY STATEMENT

All applicable information/data are available as supplementary material if required.

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