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harberth Mkangala

harbertmkangala@gmail.com

Mbeya University of Science and Technology

Joel Mbwiga

Mbeya University of Science and Technology

Masoud Kamoleka

Mbeya University of Science and Technology

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Harberth Mkangala[1,2,]

[1]Department of Mechanical and Industrial Engineering, MUST-Main Campus

[2]Mbeya University of Science and Technology, P.O. Box 131, Mbeya, Tanzania

Email: harbertmkangala@gmail.com

Corresponding Author

Joel Mbwiga [1,2]

[2]Department of Mechanical and Industrial Engineering, MUST-Main Campus

[1]Mbeya University of Science and Technology, P.O. Box 131, Mbeya, Tanzania

Email: jmbwiga@gmail.com

Masoud Kamoleka Mlela[2,3,]

[3]Department of Mechanical and Industrial Engineering, MUST-Main Campus

[2]Mbeya University of Science and Technology, P.O. Box 131, Mbeya, Tanzania

Email: masoudkamoleka@gmail.com,

Abstract

Sewage sludge was by-product of wastewater treatment that can be a potential resource for energy production particularly for community and household families. Sewage sludge from Kalobe has no any economic benefit despite the organic matters it contains potential to producing energy. Mbeya Water Supply and Sanitation Authority incur a lot of money to treat the sewage to safeguard the environment by introducing biogas production plant would add value to the sewage sludge which is currently a waste.

This study focuses on physicochemical characterization of sewage sludge to evaluate its suitability for biogas production through anaerobic digestion. Parameters including total solids (TS), volatile solids (VS), pH, temperature, COD, BOD, DO and EC were analyzed to

determine the sludge's potential as a feedstock for biogas generation. The results revealed moderate organic content (VSS: 191-300 mg/L), unstable pH levels (8.4-9.2) indicated the presence alkalinity condition of the sewage sludge, suggesting the need of pre-treatment in order to obtain required standard pH levels (6.5-7.5) and optimal suitable temperature conditions of 370C which are conducive to anaerobic digestion. However, the high COD/BOD ratio (1325 mg/L COD and 679.7 mg/L BOD) indicated the presence of non-biodegradable organic matter, suggesting the need for pre-treatment to enhance biodegradability. This research contributes to the growing body of knowledge on sustainable energy solutions and waste management particularly in developing regions like Tanzania, where energy access and waste disposal remain critical challenges.

Keywords: Sewage sludge, Characterization, pH, Total Suspended Solids and Temperature.

Introduction

Background Information

Sewage sludge was the by-product of wastewater treatment has gained significant attention as a potential resource for renewable energy production particularly biogas. With the global energy crisis and increasing environmental concerns the need for sustainable energy sources has become paramount. A study carried out by Appels et. al., (2008) shows that biogas produced through anaerobic digestion of organic matter from sewage sludge offers a dual benefit; it provides energy source and helps to manage waste effectively. Increasing urbanization and industrialization in Mbeya City have led to a rise in wastewater generation necessitating efficient sludge management strategies. Kalobe Water Stabilization Pond, a critical component of the city's wastewater treatment infrastructures, produces significant amounts of sludge. Characterizing this sludge is essential to determining its suitability for biogas production and managing potential risk from currently large piles of solid wastes from dried sludge within their premises.

This study aims to measure key parameters of sewage sludge such as organic content, moisture, nutrient balance and toxicity, which are critical for optimizing biogas

production. The findings will contribute to the broader discourse on sustainable waste management and renewable energy generation, particularly in developing regions like Tanzania, where energy access remains a challenge.

Sewage Sludge and Biogas Production

Sewage sludge is a rich source of organic matter, making it a suitable feedstock for anaerobic digestion, a process that converts organic waste into biogas (Appels et al., 2008). Metcalf & Eddy, (2014) also in their study, indicates that biogas, primarily composed of methane (CH_4) and carbon dioxide (CO_2), is a renewable energy source that can be used for electricity generation, heating, and as a vehicle fuel. According research by Tchobanoglous et al., (2003), anaerobic digestion process involves four key stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis, each requiring specific acidic, temperature and suspended solid conditions as well as microbial activity.

Environmental and Economic Implications

Improper disposal of sewage sludge can lead to environmental pollution, including soil and water contamination due to heavy trace metals and pathogens (Singh & Agrawal, 2008). However, when managed effectively, sewage sludge can contribute to environmental conservation by reducing landfill use and greenhouse gas emissions. Economically, biogas production from the sludge can offset energy costs and provide a revenue stream through energy sales and by-products like digestate, which can be used as fertilizer (Werther & Ogada, 1999).

Parameters for Biogas Production

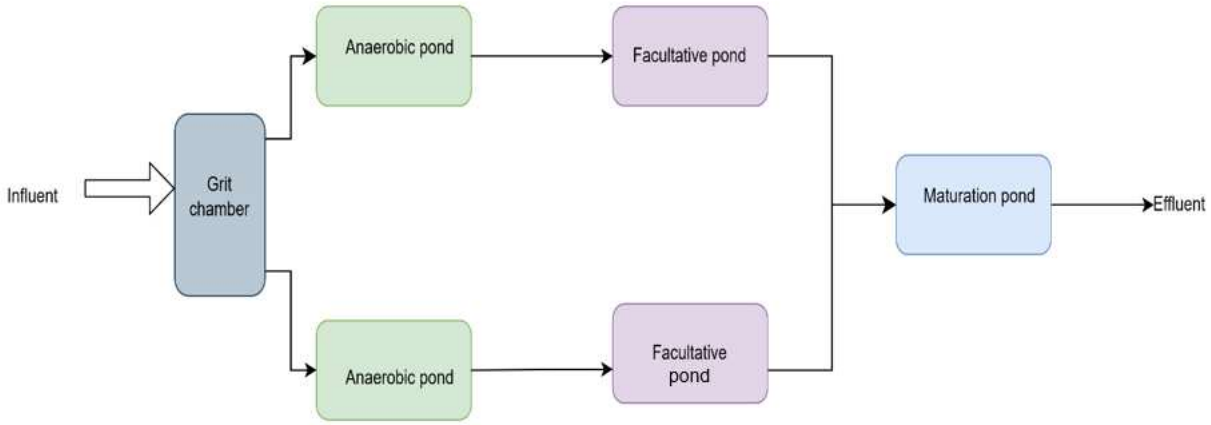
Biogas production depends on several characteristics of sewage sludge, including organic content measured as Total Solids (TS) and Volatile Solids (VS). Organic content determines amount of biodegradable material available for digestion (Metcalf & Eddy, 2014). Moisture content is a paramount parameter that is necessary for microbial activity. Optimal moisture levels of (90-95%) is recommended. The third parameter is nutrient balance, which require a balanced ration of carbon-to-nitrogen (C/N) of (20-30) is essential for microbial growth. The fourth one is Toxicity that low levels of heavy trace metals and inhibitors are required in order to avoid toxicity and process inhibition (Singh and Agrawal, 2008).

Materials and Methods

Study Area

The research was conducted at the Kalobe Wastewater Stabilization Ponds in Mbeya City, Tanzania. Kalobe wastewater Stabilization Ponds is managed by Mbeya Water Supply and Sanitation Authority. The total Sewer network is 138 km with total coverage area of 14.8% of Mbeya city. The Pond serves 12 wards in Mbeya city which are Sinde, Isanga, Sisimba, Ghana, Mbalizi road, Forest, Iyunga, Maanga, Old Airport, Ruanda, Kalobe and Itende. Kalobe WSP contain five ponds with two anaerobic ponds, two facultative ponds and one maturation pond as layout illustrated in Figure 1. Kalobe WSP designed to treat estimated average inflow (Influent) of 150 m^3/hr and estimated average outflow (effluent) of 120 m^3/hr.

Figure 1 :Layout of Kalobe WSP



Measurement of Key Parameters

Physic-Chemical Parameters

pH was measured using a pH meter WTW 3310, while Total suspended solids (TSS) was determined by differential weighing through filtration on a glass fiber filter (GFC) method followed by oven drying at 105 °C for 2 h. Total solids (TS) was determined by oven drying at 105 °C after 24 h. Volatile solids (VS) was determined by oven combustion at 550 °C for 2 h, Chemical oxygen demand (COD) was determined by using Ion selective methods with HACH DR 3900 UV/VIS Spectrophotometer and

COD Reactor according to the standard method AFNOR T-90-101. Biochemical oxygen demand (BOD) was determined by using Ion selective method and Winkler method. Total carbon (TC) was estimated using the Walkley and Black method. Temperature was monitored using a thermometer. Nitrogen balance (N) was determined using Kjeldahl method, while Total phosphorus (TP) was determined using the Photometric Molybdovanadate Method with extraction. Major ions like Orthophosphate ($PO_3^{-4}O_4^{3-}$), Ammonium (NH^{+4}), Nitrite (NO^{-2}) and Nitrate (NO^{-3}) were determined using colorimetric methods and read using a HACH DR 3900 spectrophotometer. Volatile Fatty Acid (VFA) And Total Alkalinity (TA) concentrations were determined through titration using the Biogas Titrator for FOS/TAC Analyses, Hach LANGE, employing the method outlined by NORDMANN.

Results and Discussion

Data collected from Kalobe Water Stabilization Pond was analyzed to determine the suitability of the sludge for biogas production. Key parameters such as COD (Chemical Oxygen Demand), BOD (Biological Oxygen Demand), VSS (Volatile Suspended Solids), and pH was evaluated. The SWS presented the following physical-chemical characteristics: pH (8.4–9.31), COD (1310.7 ± 12 mg L−1), BOD (674 ± 8 mg L−1), EC (2363 ± 11 mgL−1), TFS (1414 ± 5 mg L−1), DO (0.1 ± 0.09 mg L−1), and VSS (150 ± 50 mg L−1) as shown in figures 2 to 5. Temperature directly affects speed of biological and chemical reactions that take place in treatment plant. More specifically it influences the activity of the micro-organisms responsible for the decomposition of organic matter (Alvaréz, and Lidén, 2008). Higher temperatures generally lead to higher reaction rates, which can improve treatment efficiency. In addition, temperature affects the solubility of gases which has an impact on the release of potentially harmful compounds. Temperature control in the sludge treatment ensures optimal conditions for biological processes and helps maintain overall system performance. pH is an important factor in the sludge treatment processes because of its influence on the performance and efficiency of the process. It plays an important role in chemical and biological wastewater treatment systems Baldé, et. al., 2016). A pH that is too basic inhibits the action of micro-organisms. If the pH is too acidic, it

prevents certain bacteria from functioning and causes unpleasant smells. Total nitrogen encompasses all forms of nitrogen in the sludge samples, such as organic nitrogen, ammonium, and nitrate/nitrite. It provides a comprehensive measure of the total nitrogen content of a given substance or environment. The most critical parameters for assessing the suitability of a substrate for AD are pH, TS, VS, C/ N, and inhibitory parameters such as ammonium (NH4+).

Results from analysis (fig.2) revealed that pH remains within the unstable range (8.4-9.31) for anaerobic digestion, and the temperature is stable which favoring microbial activity results analyzed from (fig.3). The results of the PH are of the same order compared to those obtained by Torres, and Osorio, (2009) from Cameroon and Accra of which, from Cameroon is (8.96 ± 0.23). The pH plays an important role in the AD process. pH influences chemical equilibrium of ammonia (NH3), hydrogen sulfide (H2S) and volatile fatty acids (VFA) which could inhibit microorganisms' activities. According to study by Atuanya, and Aigbirior (2002), ideal pH range for AD would be between 6.5 and 8 hence it required pretreatment in order to stabilize Ph level

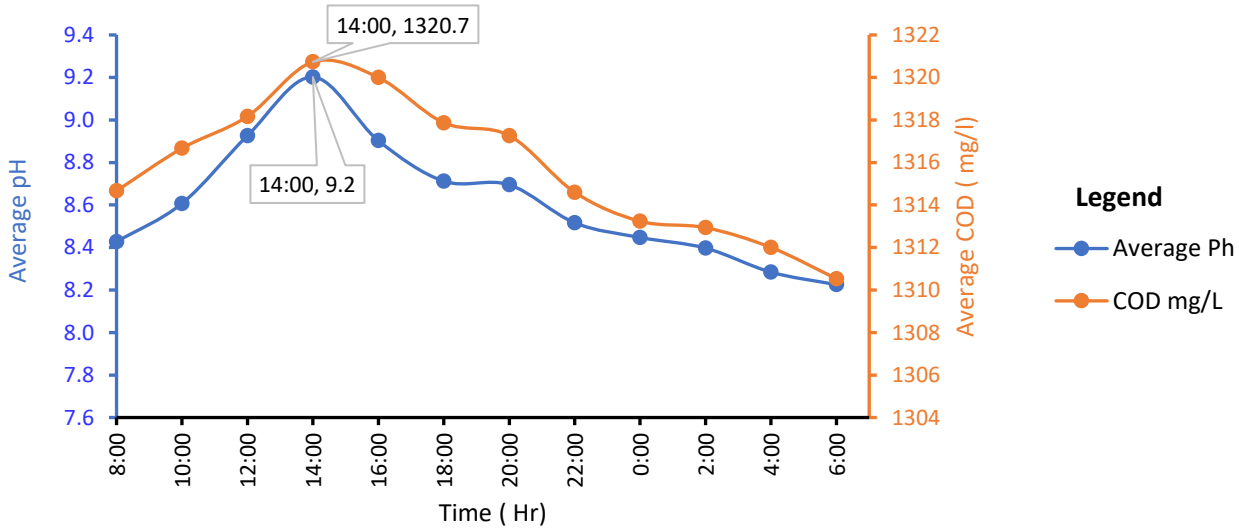


Figure 2: pH and COD against time for Sewage Sludge from Kalobe Treatment Pond

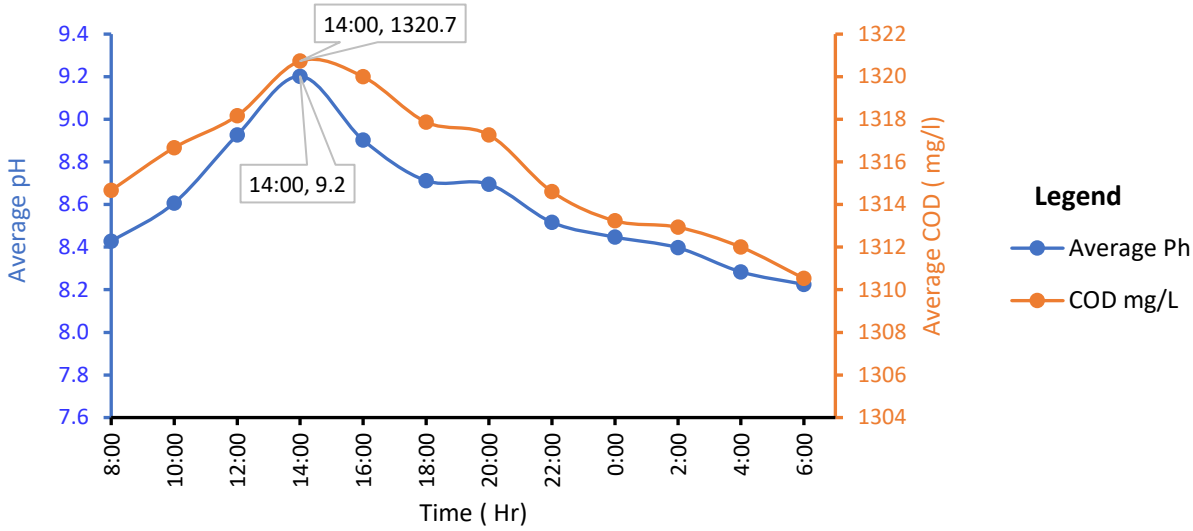
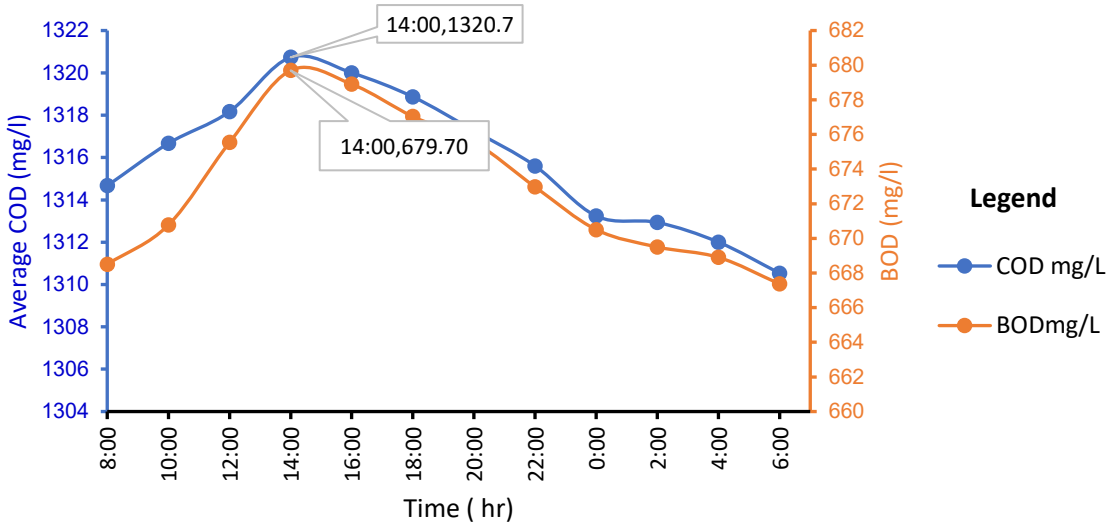


Figure 3: pH and Temperature with time

Biodegradability

From the graph it indicates that the sludge is not easily biodegradable. Low biodegradability, characterized by a high COD/BOD5 ratio indicates that the sludge has been stored for long periods or that it contains a significant amount of inorganic The biodegradability of organic matter depends directly on the biochemical composition of the substrate to be treated. The COD and BOD values are shown Figure 4. An indicator of the degree of biodegradability of the sludge is the obtained in figure 4 shows a great variability of COD and BOD. The COD levels range between 1305 and 1325 mg/L, while biodegradable organic matter which may require pretreatment for optimal biogas yield as illustrated in figure 4. BOD levels are around 679.7 mg/L. The high COD/BOD ratio suggests the presence of non- COD/BOD ratio. It provides the basis for determining whether they can be treated biologically. If this ratio is not less than 3, the sample can be said to be readily biodegradable, otherwise it is not (Igoni, et., al 2008). The analytical results found a biodegradable results in the literature for instant for Ouagadougou with an average of 6.1 ± 4.2 on composite samples and others found in Ghana on PT (Díaz, et,. al, 2015). On the other hand our results were not the same as those found in Cameroon (2.31 ± 0.26) on PT (Gerardi, 2003).

Figure 4: COD and BOD vs Time



Volatile Suspended Solids (VSS): VSS levels range between 191 and 300 mg/L, indicating a moderate organic content suitable for biogas production as indicated in figure 5.

Figure 5: VSS and DO against Time

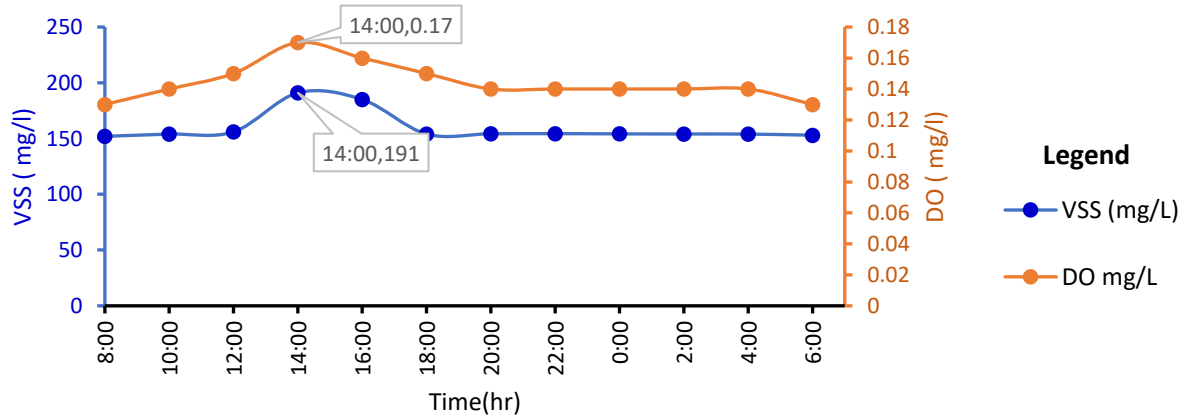
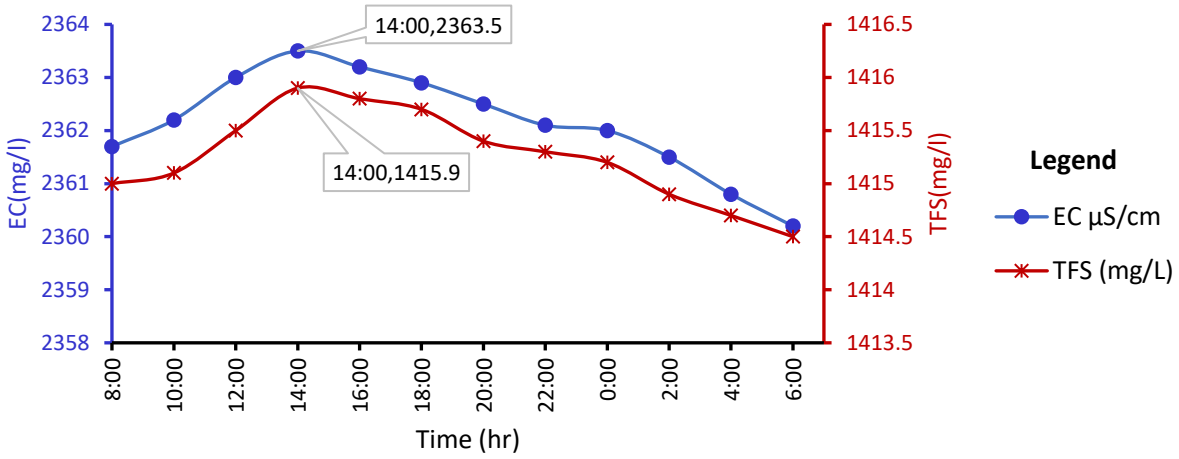


Figure 6: EC and TFS against Time



The Electrical Conductivity (EC) and Total Fixed Solids (TFS) values range between 1413.5 and 2364 µS/cm, indicating moderate salinity while TFS levels are consistent, suggesting stable inorganic content as depicted in figure 6.

The data suggests that the sludge from the Kalobe Water Stabilization Pond has significant potential for biogas production. However, the presence of non-biodegradable organic matter (indicated by the high COD/BOD ratio) may require pretreatment to enhance biodegradability. The unstable pH may require pretreatment to in order to improve pH of the sewage sludge and temperature are favorable for anaerobic digestion, while the moderate VSS levels indicate sufficient organic content for microbial activity.

Conclusion

This research demonstrated that sewage sludge from the Kalobe Water Stabilization Pond is potential as a feedstock for biogas production. The sludge exhibits favorable characteristics, including moderate organic content, unstable pH, and optimal temperature. However, unstable pH and the high COD/BOD ratio suggest the need for pretreatment to improve biodegradability and alkalinity. Biogas production from this sludge can address energy shortages in Mbeya City while contributing to environmental conservation through sustainable waste management.

Recommendations

It is recommended to implement pretreatment methods such as thermal or chemical hydrolysis to enhance the biodegradability of non-biodegradable organic matter. Optimize anaerobic digestion conditions by maintaining optimal pH (6.5-7.5) and temperature (35-37°C) (Karatop et al,. 2016). Furthermore, economic feasibility to be conducted in order to evaluate economic viability of biogas production from the sludge and supporting policy may be advocated to promote energy generation from waste, including incentives for biogas production (Karatop et al,. 2016).

List of Abbreviation

APHA ……. American Public Health Association

BOD ……. Biochemical Oxygen Demand

COD …… Chemical Oxygen Demand

CRDS ……...Cavity Ringdown Spectrometer

DO ……...Dissolved Oxygen

EC ……Electrical Conductivity

KWSP …….…...Kalobe Wastewater Stabilization Ponds

LED …… …. Light Emitting Diode

PPE ……...Personal Protective Equipment

SDG ……. Sustainable Development Goal

TANESCO …… Tanzania Electric Supply Company Limited

TS ……Total Solids

TSS ……. Total Suspended Solids

URT ……United Republic of Tanzania

USEPA ……..…United States Environmental Protection Agency

VFAs …… Volatile Fatty Acids

VS …… Volatile Solids

VSS …… Volatile Suspended Solids

WSSA …… Water Supply and Sanitation Authority

Declarations

Ethics approval and consent to participate

Not applicable.

Availability of Data and Materials

The datasets employed and examined in this study can be obtained from the corresponding author upon a reasonable request. Lake Rukwa Basin Water Board provided calibrated equipment's for measuring the physic-chemical parameters of the sewage sludge at Kalobe waste water stabilization ponds. Also, we got sewage sludge data from the Mbeya Water Supply and Sanitation Authority (Mbeya UWSA) at Kalobe waste water stabilization ponds for comparisons. To access these datasets may depend on the permissions and data-sharing policies of the organizations that own them.

Competing Interests

The authors declare that they have no competing interests

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Authors' Contributions

All authors read and approved the final manuscript.

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