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Human Excreta Estimation for Biogas Production in the University of Abuja, Nigeria

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Abstract

Purpose: Effective waste management is crucial for institutions like the University of Abuja, and estimating the availability of human excreta is essential in this regard. The purpose of this study is anchored in the critical need to develop sustainable energy solutions and waste minimization in the face of escalating global energy demands and environmental concerns. By estimating the availability of human excreta for biogas production, this study aims to contribute to the promotion of renewable energy, waste reduction, and environmental stewardship at both local and global scales.

Methodology: This dissertation employs computational models, specifically the pseudo-inverse and predator-prey models, to derive an estimator for the availability of faecal matter. The pseudo-inverse component determines faecal matter availability linearly, while the predator-prey component accounts for depreciation due to storage. Additionally, the human excreta were characterized using both proximate and ultimate analysis. The proximate analysis considered pH, moisture content, volatile solid, total solids, total nitrogen, total organic carbon, carbon to nitrogen ratio (C/N) and chemical oxygen demand (COD). The ultimate analysis considered Fe, Zn, Mn, B, and Cu.

Findings: The outcome of this study indicated the characterized human excreta from the University of Abuja main campus shows promising potential for biogas production; however, careful management and possibly some adjustments would be necessary to optimize the process. From survey data, the model estimates an average deposition of 25.42 m3 /day of faecal matter at a decay rate of -0.003938 per hour can generate 13.53 Mega-Joule of biogas per day. This showcases the potential and sustainability of biogas production from the university's hostels.

Unique Contribution to Theory, Policy and Practice: The study concludes that human excreta is a viable resource for biogas production at the University of Abuja, highlighting the quantity generated and its feasibility for utilization. Recommendations include investing in infrastructure, continuing research and development efforts, and garnering policy support to leverage human excreta for sustainable biogas production.

Keywords: *Effective Waste Management, Human Excrete, Predator, Prey Component, Potential, Biogas Production*

I. Introduction

The global pursuit of sustainable development has intensified, with energy identified as a cornerstone for progress and prosperity [1, 2, 3, 4]. Energy is not only vital for the survival of all life forms but also serves as the engine driving economic and industrial advancement [2]. Amidst rapid industrialization and rising living standards, the demand for energy is surging, with fossil fuels currently meeting the majority of this demand. However, these non-renewable sources contribute significantly to greenhouse gas emissions, underscoring the imperative for sustainable energy systems that support long-term human development across social, economic, and environmental dimensions [5, 6, 7]. In the pursuit of sustainable energy solutions, the utilization of renewable resources has become imperative, driven by concerns over fossil fuel depletion and environmental degradation [8, 4, 5, 2]. Among renewable energy sources, biogas produced through anaerobic digestion holds significant promise, offering a clean and renewable alternative to traditional fuels [3, 9]. [10] described it as a versatile renewable energy source that can be used as; replacement of fossil fuels in power and heat production, gaseous vehicle fuel; feedstock for producing chemicals and materials. [11] averred that when compared to other renewable energy sources such as wind and solar photovoltaics, biogas has the advantage of providing flexible power production, including in times of low wind and solar intensity. In addition, biogas has an added advantage of waste minimization, thus enhancing waste management [5, 12, 13, 14, 15].

Biogas can be produced from a wide range of biological feedstock's; in recent years, there has been increasing interest in utilizing organic waste, because it aligns with the broader goals of sustainability, renewable energy development, and waste management optimization [16, 17, 2 18]. Human excreta, often overlooked as a waste stream, holds significant potential as a biomass feedstock for biogas production, given it is one of the more abundant and easily available bio-resource, that is available everywhere [19], moreover, it does not require additional starter (microorganisms seed), and a supply of microorganisms occurs continuously during the feeding of raw materials, thus directly supporting the sustainability of the biogas production [18]. [20] alleged that human waste, specifically human faeces, has the ability to produce biogas 0.35–0.5 m3 /kg.

Meanwhile, the economic viability and process optimization using any substrate requires accurate information on the gas composition and estimated generation projections [21]. [22] stated that the availability and composition of the substrate (organic waste) can significantly impact the performance of biogas digesters. Thus, estimations play a pivotal role in assessing the feasibility and potential yield of biogas production from human excreta (HE).

The University of Abuja, situated in Nigeria, provides a pertinent context for exploring the potential of HE for biogas production. As a densely populated academic institution, the university generates a significant volume of human waste daily. Harnessing this resource for biogas production holds the promise of addressing multiple challenges faced by the university, including waste management, energy security, and environmental sustainability. This study seeks to estimate

the availability of HE for biogas production at the University of Abuja through theoretical modelling and analysis.

I Aims and objectives of study

This study aims to assess the availability of human waste for biogas production on the main campus of the University of Abuja. The specific objectives are to:

(a) Collect data and characterize substrates (human excreta);

(b) Evaluate the faecal matter decomposition using the prey-predator population Model

(c) Estimate the faecal availability using linear modelling; and

(d) Estimate biogas yield.

II Statement of the research problem

Waste management is a pressing issue in urban environments globally, and the University of Abuja, nestled within Nigeria's vibrant capital, is no exception. Also, the university of Abuja, like many institutions in Nigeria, is grappling with energy security issues, relying heavily on non-renewable fossil fuels that are costly and environmentally detrimental.

There is a pressing need for sustainable solutions that can address these problems concurrently. Despite the potential of biogas production from human excreta as a renewable energy source and waste management strategy, there is a lack of accurate data and reliable estimates regarding its feasibility and yield at the University of Abuja. This study aims to fill this gap by using theoretical modelling to estimate the availability and potential of human excreta for biogas production, providing a foundation for developing sustainable energy and waste management solutions.

III. The Study Area

The study area is the University of Abuja, which is a prominent institution in Nigeria, established in January 1988 as a dual-mode university with the mandate to run conventional and distance learning programs. It is located in the Federal Capital Territory (FCT) of Nigeria and serves as a significant academic and research hub. The University of Abuja is situated between latitude 8°58 north of the equator and longitude 7°10 east of the Greenwich meridian [106]. According to the National Population Census in 2006, the population of the University of Abuja community, including staff and students, was estimated to be around 20,000, with projections indicating a significant increase over the years due to expansion and development.

Covering an area of about 11,824 hectares, the University of Abuja is positioned in the western part of the Federal Capital Territory, near the Gwagwalada Area Council.

The university plays host to a number of important faculties, research centers, and institutions, including the Faculty of Engineering, Faculty of Health Sciences, Faculty of Law, Faculty of Agriculture, Centre for Distance Learning and Continuing Education, and the University Teaching Hospital.

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The map of the study area is presented in Figure 1, illustrating the geographical layout and significant landmarks within the university campus and its surrounding areas. The University of Abuja is not only a center for academic excellence but also a community that encompasses various essential services and facilities contributing to the overall development of the region. Also presented in figure 2 is the Map of the Study Area which is the Federal Capital Territory (FCT), Nigeria.

Figure 1: Map of University of Abuja

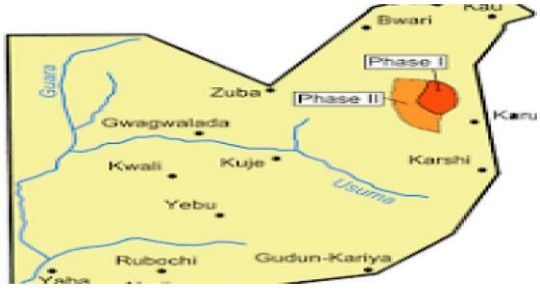

Fig. 2 Map of Study Area: Federal Capital Territory (FCT) Abuja

IV Justification; -

The justification for this study is anchored in the critical need to develop sustainable energy solutions and waste minimization in the face of escalating global energy demands and environmental concerns. By estimating the availability of human excreta for biogas production, this study aims to contribute to the promotion of renewable energy, waste reduction, and environmental stewardship at both local and global scales.

Moreover, the application of modelling in this study enables precise predictions, resource optimization, feasibility assessment, and economic and environmental impact analysis; consequently, supporting data-driven decision-making, scenario analysis, and risk management, providing a comprehensive understanding of the biogas production process. Additionally, it ensures that the methodology can be replicated and standardized across different settings, enhancing the overall success and sustainability of the process.

Ultimately, the findings of this study are instrumental in promoting the adoption of human waste biogas technology on the university campus and beyond. Plus, the knowledge generated 4 can inform policy development, research initiatives, and public awareness efforts aimed at advancing sustainable energy solutions in Nigeria. Additionally, the study will and contribute to the broader discourse on waste-to-energy technologies and their potential impact on environmental sustainability and energy security.

V. Methodology

Samples were collected from all sampling points following proper sampling procedures that enabled collection of representative and viable samples. Typically, fresh human excreta were obtained from storages of the preinstalled toilets upon proper mixing with sticks, stored in airtight

plastic containers, labelled and transported to the laboratory in ice-packs where both the proximate and ultimate analysis were conducted.

Additionally, safety protocols such as the use of personal protective equipment (PPE) including gloves, goggles, overalls, head covers, mask, and boots; washing of hands with antiseptics and application of sanitizers were observed to protect from potential biohazards during sampling.

Relevant data necessary for the computation and modelling was obtained via physical survey and sourcing from the University's Works Department. Survey of the hostels to obtain data such as the numbers of installed toilets, in both male and female hotels was conducted over a 49-day period from 05/10/2023 to 23/11/2023. While data on the population; Septic and Soak away including, number of soak away pits, number of septic tanks, sizes of the soak away tank, size of septic tanks, depth of septic tank, number of rooms, number of students / room, number of students accommodated / hostel block, number of hostels considered in the study was collected for University Works Department.

Additionally, the surveys and data collection process also obtained information on the students' typical diet and lifestyle factors that may influence faecal output. Volume fluctuation of septic tanks was determined by measurements from deep sticks. Figure 3.2 shows the measurement schemes. The measurement is then used in determining the volume of the septic tank. The volume fluctuation of septic tanks is determined to be the average volume of the septic tank measured at intervals of 4 hours and is taking to be in direct proportion to the amount of available faecal matter with proper drainage of excess water. The measurements were taken at 8:00am, 12:00pm, 4:00pm and 8:00pm respectively.

The human excreta were characterized using both proximate and ultimate analysis in this study. The proximate analysis considered parameters such as pH, moisture content, volatile solid, total solids, total nitrogen, total organic carbon, carbon to nitrogen ratio (C/N) and chemical oxygen demand (COD). The ultimate analysis considered Fe, Zn, Mn, B, and Cu. The pH was done using a pH meter, while other proximate and ultimate parameters were analysed at the Chemical Engineering Laboratory, University of Abuja following American Society for Testing and Materials (ASTM) standard methods.

VI. Results and Discussion

Table 1 presents the summary of the demographics and details of septic tanks and soakaways.

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Table 1 Summary of population, septic and soak away data collected from the University Works Department

S/No.	Item(s)	Number	Length (m)	Width (m)	Volume (m3)
1	Number of Soak Away Pits	5			
2	Number of Septic Tanks	5			
3	Sizes of the Soak Away Tank	5	3.5	3.5	61.25
4	Size of Septic Tanks	5	3.7	3.7	68.45
5	Depth of Septic tank	98	2.4		
6	Number of Rooms	8			
7	Number of Students / Room	/ 784			
8	Number of Students Accommodated	2			
9	Hostel Block				

While figure 2 present the fluctuations in the storage volume of the septic tanks.

Figure 3: The Population of the Storage Volume of Septic Tanks

Using the raw data collected from Table 2, Average volume fluctuation of septic tanks (m^3)/day, number of students leaving hostel (n), cumulative number of students remaining in hostel (n), water demand (m^3/n/day), number of toilet used/day and average daily temperature (^{0}C) were computed as requirement for determining the response model.

The desirability of the proposed model is that it can be used for determining the cycle of septic tank maintenance for hotels or communities with central sewer system that require evaluation.

Details of the average volume fluctuations noted in the septic tanks is presented in Table 2.

Table 2: Variation in the Volume of Five (5) Septic Tanks

S/No.	Date	Depth (m)					Volume (m^3)				
		Septic Tank 1	Septic Tank 2	Septic Tank 3	Septic Tank 4	Septic Tank 5	Septic Tank 1	Septic Tank 2	Septic Tank 3	Septic Tank 4	Septic Tank 5
1	05/10/2023	0.55	0.15	0.86	0.56	0.41	25.37	30.83	21.04	25.14	27.24
2	06/10/2023	0.52	0.97	0.97	0.55	0.92	25.72	19.63	19.59	25.31	20.26
3	07/10/2023	0.26	0.30	0.77	1.00	0.97	29.27	28.76	22.34	19.21	19.52
4	08/10/2023	0.15	0.87	0.95	0.49	0.43	30.78	20.89	19.88	26.11	27.01
5	09/10/2023	0.03	0.93	0.57	0.55	0.41	32.38	20.19	25.10	25.37	27.22
6	10/10/2023	0.15	0.10	0.86	0.20	0.21	30.77	31.52	21.03	30.18	29.95
7	11/10/2023	0.90	0.40	0.86	0.48	1.00	20.47	27.42	21.07	26.33	19.20
8	12/10/2023	0.41	0.68	0.54	0.80	0.73	27.30	23.54	25.49	21.85	22.85
9	13/10/2023	0.87	0.76	0.94	0.64	0.73	20.98	22.49	19.94	24.09	22.88
10	14/10/2023	0.90	0.32	0.86	0.65	0.52	20.48	28.53	21.11	23.92	25.77
11	15/10/2023	0.90	0.47	0.51	0.80	0.26	20.56	26.41	25.89	21.87	29.28
12	16/10/2023	0.36	0.98	0.75	0.59	1.00	27.98	19.38	22.53	24.72	19.22
13	17/10/2023	0.14	0.69	0.84	0.78	0.95	30.93	23.35	21.42	22.20	19.88
14	18/10/2023	0.60	0.71	0.11	0.53	0.42	24.71	23.17	31.31	25.57	27.11
15	19/10/2023	0.06	0.94	0.44	0.16	0.02	31.97	19.92	26.87	30.64	32.55
16	20/10/2023	0.21	0.64	0.55	0.32	0.87	30.01	24.13	25.28	28.53	20.96
17	21/10/2023	0.46	0.48	1.00	0.79	0.40	26.52	26.22	19.23	22.02	27.34
18	22/10/2023	0.37	0.28	0.77	0.12	0.98	27.85	28.95	22.28	31.26	19.46
19	23/10/2023	0.91	0.81	0.66	0.34	0.52	20.38	21.77	23.80	28.18	25.71
20	24/10/2023	0.38	0.00	0.53	0.44	0.94	27.60	32.83	25.65	26.82	20.00
21	25/10/2023	0.91	0.37	0.29	0.59	0.37	20.34	27.78	28.88	24.84	27.78
22	26/10/2023	0.08	0.60	0.86	0.54	0.79	31.70	24.67	21.03	25.45	22.05
23	27/10/2023	0.91	0.38	0.62	0.72	0.58	20.35	27.61	24.39	23.02	24.91
24	28/10/2023	0.33	0.66	0.48	0.67	0.64	28.33	23.78	26.27	23.71	24.09

4.1.2 Result of Excreta Characterizations

Table 4.3 presents the average characteristics of sampled human excreta from the University of Abuja main campus considering relevant proximate (pH, moisture content, VS, TS, TN, TC, Carbon to Nitrogen,(C/N) and COD and the ultimate analysis (Fe, Zn, Mn, B and Cu) The proximate analysis revealed that a pH of 7.42,the neutral pH of 7.42 is conducive for microbial activity in anaerobic digestion, it falls within the optimal range (7-9) report in similar studies [4,18,33,84] indicating a favorable environment for biogas production.

Table 3: Result of Proximate and Ultimate Analysis

Parameters	Unit	Average value
pH		7.42
Moisture content	%	85.33
Volatile solid (VS)	%	79.62
Total solids (TS)	%	18.14
Total nitrogen (TN)	mg/g	16.40
Total phosphorus (TP)	mg/g	6.81
Total carbon (TC)	mg/g	234.85
C/N		14.32
Chemical oxygen demand (COD)	mg/L	89700.00
Fe	mg/Kg	42.50
Zn	mg/Kg	34.20
Mn	mg/Kg	0.32
B	mg/Kg	3.00
Cu	mg/Kg	3.80

The observed moisture content as reported in Table 4.3 is 85.33%, which also corresponds to that reported similar studies within a range of 78-84% [4, 18, 84, 48, 82]. Notably, high moisture content is beneficial for anaerobic digestion as it facilitates microbial activity, however, it is worth noting that too high moisture content can dilute the nutrients and reduce the efficiency of the process, so careful management would be necessary.

VS represents the organic fraction of the waste that can be converted into biogas. The observed value of 79.62% is in line with the reported range of 81-88.5% [48, 82], indicating a good potential for biogas production. TS indicates the total solid content in the waste. The value of 18.14% agrees with the range of 17.28-18.4% reported in similar studies [33, 48, 82], suggesting that the excreta is appropriately concentrated for anaerobic digestion.

TN and TP are crucial for microbial growth. The observed TN (16.4 mg/g) and TP (6.81 mg/g) falls within the range of 11 to 31 mg/g and 4-7.7 mg/g reported in literature [4, 18, 48, 84], indicating adequate nitrogen and phosphorus for the digestion process. Meanwhile, TC in this study as presented in Table 4.3 is 234.85 mg/L. High TC value indicates substantial organic content available for conversion into biogas.

Carbon to Nitrogen ratio (C/N) is crucial for maintaining the balance of nutrients for optimal microbial activity. The C/N ratio for the sampled human excreta in this study was 14.32 which also corresponds well with the reported C/N with range 12 to 20.1 in similar studies [8, 48, 82]. A C/N ratio within the range of 20-30 is generally considered ideal for anaerobic digestion [107, 108], so based on the obtained average C/N of 14.32 the human excreta in university of Abuja might require some adjustment or co-digestion with other substrates to achieve this balance. COD measures the amount of organic compounds available for anaerobic bacteria to convert into biogas. The value of 89,700 mg/L is within the range of 42,182 to 98,200 mg/L reported in similar studies

[33, 48, 82], indicating high potential for biogas production.

The ultimate analysis revealed average values of Fe, Zn, Mn, B and Cu in the sampled human excreta to be 42.5 mg/Kg, 34.2 mg/Kg, 0.32 mg/Kg, 3 mg/Kg and 3.8 mg/Kg respectively. Notably when compared to [82] the obtained values compare favorably, however, they pale in comparison with [8], which may be because the composition of these elements can be influenced by a variety of variables such as diet, age, etc. Notably, these elements are essential micronutrients for the microorganisms involved in biogas production, although their optimal concentrations can vary.

Over all, the characterized human excreta from the University of Abuja main campus shows promising potential for biogas production. However, careful management and possibly some adjustments would be necessary to optimize the process.

Conclusion

Despite the potential of biogas production from human excreta as a renewable energy source and waste management strategy, there is a lack of accurate data and reliable estimates regarding its feasibility and yield at the University of Abuja. This study thus applied theoretical modelling via the pseudo inverse and the predator - prey model, to estimate the availability and potential of human excreta for biogas production, providing a foundation for developing sustainable energy and waste management solutions. The outcome of this study indicated the following:

(a) The characterized human excreta from the University of Abuja main campus shows promising potential for biogas production; however, careful management and possibly of some adjustments would be necessary to optimize the process.

(b) The evaluation of the faecal matter decomposition using the prey-predator population model indicates that indeed a decay was occurring, this shows the suitability of the model for estimation of faecal matter from the hostels of the university of Abuja.

(c) Based on the data of faecal matter availability, the linear model estimates the deposition of an average quantity of 25.42 m3 /day of faecal matter at a decay rate of -0.003938 per hour. Thereby showcasing the potentiality and sustainability of biogas production from the hostels of the University of Abuja.

(d) Computational analysis of the faecal matter availability in the data obtained shows an average biogas yield of 13.53Mega-Joule of biogas per day, making this a viable source of energy.

Recommendations

The following recommendations were considered;

i. Considering the inherent limitations of theoretical estimates, which may diverge from practical realities, a further research based on a pilot scale on biogas extraction using human excreta on campus is recommended.
ii. ii. To enhance the potential of biogas production from human excreta at the University of Abuja main campus, it is advisable to conduct further research aimed at improving

the characteristics of the excreta for optimal biogas yield. Additionally, exploring the use of alternative co-substrates could offer avenues for enhancing biogas production and ensuring sustainable waste-to-energy conversion.

iii. iii. To fully leverage the potential of human excreta for biogas production, the university could invest in appropriate infrastructure such as biogas digesters, collection systems, and gas utilization technologies.

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