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Assessment of Adaptation and Diffusion of Biogas Technology A Case Study of Dar es salaam City, Tanzania

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ABSTRACT

This study investigated the adaptation and diffusion of biogas technology in Dar es Salaam, driven by the increasing need for sustainable energy solutions. The study's is rooted in addressing urban energy challenges and providing an eco-friendly waste management alternative. Various factors, including socioeconomic variables, technical efficiencies, and community-level acceptability, were examined to assess the technology's adaptability and diffusion. Data collection methods and techniques included lab analysis using American public health association (APHA) standard methods, interviews, questionnaire administration the data analysis was undertaken using statistical package for the social sciences (SPSS) with a sample size comprising 100 household heads from Mburahati, 50 biogas technology adopters, 50 non-adopters, and 16 key informants. The findings disclosed that 40% of respondents learned about biogas technology through their friends and neighbours who had already adopted it, while 6% discovered it through exhibitions. About 54% of the respondents who were aware of the biogas technology received the information from sources including seminars, biogas researchers, extension officers, and technicians who had adopted the technology. The most influential factor affecting the adoption of biogas technology was the community's income level, accounting for 50.4% of all factors. Inadequate funds were a significant challenge for 75% of respondents, and 64.05% hadn't attended training sessions or seminars related to biogas technology, despite their importance, this is because most them did not hear about these trainings, and seminars although they were aware with the technology. The study also found that neutral pH levels enhanced anaerobic digestion efficiency, leading to efficient biogas production. Efficiency rates varied among case studies, with the International School of Tanganyika achieving rates between 93.52% and 99.35%, Mburahati DEWATs ranging from 82.15% to 98.24%, and CCBRT ranging from 81.98% to 99.61%. The higher the efficiency of biogas technology, the high higher the adoptability of the systems by the majority and vice versa. In conclusion, the study revealed a low level of biogas technology adoption and diffusion in Dar es Salaam. To enhance this process, the government should review and establish a supportive environment for the advancement of this technology.

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INTRODUCTION

The wastewater generated from different sources including domestic, industrial, and agriculture can be recovered to produce valuable resources such as alternative energy source, and water for irrigation purpose. Amidst concerns about inadequate water access and sanitation, biogas technology emerges as a promising wastewater treatment method (UN, 2010). The potential of biogas technology to provide sustainable waste management and energy challenges has gained significant attention globally (Niwagaba *et. al*., 2020). Biogas defined as a renewable energy source derived from the anaerobic digestion of organic materials such as agriculture, human and animal wastes with global sustainability goals particularly sustainable goal (SDG 7) which advocates for clean and affordable source of energy for all with the aim of reducing greenhouse gas emissions.

Despite its potential, Dar es Salaam, Tanzania faces several challenges hindering the adoption and diffusion of biogas technology. The city's heavy reliance on traditional biomass energy sources, mainly firewood and charcoal, increases deforestation and environmental degradation. Additionally, waste management systems are lacking, contributing to pollution and health hazards to the environment and public health respectively. These challenges require the urgency need for the adoption of innovative solutions particularly biogas technology. Biogas technology provides an alternative energy source, countering issues like fuel wood scarcity and urbanization-related energy challenges (Doggart, 2017). Biogas technology adoption and diffusion has been sluggish in many parts of Tanzania due to lack of knowledge or awareness on the technology and the capital cost of implementing biogas technology (Ashraf *et. al*., 2019). Yet, Biogas technology offers an alternative energy source, mitigating reliance on unsustainable biomass fuels while simultaneously improving waste management systems which are directly linked to social and environmental aspect (Cheng *et. al*., 2014). This study therefore, aims at assessing the adaptation and diffusion of biogas technology in Dar es Salaam by addressing the current level of adaptation and diffusion of biogas technology, to identify factors influencing its adoption and propose strategies to enhance adoption and diffusion. (Ashraf et al., 2019).

METHODS AND MATERIAL

Description of the study area

The study area included the CCBRT Wastewater Treatment Plant, International School of Tanganyika Wastewater Treatment Plant Upanga, and Mburahati Ward, all situated in Ubungo and Kinondoni Districts of Dar es Salaam, Tanzania. These sites were selected to check a diverse operational scale from the health care facility (CCBRT), education institution (IST), and the community level treatment system (Mburahati) CCBRT, a leading provider of disability and rehabilitation services, handles a substantial daily wastewater volume of approximately 790,000 litres, necessitating the establishment of a wastewater treatment plant (biogas plant) to protect hospital beneficiaries. International school of Tanganyika Wastewater Treatment Plant in Upanga is located within the school campus and in 2023 the school had 1023 enrolled students. The biogas produced from this system is supplied to the BBQ and the system is working well, with the biogas burning well.

Mburahati, as of the 2022 census, is an administrative ward inhabited by 34,123 individuals 16,784 men and 17,339 women. The DEWATS project implementation in Mburahati, carried out by BORDA, IHI & TMC from November 2017 to February 2018, was allocated a budget of 150,000,000.00 TZS. The project aimed to address a daily wastewater volume of 10m3, benefiting 40,000 individuals in

Mburahati. The system layout featured a ramp, feeding tank, biogas dome, anaerobic baffled reactor (ABR), and sludge drying beds, banana plantation, and office, store, and toilet facilities. The case study involved in this study are displayed in Figure 1 showing the selected areas as shown in legend on the map.

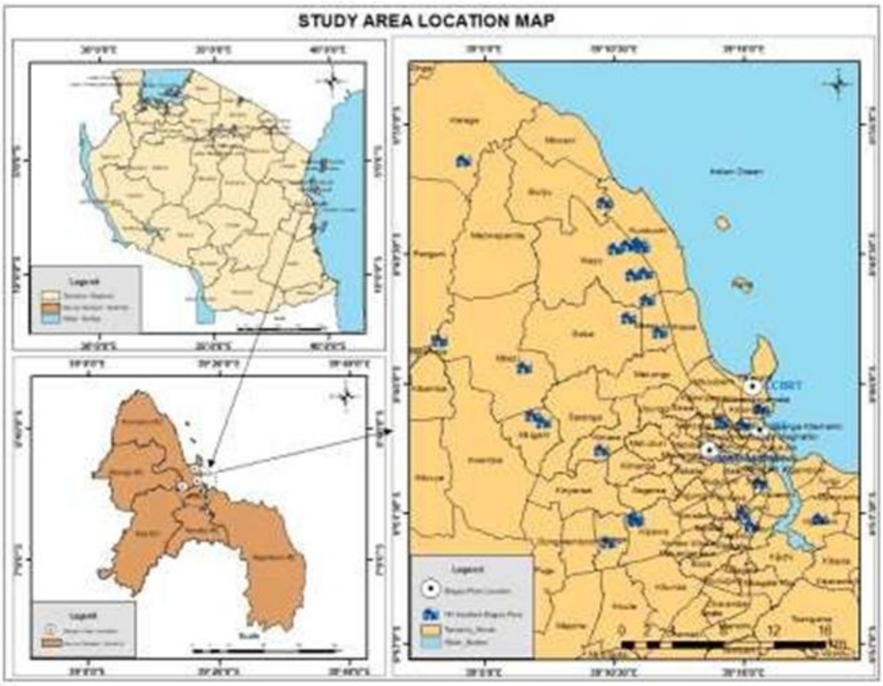

Figure 1: Physical map of the study area.

Study design and selection of the case study

A combination of laboratory experiments, literature reviews, thorough site visits, and in-depth stakeholder consultations were utilized to collect both quantitative and qualitative data for this study. To gather insights, a carefully chosen sample size was interviewed using a combination of open-ended and closed-ended questionnaires, effectively capturing both qualitative and quantitative data. These methodologies were thoughtfully employed to gain a profound understanding of the various driving factors that influence the adaptation and diffusion of biogas technology in the city of Dar es Salaam. Dar es Salaam Region has five municipalities: Kinondoni, Kigamboni, Ilala, Ubungo, and Temeke. However, for this study, we chose to focus on Kinondoni, Ilala and Ubungo municipalities due to the high significance of wastewater treatment plants (Biogas Plants) as adopters of technology includes CCBRT Wastewater Treatment Plant and International School of Tanganyika Wastewater Treatment Plant Upanga,which serves on institutions and also Mburahati community, which serves the community.

Investigation of the current level of adaptation and diffusion of biogas technology in Dar es Salaam

Questionnaires and interviews with key informants were conducted, representing diverse stakeholders deeply involved in biogas technology, including officials from DAWASA (Kisutu), CCBRT and the IST officials with the aim of identifying and ranking the current quantity of biogas plants in Dar es Salaam and their respective states. Concurrently, a household questionnaire (administered to both adopters and non-adopters of biogas technology residing across the case study area and Mburahati ward. This survey encompassed a series of inquiries specifically designed to investigate the ongoing extent of biogas technology.

Assessing drivers that influence adaptation and diffusion of biogas technology in Dar es Salaam

Informal interviews were conducted with key informants to gather essential insights regarding the drivers influencing the adaptation and diffusion of biogas technology in Dar es Salaam. The key stakeholders involved in these discussions included entities such as the Bremen Overseas Research and Development Association (BORDA), Tanzania Traditional Energy Development Organization (TaTEDO), Tanzania Industrial Research and Development Organization (TIRDO), Dar es Salaam Water and Sewerage Authority (DAWASA), Centre for Agricultural Mechanization and Rural Technology (CARMATEC), Energy and Water Utilities Regulatory Authority (EWURA), as well as government bodies like the Ministry of Education, Science and Technology, Ministry of Health, Ministry of Water, and local community members. The interview approach employed was semi-structured, allowing the interviewees to elaborate on their involvement and perspectives.

Investigation of physical and chemical factors affecting the performance and efficiency of biogas production from biogas plants in Dar es Salaam

Sampling procedures and sample size

Samples of well-mixed 1000 ml raw faecal sludge were collected from various mixed containment sources (pit latrines and septic tanks) in domestic households. These samples were discharged by desludging trucks into the treatment system in Mburahati. Additionally, well- mixed 100ml samples were obtained from the wastewater treatment plants at CCBRT and IST. Prior to analysis, the sampling bottles were carefully labelled and placed in a cool box with ice for preservation. They were then transferred to the Water Quality laboratory at the University of Dar es Salaam within 24 hours. Samples that couldn't be analysed on the same day of collection were stored in a refrigerator at four degrees Celsius (4°C). There are several ways of determining sample size, and which method to use depends on various factors such as time constraints, diversity of the population, and population size and researcher's preference-using the Yamen formula to obtain the sample size of the stratified group.

$$n = N/(1+N \, (e)^2) \qquad (1)$$

whereby n is the sample size, N is the population size, and e is the acceptable margin of error for this research 10% (0.1) will be the acceptable margin of error at a 90% confidence level. Generally, the sample size of 100 users was adopted for the study area at Mburahati ward since around 40,000 population are served with the system.

Table 1: Sample size of the study

Population target	Sample size (n)
Mburahati Users/Community	100
Adopter of Technology	50
Non adopter of Technology	50

Wastewater Analysis

The investigation of physical and chemical factors affecting the performance and efficiency of biogas production was conducted using the APHA standard method approach. This involved analysing parameters in influent samples (raw faecal sludge and breweries wastewater) and effluent samples (treated wastewater) in the UDSM laboratory. The parameter analysed include COD, pH, volatile solids and total solids and were compared to the TBS wastewater quality standard (TZS 860:2006).

Data Analysis

Quantitative analysis

The quantitative data analysis for this study was done using analysis of variance (ANOVA), in which the statistically significance difference between samples of wastewater collected from CCBRT, IST and Mburahati derived samples was computed at α=0.05 considering 95% confidence interval. ANOVA was performed using Excel 2019. The statistical analysis was done for all the wastewater quality parameter including COD, pH, temperature, total solids and volatile solids. The results from questionnaires were analysed using descriptive statistics in which frequency tables and graphs were made using SPSS version 27.

Qualitative Analysis

The qualitative data collected from key informant interview checklists, was analysed using content analysis for each interview questions. This content analysis process was based on the conditions for adaptation and diffusion, as well as the drivers influencing the adaptation and diffusion of biogas technology.

RESULTS AND DISCUSSION

The current level of adaptation and diffusion of biogas technology in Dar es Salaam

Community in Mburahati Ward

The study reveals a limited level of biogas technology adaptation and diffusion in Dar es Salaam. This is influenced by factors like awareness levels, attitudes towards awareness, technology acceptability, the number of biogas installations, and the proportion of households or businesses using biogas.

In Mburahati ward, a substantial number of respondent (78.47 %,) demonstrated awareness of biogas technology, particularly among those with secondary and tertiary education. Most of these respondents are using the biogas produced from Mburahati DEWAT. The extent of technology awareness was found to hinder adaptation, aligning with the findings of Letters (2014). Education level appeared to significantly influence both awareness and the size and cost of installed biogas plants, possibly linked to respondents' salary earnings. Community acceptability emerged as a key factor for technology distribution in Dar es Salaam. Among 100 respondents in Mburahati ward, over two-thirds (69.60%) were willing to adopt biogas due to its proximity to households for waste disposal. Economic viability, environmental friendliness, and the benefits of end products such as biogas energy, compost, and irrigation water were also reasons for acceptability (8.34%). (Figure 2 further illustrates these findings).

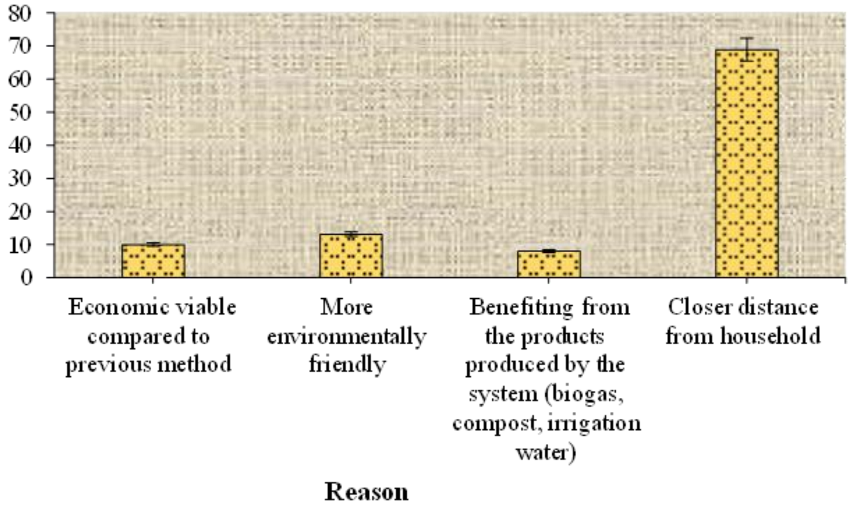

Figure 2: Reason of using the system to disposal of human waste or excreta from household.

Adopter and non-adopter of biogas technology in Dar es salaam

The study indicated that the respondent's perception or awareness of biogas technology influenced for its desire to adopt or not in Dar es Salaam. This implies that there are other factors which influence biogas technology adaptation. The respondents who were aware and also those who were not aware of the biogas technology were required to indicate whether or not desired to adopt the technology as described in Table 2.

Table 2: Respondent information on awareness and desire to adopt biogas technology

		Desire Adopt to	Desire adopt not to	Total
Awareness of biogas technology		YES	NO	
	YES	12	2	14(33.8%)
	NO	62	14	86(66.2%)
Total		**84 (64.6%)**	**16(35.4%)**	**100(100%)**

The attitude towards adapting biogas technology was assessed among adopters and non- adopters. Out of 42 respondents, 88% found the technology appropriate, 2.4% considered it inappropriate, and 9% did not respond. Recommendations were categorized into strong, moderate, and none. Those strongly recommending were well-informed adopters or observers of the technology's benefits, while those moderately recommending had some doubts based on hearsay, leaving it to user preference. Non-recommenders either hadn't heard of the technology or seen its functionality.

The study's findings revealed reasons for non-adoption among respondents. Approximately 32% (n=16) found the technology difficult to understand and operate locally, 6% (n=3) cited cultural beliefs against using human waste in cooking due to health hazards, 20% (n=10) found installation expensive due to low monthly incomes (often below 50,000 Tshs), 24% (n=12) believed other energy sources like electricity, solar energy, fuel wood, and charcoal were superior, and 10% (n=5) cited cheaper alternatives. Figure 3 displays the reasons for Non-Adopters). These findings align with Mwirigi et al. (2009) results, highlighting social-cultural factors as barriers to biogas technology promotion and dissemination.

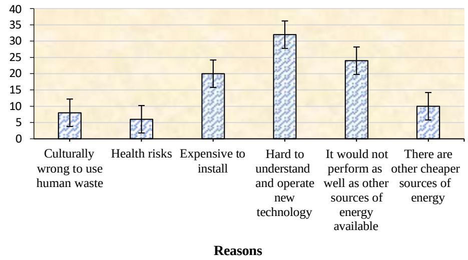

Figure 3: Reasons for not Adopt the Biogas Technology.

Number of biogas installations and the percentage of households or businesses using biogas technology in Dar es Salaam

Based on research findings as shown in Figure 4, the low level of biogas technology adaptation and distribution in Dar es Salaam can be attributed to specific factors. Firstly, the limited awareness among residents about the benefits and feasibility of biogas technology has hindered its adoption. This lack of awareness suggests the need for targeted education and awareness campaigns to highlight the advantages of biogas systems. Additionally, the attitude of the population towards biogas technology, especially in terms of awareness and acceptability, has played a pivotal role in its slow adoption. Many residents may not fully understand the economic and environmental benefits of biogas, which contributes to their reluctance to embrace the technology.

Furthermore, the unequal distribution of biogas plants, with Kinondoni having 120 biogas plants compared to other districts, points to disparities in non-government organizations support, awareness efforts, and community engagement. Ensuring a more equitable allocation of resources and support among districts is essential to promote widespread access to and adaptation of biogas technology.

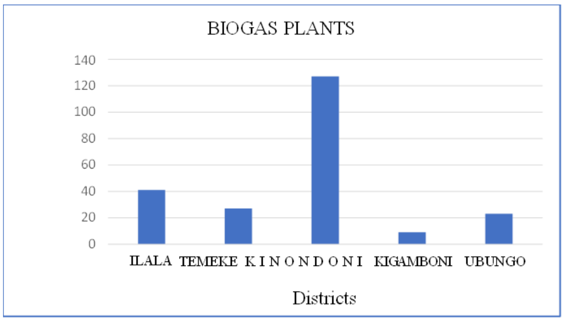

Figure 4: Number of biogas plants against Dar es Salaam districts.

Drivers influencing the adaptation and diffusion of biogas technology in Dar es Salaam

Income to Community

Household monthly income was compared to the desire to adopt biogases technology indicated a negative coefficient (r= -0.041). This implies that there is a high possibility of the respondents who earn lower income taking up the biogas technology compared to the respondents who earn higher income. The reason behind this could be because higher income earners have alternative sources of fuel which they can afford like electricity. But for the low-income earners they would wish for a source of energy that needs the initial installation cost only. The finding was supported by Wawa (2012), which indicated that, the individuals whose monthly earnings were lower were willing to adopt the technology as compared to high income earners. However, they contradict the studies of Ng'wandu *et. al*., (2009) who suggested that the individuals whose income was higher were more willing to adopt the technology compared to the low-income earners.

Funds

In the context of the selected cases in Dar es Salaam, the influence of inadequate funds on the adaptation of biogas technology is examined. Responses were categorized into those viewing inadequate funds as the main challenge and those not considering it a challenge. About 75% out of 150 total respondents identified inadequate funds as a significant challenge, and only 25% (n=50) who desired to adopt the technology saw a lack of sufficient funds for installation as the main hindrance.

The lack of funds for biogas plant installation could be attributed to the nature of respondents' occupations in the studied cases. It's possible that these occupations didn't yield enough profit to support both family needs and a project like biogas installation. The findings reveal a positive correlation between the occupation of respondents and the inadequacy of funds for biogas installation, suggesting that lower-income occupations correspond to higher inadequacy of funds. This correlation is statistically significant (r=0.476, n=200, p=0.013). This demonstrates that households' low-income levels hindered the adaptation of biogas technology, which aligns with the findings of Njoroge *et. al*. (2013). While income is a forecasting factor for biogas technology adaptation, other factors like access to information, inputs, and household heads' perceptions also play pivotal roles in influencing technology adoption.

Training, Seminars and Promotion

Promotion of biogas through different channels impacted the choice to switch and receive the innovation. Reactions distinguished agrarian appears, radio, expansion officers, subsidization of introducing costs as well as show ranches as major sources of data. The use of training by the use of seminars also was identified by 64.05% of the respondents in Mburahati ward to take place once a year of which they rarely attended. Trainings are organized by various promotion groups during the exhibitions in the attendance is always low as affirmed by one of the extension officers in Mburahati ward. Therefore, the promotion strategies should implement included giving subsidy, organizing shows and campaigns and developing of demonstration farms for the aim of adopt and growing biogas technology in their areas.

Presence of Alternative Fuel Sources

The presence of alternative fuel sources, including Liquefied Petroleum Gas (LPG) and other options, in Dar es Salaam has both influenced and complemented the adaptation and diffusion of biogas technology. While LPG serves as a well-established and convenient fuel choice, its coexistence with biogas has highlighted the importance of diversified energy sources in the city. The availability of various alternatives, such as solar power, hydroelectricity, and natural gas, alongside LPG, has prompted a broader conversation about sustainable energy solutions. This diverse energy landscape encourages environmental consciousness and prompts the adoption of biogas as a complementary and environmentally friendly technology. Furthermore, as biogas technology addresses waste management and energy security, it contributes to reducing Dar es Salaam's dependence on imported fossil fuels like LPG and enhances the city's resilience and sustainability in the face of energy challenges.

Physical and chemical factors affecting the performance and efficiency of biogas plants

The physical parameter indicated in Figure 7, 8, 9, 10, 11 and Table 2 and three may influence the adaptability and diffusion of biogas in such way that, when these parameters are within the appropriate standards required for biogas production, majority would accept and adopt using them because they will be expecting to get higher yields of biogas.

Temperature Factor

The temperature is a crucial factor that significantly influences biogas production.
In this study, ambient temperatures ranged from 22°*C* to 30°*C* over the five-week measurement period for each case study area as shown in Table 3. The influent from IST had the highest temperature in March 2023 as compared to all other temperatures recorded in the Mburahati DEWAT and CCBRT. All the temperature recoded in this study are little down to appropriate maximum biogas production which ranges between 35℃ to 40℃ but temperature between 25℃ to 35℃ can be appropriate for higher biogas production.

Table 3: Temperature variations between Mburahati DEWAT, IST and CCBRT for inlet and outlet

Temp (°C)	Mburahati DEWATs		IST		CCBRT	
Day	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**
31-Mar	21.5±0.45	20.8±0.05	30.3±0.60	28.4±0.04	28.3±0.03	28.7±0.40
8-Apr	22.6±0.21	25.1±0.38	28.7±0.25	27.1±0.61	28.6±0.10	27.4±0.12
16-Apr	25.4±0.16	26.5±0.03	29.1±0.41	26.8±0.13	27.5±0.28	26.1±0.33
24-Apr	26.9±0.34	25.8±0.40	28.6±0.01	27.1±0.22	25.7±0.67	25.3±0.16
2-May	26.2±0.57	25.1±0.01	27.2±0.08	26.6±0.15	25.2±0.03	24.8±0.24

pH Factor

One critical factor affecting biogas production is pH, which was measured at five intervals over the five-week period in the reactors and after the termination of the process in Mburahati DEWATs, CCBRT, and IST. The results in Figure 7 in Mburahati DEWATs, inlet pH values were recorded as 8.85, 7.27, 6.7, 7.01, and 7.71 on the respective dates, while outlet pH values were 7.27, 7.4, 7.23, 7.8, and 7.08. In IST as shown in Figure 8, inlet pH values ranged from 7.82 to 7.07, and outlet values ranged from 8.23 to 7.56. Similarly, in CCBRT, inlet pH values ranged from 9.49 to 7.73, and outlet values ranged from 7.78 to 7.76 as indicated in Figure 9.
All measured pH values from Figures 5, 6,

and 7 fell within the optimal range for anaerobic digestion, which is typically between 6 and 8 (Ameen *et. al*., 2016). These findings align with previous research by Mengistu *et al*. (2018), indicating that most bacteria thrive within a pH range of 6.0 to 7.5, while fungal activities are optimal between 5.5 and 8. Therefore, the pH levels observed in the influents and effluents from different case studies in Dar es Salaam remained within the recommended range, promoting favourable conditions for microorganisms during the biogas production process.

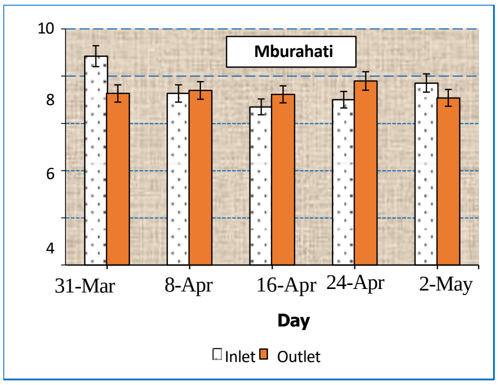

Figure 5: pH variation in Mburahati DEWAT.

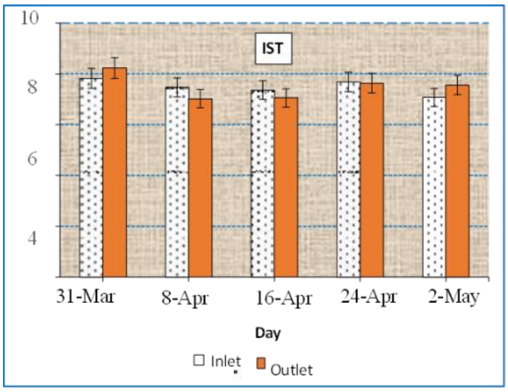

Figure 6: pH variation at IST.

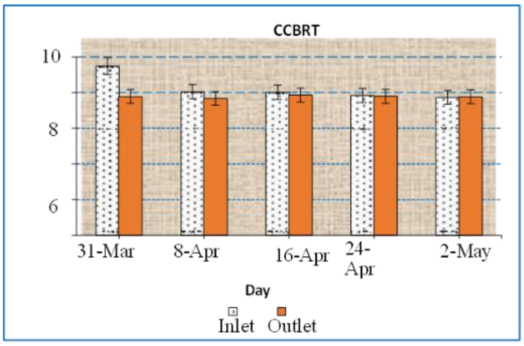

Figure 7: pH variation at CCBRT.

Volatile Solid Factor

The study's findings shown in Figure 8, reveal notable trends in the concentration of volatile solids in effluents from various case study inlets. In Mburahati DEWATs, the concentrations were 896mg/l, 789mg/l, 678mg/l, and 664mg/l on 31-Mar, 8-Apr, 16-Apr, 24-Apr, and 2-May, respectively, as illustrated in Figure 4.4. Similarly, in IST, the concentrations were 864mg/l, 794mg/l, 689mg/l, 625mg/l, and 589mg/l on the same dates. Likewise, in CCBRT, the concentrations were 779mg/l, 688mg/l, 607mg/l, 592mg/l, and 594mg/l.

The observed decline in effluent concentrations over time suggests the progressive anaerobic digestion of wastes by microorganisms. This microbial activity contributes to the reduction of organic solids within the waste, with volatile solids serving as an indicator of waste strength in wastewater treatment. This trend is supported by Yield *et. al*. (2017), who explained that materials rich in volatile solids contain a higher proportion of biodegradable organic matter that gets converted into methane during biogas production.

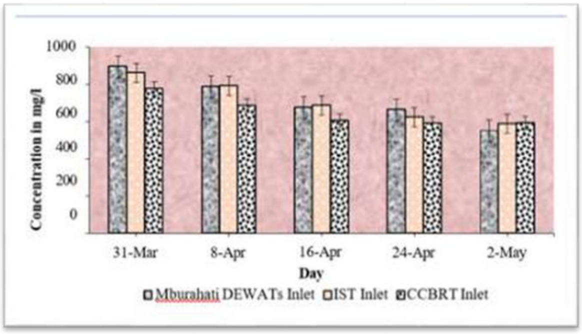

Figure 8: Volatile solid concentration in the case study areas.

Chemical Oxygen Demand (COD)

The significance of Chemical Oxygen Demand (COD) on biogas production is notable, as higher COD levels in effluents correlate with increased biogas generation. The process involves bacterial consumption of organic matter, leading to progressive COD reduction until digestion is complete. Lab analysis reveals COD variations across different case studies as shown in Figure 9. In Mburahati DEWATs, inlet COD concentrations decreased from 894mg/l to 687mg/l over five dates, while outlet COD decreased from 162 mg/l to 118 mg/l. In IST, inlet COD decreased from 782mg/l to 624mg/l, and outlet COD decreased from 170mg/l to 109mg/l over the same dates. This inverse COD-biogas production relationship highlights the microbial breakdown of organic matter crucial for methane generation. The observed COD patterns offer insights into anaerobic digestion dynamics and its impact on biogas production.

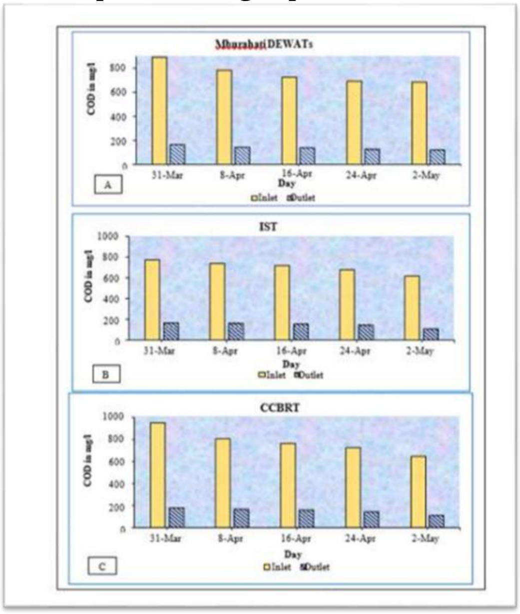

Figure 9: COD levels in the case study area.

Total solids factor

The significance of total solids in biogas production was explored in this study, drawing from research conducted by Yield *et. al.* (2017), which suggests that the optimal range for anaerobic digestion lies between 10-25% total solids. However, deviations in total solids concentrations among the selected case studies in Dar es Salaam could potentially impact biogas production, given the sensitivity of methanogenic bacteria to solid concentrations. Table 4 highlights the variations in total solids content in both inlet and outlet samples of the selected cases.

Table 4: Total solid variation between the case study areas

TS (mg/l)	MBURAHATI- DEWATS		IST		CCBRT	
DAY	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**
31-MAR	2356 ±0.01	1512 ±0.40	2495 ±0.05	1600 ±0.12	2570 ±0.45	1501 ±0.05
8-Apr	2140±0.24	1135±0.36	2397±0.69	1036±0.09	2350±0.06	1369±0.03
16-Apr	1210±0.60	985±0.08	1883±0.45	972±0.01	2104±0.13	1026±0.60
24-Apr	1100±0.02	902±0.40	1567±0.03	895±0.30	1796±0.22	878±0.05
2-May	996±0.61	404±0.52	1001±0.22	563±0.27	1189±0.84	560±0.02

Strategies to Enhance the Implementation of biogas technology in Dar es Salaam

Socio-Cultural Aspect

Education, Training, and Exhibition

Community members and non-adopters should be targeted with comprehensive education and training initiatives that emphasize the benefits and necessity of adopting biogas technology. This is particularly important considering the depletion of fuel wood resources and the environmental advantages offered by the technology. As shared by a representative from a private company (Gas Asilia),

Tanzania Residential Biogas Programme (TDBP) has established a network of trained biogas technicians who are responsible for installing, operating, and maintaining biogas systems in Tanzania. Over 5,000 biogas technicians have been trained since its inception in 2009, and the program continues to provide training and support to local communities and entrepreneurs."

Media Outreach (Television, Radio, Social media)

Utilizing mass promotional campaigns through various media platforms such as TV, radio, and print media will help reach a broader audience. Additionally, targeted activities like workshops and local-level visits to demonstration sites and seminars, in collaboration with active Non- Government Organizations and associations, should be conducted within the selected case studies in Dar es Salaam. The role of informal channels for information dissemination and motivation, as highlighted by Berhe, G. H. (2017), should also be acknowledged.

Capacity Building for Communities

Enhancing awareness about the benefits of biogas fuel through capacity-building initiatives is essential. Providing educational materials about environmental significance and the advantages of biogas fuel can empower community members to make informed decisions. Raising community awareness about biogas technology's benefits and potential requires collaborative efforts from both public and private biogas stakeholders, demonstrating the advantages to every segment of the community.

Technical and Operational Aspect

Technician Services to Users

Many households in Mburahati reported dissatisfaction with service provision by technicians. The absence of offices, lack of written agreements for after-sales services, and high service costs were notable concerns. To rectify this, establishing a mutual written agreement between biogas system contractors and owners, as recommended by a previous study (Ullrich, 2008), would ensure clear rights and responsibilities for both parties.

Installation of Biogas Systems

Respondents frequently cited financial benefits as their motivation for installing biogas digesters. These advantages stem from the savings in time and money previously expended on accessing and using traditional energy sources. Minimizing installation costs is crucial to enable households and adopters to afford the technology, especially considering that biogas technology installation costs are relatively high, often exceeding 50,000 Tanzanian Shillings per individual in the selected case studies. Notably, biogas technology also offers health benefits by avoiding smoke emissions, which are known to cause respiratory illnesses.

Adequate Technical Support

Inadequate design, lack of raw materials, and insufficiencies in storage tanks and pipelines can lead to insufficient biogas production. Expanding biogas adoption without sufficient technical support poses challenges. To ensure successful biogas adoption, the perspectives of biogas users must be considered, as a lack of expertise can hinder the implementation and maintenance process, potentially leading to negative outcomes. A key informant from a private company highlighted that inadequate technical support can result in technical subsystem failures, affecting structural components, inlet and outlet issues, and digester effluents, among other issues.

Economic and Financial Aspect

From a financial perspective, introducing a biogas plant represents an investment in modern capital. This investment is expected to improve household financial performance and yield returns in terms of increased income or savings in the Mburahati ward. However, the initial costs of residential biogas plants often surpass the financial capacity of potential users. In addition to the cost itself, factors such as subsidy availability, access to credit sources, and financial assistance programs influence potential clients' decisions to invest in a biogas plant. More financial support for research and development in developing countries is essential, as it is considered a significant barrier to technological innovation.

Environmental and Health Aspects

Demonstration Projects and Case Studies

Establishing demonstration projects in key areas can effectively showcase the successful implementation of biogas technology. Highlighting case studies that emphasize the technology's environmental, health, and economic benefits, such as reduced energy costs and improved waste management, as demonstrated by this research in Dar es Salaam, can further encourage adoption.

Policy Support and Incentives

Advocating for supportive policies and regulatory frameworks from environmental, water, education, vocational training, industries, and energy ministries is vital.
This advocacy should include financial incentives, tax breaks, grants, and support for individuals, communities, and businesses investing in biogas systems. Clear guidelines and streamlined approval processes will facilitate easier adoption, resulting in substantial environmental and health benefits such as reduced greenhouse gas emissions, improved air quality, and sustainable waste management practices, ultimately contributing to the overall well-being of the community.

CONCLUSIONS AND RECOMMENDATION

Conclusion

The study highlights a low level of biogas technology adaptation and diffusion in the area. Factors influencing this include awareness, attitudes, acceptability of the technology, biogas installations, and the percentage of adopters. Most respondents learned about biogas from informal sources, which might contribute to the technology's limited adoption. Drivers for adoption include income and funding availability, with lower-income earners being more likely to adopt due to affordability. Inadequate funds were a significant hindrance, affecting 75% of respondents, while socio-economic attributes like education showed mixed influences.
The study also analyses factors affecting biogas plant performance, such as pH and temperature. Effluent concentrations indicate that the studied cases are suitable for biogas production due to their biodegradable organic matter content. Optimal pH and variations in VS, TS, and COD removal efficiencies are examined across different cases. The strategies proposed for enhancing technology adaptation and diffusion in Dar es Salaam involve educating communities, conducting mass campaigns through diverse media, organizing workshops, and engaging with NGOs. Addressing concerns related to services and costs is also essential for promoting biogas technology adoption and diffusion in the area. These comprehensive strategies, tailored to specific findings, aim to drive sustainable sanitation innovation in Dar es Salaam.

Recommendations

i. The analysis underscores the current low level of biogas technology adaptation and diffusion in Dar es Salaam. To address this, a comprehensive public awareness campaign is recommended, focusing on educating the community about biogas benefits like renewable energy, waste reduction, and cost savings. Constructing demonstration units in accessible areas, such as marketplaces, can make the technology tangible and motivate adoption.
ii. The study identifies administrative measures to drive adaptation and

diffusion. Establishing a regulatory body to oversee and support the biogas sector is crucial. This entity would enforce guidelines, provide assistance, and ensure efficient project implementation. Government incentives, like tax breaks, loans, or grants, can encourage wider adoption. Simplifying approval processes and targeting marginalized communities could enhance adaptation.

Physical and chemical factors influencing biogas plant performance highlight the need for technical support and proper installation. Training technicians and minimizing installation costs are essential. Collaboration among ministries, agencies, research institutions, and stakeholders can facilitate knowledge sharing, best practices, and a unified strategy for the growth of the biogas sector. This collaborative approach creates a supportive ecosystem for biogas and other sanitation innovation technologies to thrive.

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Conflict of Interest

We declare no conflict of interest in this research work.

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