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Analytical assessment of knowledge, attitude and practices (KAP) of waste management practices to optimize energy and food nexus: A case study of Oleh, Isoko South LGA, Delta State, Nigeria

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The circular life cycle of waste management, designed for waste-to-energy, can substantially contribute to efficient waste management, a precursor for sustainable energy and food production. This study evaluates knowledge, attitudes, and practices (KAP) related to waste management and identify its potential for improving energy and food production. Surveys, interviews, and data analysis were employed to investigate current waste management scenarios, socio-cultural perceptions, and policy frameworks in Oleh, Nigeria. Factor analysis was used to reduce the multitude of attitudinal variables collected during surveys and interviews. The results exposed gaps in waste management perception, principles, policy implementation, and waste-to-energy conversion. SWOT analysis was conducted to validate identified factors, highlighting significant strengths, weaknesses, opportunities, and threats associated with current waste management practices. To enhance energy generation and food security, a waste management model was proposed with recommendations for pathways promoting policy enhancements and community engagement strategies to foster a more efficient energy and food nexus.

Key words: Waste management, factor analysis, social attitudes, community engagement, public perception.

INTRODUCTION

Globally, the pursuit of sustainable municipal solid waste (MSW) management is intrinsically linked to the efficient operation of waste-to-energy (WTE) systems (Alzate et al., 2019; Doaemo et al., 2021; Fernández-Nava et al., 2014).

Developed nations have adopted strategies emphasizing waste reduction, recycling, and conversion into electricity, highlighting the potential of WTE operations to address waste challenges (Alzate et al., 2019). The United States Environmental Protection Agency (USEPA) recently recognized Municipal Solid Waste (MSW) as a renewable energy source, placing it alongside hydro, solar, wind, and other clean energy forms (Pandyaswargo et al., 2012). This acknowledgment underscores the potential benefits of utilizing non-recyclable MSW in contributing to the renewable energy portfolio and diversifying energy sources (Amuda et al., 2014; Luoranen and Horttanainen, 2007).

The surge in global waste production stems from complex factors such as industrialization, globalization, urbanization, lifestyle choices, economic growth, and population increase. This rise, predicted by the World Bank to increase from 2.01 billion tonnes in 2016 to 3.40 billion tonnes by 2050, accentuates the urgency of effective waste management (Amuda et al., 2014; Tan and Khoo, 2006). Despite advancements, at least 33% of this waste globally remains unmanaged, contributing to environmental degradation (Owamah et al., 2017). Open-air burning, prevalent in Africa, compounds health risks by releasing unchecked gaseous pollutants (Ackerman, 2000; Ajieh et al., 2023; Albanna, 2012). Despite Africa's abundant energy resources, the continent struggles to meet its energy needs, emphasizing the need for innovative solutions such as waste-to-energy plants to achieve Sustainable Development Goals (SDGs) (Ezemonye et al., 2018).

The proliferation of open dumps not only poses environmental and public health risks but also hinders sustainable development in Nigeria, which faces a significant challenge in managing its increasing volume of waste amidst rapid population growth and urbanization. The intertwined nature of these challenges presents a critical obstacle to the country's energy sector, characterized by heavy dependence on imported fossil fuels leading to chronic energy shortages and an unreliable power supply. This reliance strains the national budget due to high import costs and leaves Nigeria vulnerable to fluctuations in global fuel prices and supply disruptions. In this context, the conversion of MSW into energy emerges as a viable solution capable of addressing both waste management and energy challenges. The shift toward decarbonization technologies is crucial to curtailing CO_2 emissions and transitioning toward a low-carbon trajectory (Igboanugo et al., 2015; Jetter et al., 2012).

Within the spectrum of clean energy sources, WtE stands out as a renewable energy alternative efficiently harnessing MSW to produce electricity and heating steam. This approach not only offers a sustainable alternative to landfilling but also reduces land requirements and solid waste volume (Barr et al., 2001; Hou et al., 2019). The poor attitudes towards waste disposal in Oleh in Isoko South Local Government Area are typical in many Nigerian and African communities and have significantly contributed to challenges in waste management, leading to open waste dumping and associated environmental and health hazards (Ajieh et al., 2021a). Metropolitan and peri-urban areas grapple with the adverse effects of inadequate waste management, including pollution, disease vectors, and soil contamination (Ezechi et al., 2017; Kofoworola, 2007; Nabegu, 2010). Indiscriminate waste disposal hampers water channels, drains, and roadways, posing severe threats to human health (Drimili et al., 2020; Isagba et al., 2023).

Therefore, existing waste management techniques in Nigeria focus on environmental education, governance, public agencies, laws, technologies, infrastructure, and monitoring (Uwadiegwu and Chukwu, 2013). Embracing the 4R concept (reduce, reuse, recycle, reclaim) aligns with contemporary circular economy principles (Owebor et al., 2019).

The implementation of WtE technologies such as combined heat and power (CHP) and incineration offers viable means of energy production, particularly from non-degradable municipal solid waste (MSW). CHP involves a waste treatment system that concurrently generates electricity and heat by burning waste. This process utilizes hot flue gases to produce steam, which powers turbines for electricity—a common approach in the CHP cycle (Bagherian et al., 2021). The recovered heat benefits industries or local communities by providing additional thermal energy (Bagherian et al., 2021). Nonetheless, anaerobic digestion stands as an effective WtE technology widely used in developed and developing countries (Lohri et al., 2014). It presents a less polluting alternative for waste-to-energy generation, functioning through a biochemical conversion process within oxygen-free digesters. This method efficiently manages both wet and dry waste, enabling energy recovery. Biogas, the resultant product, is a colorless, non-toxic, combustible gas primarily composed of methane (CH_4) and carbon dioxide (CO_2), with other gases making up around 1 to 5% (Amasuomo and Baird, 2016).

These technologies hold the potential to significantly contribute to the attainment of multiple SDGs such as SDG 7 - Affordable and Clean Energy, SDG 9 - Industry, Innovation, and Infrastructure, SDG 12 - Responsible Consumption and Production, SDG 13 - Climate Action, and SDG 15 - Life on Land, demonstrating their multifaceted contributions to sustainable development and global sustainability initiatives. The success of solid waste management depends on public awareness and attitudes, with studies emphasizing waste classification and segregation efforts (Babaei et al., 2015; Barr et al., 2001; Desa et al., 2011; Rahardyan et al., 2004; Tucker

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and Speirs, 2003).

However, transitioning to WtE poses multifaceted challenges spanning environmental, technological, economic, regulatory, and societal realms, demanding meticulous consideration and strategic planning. Numerous studies have explored various facets of WtE, including environmental impact assessments (Bagherian et al., 2021; Kalogo et al., 2007), technological evaluations encompassing biological treatment, thermal processes, landfill gas utilization, and biorefinery technologies, among others (Ali et al., 2021), and potential scenarios to amplify climate co-benefits. Amid the extensive WtE research landscape, our study redirects attention to the often-overlooked barriers and limitations obstructing the successful adoption of WtE solutions in emerging economies like Nigeria. This study therefore employs qualitative methods to explore factors influencing public attitudes and perceptions toward waste management, using SWOT analysis to unravel strengths, weaknesses, opportunities, and threats associated with material and energy recovery from waste.

MATERIALS AND METHODS

This study utilizes two primary approaches: quantitative and qualitative. The quantitative approach utilized numerical data and statistical analysis to quantify and measure specific aspects of the waste management scenario. It involved surveys with closed-ended questions, data collection from a larger sample size, and statistical tools to derive trends, patterns, or correlations within the gathered information. On the other hand, the qualitative approach focused on gathering non-numerical data such as opinions, attitudes, and perceptions to gain a deeper understanding of the subjective aspects influencing the waste management process. This involved interviews, open-ended survey questions, and focus group discussions to gather rich, descriptive insights. The combination of these approaches allowed for a comprehensive exploration of both quantitative data for measurable trends and qualitative information for nuanced perceptions and attitudes related to the impediments in establishing a sustainable waste value chain. Therefore, in this study, Oleh in Isoko South, Delta State (Figure 1), was selected for sampling due to its convenience and similarities to other states in Nigeria (Stratton, 2021). The determination of the sample size was computed utilizing Equation 1.

$$n = \frac{N}{1 + Ne^2} \quad (1)$$

where N is the population size, e is 0the 0.05 level of significance and n is the sample size. Waste was sampled in markets (specifically, Oleh main market and Nyanga market) and Delta State University campus in Oleh. These locations were conveniently and purposively selected based on expected volume of waste generated as well as a referenced location for areas benefiting from the services of the Delta States's coordinated waste managers. A sampling sheet was used to record the weight of waste samples, which were measured using a scale with a sensitivity of 0.01 kg. The samples were then manually divided into six categories: organic (food waste), paper, plastics, glass, metals, and unclassified waste (including textile, ceramics, electronic waste, batteries etc.). Every component was weighed and recorded, and the combined weight of all the parts was compared to the initial sample weight. Paper, glass, metal, plastics, and organics were further divided based on energy, recyclability, and biodegradability. Following sorting, each fraction was weighed independently using a digital scale that was calibrated, and the results were compared to the total. A 50-litre calibrated bin was used to calculate the bulk density (BD) and after which, the percentages of the compositions were computed (Equation 2) in line with Ogwueleka, (2013);

$$Bulk\ Density = \frac{Weight\ of\ waste\ collected\ (kg)}{Volume\ of\ container\ (m^3)} \quad (2)$$

Furthermore, understanding key latent factors that may influence attitudes toward waste disposal, enforcement of waste management techniques, energy values, and the economic importance of waste was achieved using a qualitative survey questionnaire. According to the Niger Delta Budget Monitoring Group (2023), Oleh has an estimated population size of 23,199. Applying Equation 1 at a 5% level of significance to obtain a representative sample size nnn resulted in 393. The survey questionnaire on waste management attitudes and perceptions was randomly distributed in marketplaces and the Delta State University campus in Oleh. 98% of the sample size returned the completed questionnaire with responses based on a three-point attitudinal scale: 1 for agreement, 2 for indecision, and 3 for disagreement. Interviews and respondents' opinions were structured based on the life cycle of municipal solid waste (MSW), as depicted in Figure 2.

Municipal Solid Waste (MSW) faces several challenges at its source, including littering before it reaches its destination or deliberate dumping in places such as open drains, roadsides, waterways, burrow pits, and bushes.

Mixed waste is sometimes collected at individual levels using unclassified containers before being hauled away by waste managers. Issues like poor protective covering of the buckets or breakdowns during collection contribute to problems with trucking-related littering. Plastics, batteries, cans, and glass bottles are often salvaged for recycling at dumpsites, while other waste is frequently burned directly, further harming the environment and posing significant health risks (Albanna, 2012; Ferronato and Torretta, 2019). Data matrices consisting of 61 columns by 46 rows of dependent and independent variables were created from the responses, as shown in Equation 3.

$$M = m \times n = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & a_{24} & \cdots & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & a_{34} & \cdots & \cdots & a_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{m1} & a_{m2} & a_{m3} & a_{m4} & \cdots & \cdots & a_{mn} \end{bmatrix} \quad (3)$$

The point of view of the respondents was examined using factor analysis, a Microsoft Excel (2016) add-on program (Liu et al., 2003; Wang and Xiao, 2004). Factor analysis is a technique that assesses if various variables, such as waste management economic significance, attitude toward waste, policy enforcement, and energy value, are linearly related. Each variable is regressed against the factors to test their loadings (Liu et al., 2003). Following the methodology outlined by Liu et al. (2003), factors were identified using principal component analysis (PCA), and data adequacy was evaluated using the Kaiser-Meyer-Olkin (KMO) normalization test. An unrotated factor matrix typically suggests the need for additional iterations, potentially under the theory that the best result is more likely achieved through further iterations under the same conditions.

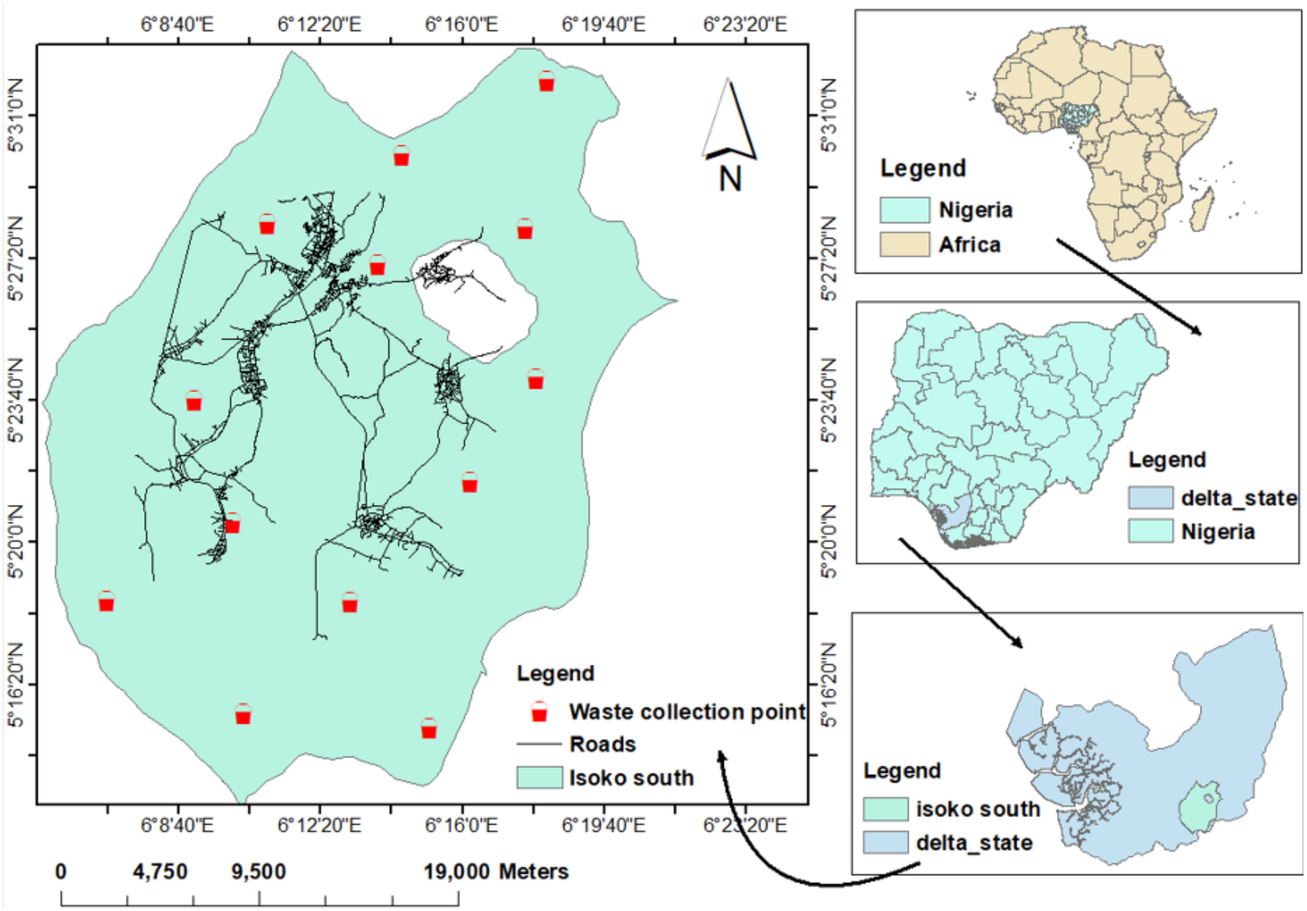

Figure 1. Map of Oleh municipal area.

According to Wang and Xiao (2004), factor loadings in a factor matrix are considered medium if they are around 0.500, significant if around 0.700, and excellent if close to 0.900.

Desa et al. (2011) noted that variables were created to investigate respondents' attitudes toward the implications of waste on the environment and its potential as an energy resource, among other derived benefits. The degree of variance in each variable is accounted for by their communalities as shown in Equation 4.

$$\hat{h}_i = \sum_{j=1}^{m} \hat{i}_{ij}^{2} \quad (4)$$

Equation 4 illustrates how the communalities of each variable account for variance in each variable, where $\hat{h}_i$ is the communality, $\hat{i}^2$ is the squared loadings for each loading. The frequency of the mode is described by the eigenvalues, which also illustrates the potential impact of each variable on the use of other products or the deployment of waste to energy. Additionally, the variance's eigenvalue is calculated in relation to its percentile. It is significant to remember that a unity in the eigenvalues ($\lambda = 1$) represents a cutoff for variable-based factor selection. The scree plot serves as an illustration of the link between the eigenvalues and the variables' constituent parts. The SWOT analysis (Figure 3) was used to further validate the factor analysis results.

Essentially, it is a straight forward but effective tool for determining a project's or organization's resource capabilities and weaknesses, market opportunities, and external threats to the project's or organization's future (Rachid and El Fadel, 2013). The advantages of disposal sites and the generation of jobs are just two of the numerous cost-effective and ecologically friendly advantages of waste management (Kalogo et al., 2007). Environmental impact assessment, waste management, and planning and development scenarios are just a few areas where SWOT analysis is used to organize and evaluate information (Nikolaou and Evangelinos, 2010; Rachid and El Fadel, 2013).

RESULTS AND DISCUSSION

Overview: Municipal waste composition

Figure 4 depicts the waste composition, highlighting food waste as the predominant component, accounting for 45% of the total. Following closely are plastic waste (including empty bottles, sachets, and packs) at 19%, paper waste also at 19%, miscellaneous glass at 4%, metals at 3%, and unclassified waste at 5%. This composition reflects the typical waste profile found in communities with predominantly low-income residents, characteristic of Oleh, Nigeria, and much of Sub-Saharan

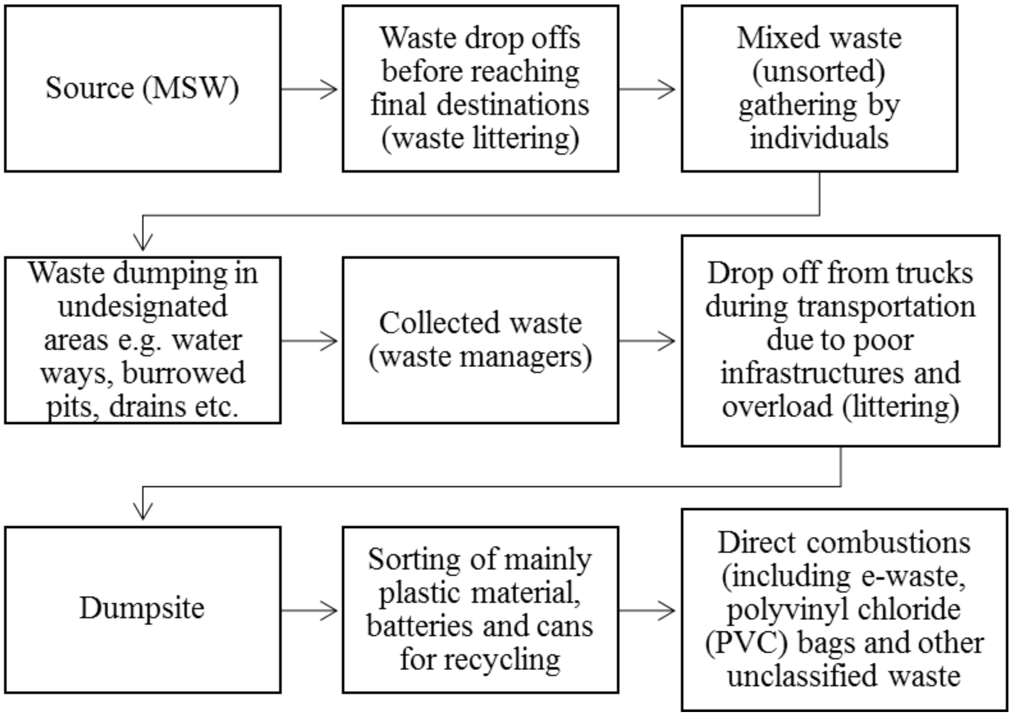

Figure 2. Flowchart of the current scenario.

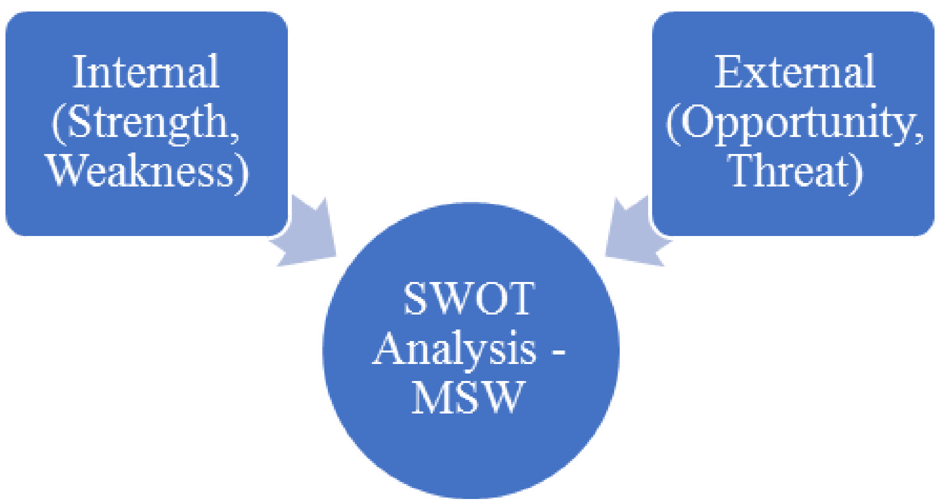

Figure 3. SWOT analysis framework.

Africa (Amuda et al., 2014; Ayomoh et al., 2008; Oyelola and Babatunde, 2008).

Analyses of attitudinal perception

The results of factor analysis after rotation and extraction are shown in Tables 1, 2, 3, 4, 5, 6 and 7. In examining Factor 1 with a loading of 0.7168, it is evident that respondents recognize the significant potential value of waste, particularly the value of digestate waste as a material (0.6909) and as a soil conditioner. Digestates, known for their rich bacterial consortiums as highlighted by Isagba et al. (2023), can effectively foster microbial multiplication, thereby supporting plant growth. Interestingly, the analysis revealed a lack of awareness among respondents regarding the potential of waste for energy production for heating and power generation.

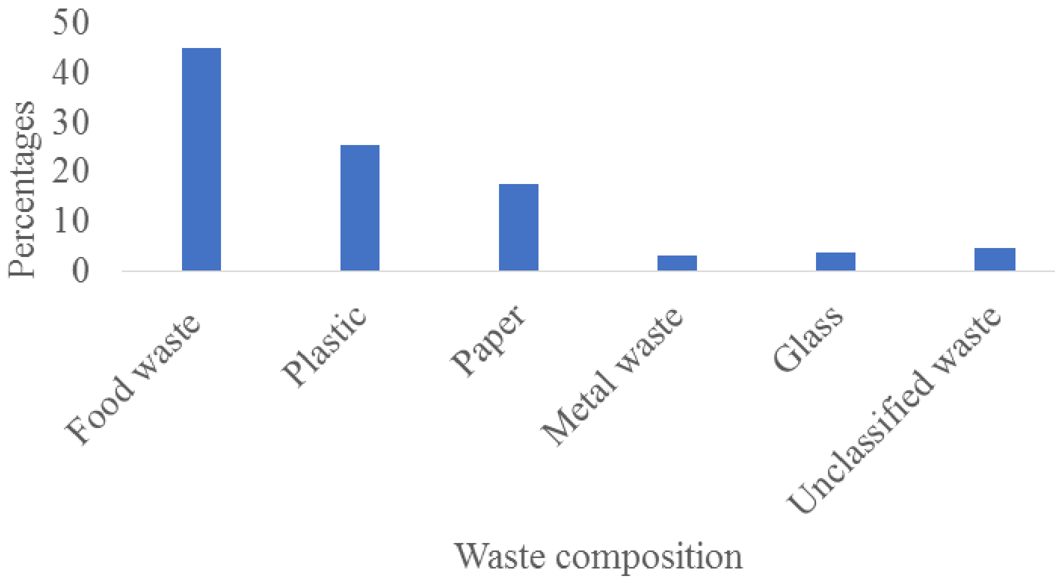

Figure 4. Composition of municipal solid waste.

Table 1. Factor 1.

Variable description	Acronym	Score	Factor loading
I am not aware of any rules and regulations on waste management	ARR	3	-0.5011
I keep a blind eye when I notice anyone disposing of waste at unauthorized places	UID	3	-0.5980
I am aware that I can derive energy from my waste	DEW	1	0.5711
Biogas can be derived from biodegradable waste	BBW	1	0.5765
Biomass waste can be converted to fuel for heating and for power generation	BCF	1	0.6860
Biogas can be used as fuel for heating and power generation	BHP	1	0.5606
Bio-fertilizer from waste treatment is useful for food production	BFP	1	0.6909
I am aware of waste sorting and segregation	WSS	1	0.5052
We are able to generate income from our waste	GIW	1	0.7168

Table 2. Factor 2.

Variable description	Acronym	Score	Factor loading
I dropped off waste anywhere	DWA	1	0.7601
I dump waste in undesignated places because it gets picked up by waste managers	DWU	1	0.5204
I am aware of the health implications of open and indiscriminate dumping of waste	HII	3	-0.6100
I care less about rules and regulations at the point of dumping my waste	DCR	1	0.5523

Moreover, some respondents expressed disagreement with conforming to established norms and regulations governing waste disposal (loading factor of 0.5011) and exhibited lower awareness of relevant policies (loading factor of 0.5980).

As shown in Table 2, some respondents indicated scores of 0.5204 and 0.5523, indicating their lack of awareness regarding norms and regulations and their adherence to best practices in waste management, respectively. Notably, a respondent scored 0.7601, acknowledging the adverse effects of indiscriminate waste disposal on health, as corroborated by studies (Ezechi et al., 2017; Igoni et al., 2007; Ugwu et al., 2020). The data presented in Table 3 underscores the evident lack of awareness among respondents regarding the significance of waste managers in ensuring efficient

Table 3. Factor 3.

Variable description	Acronym	Score	Factor loading
Waste managers are efficient in keeping the environment clean	WME	2	-0.5140
I am aware of the regulations on waste management	AWR	2	-0.5124
I engage in sorting of my waste	ESW	3	-0.6553
I have supported the authorities in enforcing relevant waste laws and regulation	SAE	3	-0.5301
We practice segregation of waste	PSW	3	-0.5858

Table 4. Factor 4.

Variable description	Acronym	Score	Factor loading
Government is responsible for cleaning the environment	GRE	1	-0.5099
I am not aware of waste regulatory bodies in Nigeria	WRO	1	-0.5738
I am not aware of any policy on waste management	PWM	1	-0.5472

Table 5. Factor 5.

Variable description	Acronym	score	Factor loading
Environmental sanitation is the responsibility of everyone	ESE	1	-0.5694

Table 6. Factor 6.

Variable description	Acronym	Score	Factor loading
I am not aware of any rules and regulations on waste management	ARR	3	0.5117
I am not aware of any waste and environmental enforcement agency	WEA	1	0.5599
Some of our raw materials are internally recycled materials	RIR	2	0.5726

Table 7. Factor 7.

Variable description	Acronym	Score	Factor loading
Environmental cleanliness is my responsibility	ECR	3	-0.5962
I am responsible for keeping my environment clean	IRE	1	-0.5467

waste management, a critical aspect for maintaining environmental cleanliness as highlighted in previous research (Ezechi et al., 2017).

Furthermore, respondents' perspectives on waste management regulations appear ambiguous (-0.5124). Additionally, they expressed a lack of awareness regarding the roles and effectiveness of waste management authorities, and disagreed with the notion of sorting and segregating waste at its source before disposal in designated areas, as noted in previous studies (Okey et al., 2013; Oyelola and Babatunde, 2008).

Factor 4 showed a moderate alignment with Factor 3, indicating respondents' lack of understanding about the roles of waste and environmental enforcement agencies. There was also discordance concerning respondents' limited awareness of waste management regulations. Moreover, respondents disagreed about the feasibility of recycling garbage into valuable products, echoing findings from previous studies (Babaei et al., 2015; Kofoworola, 2007).

Factor 5 revealed a tentative agreement regarding the understanding that the government holds responsibility for large-scale waste management. This highlights the necessity for a clearly defined waste management hierarchy spanning from individuals to corporations on

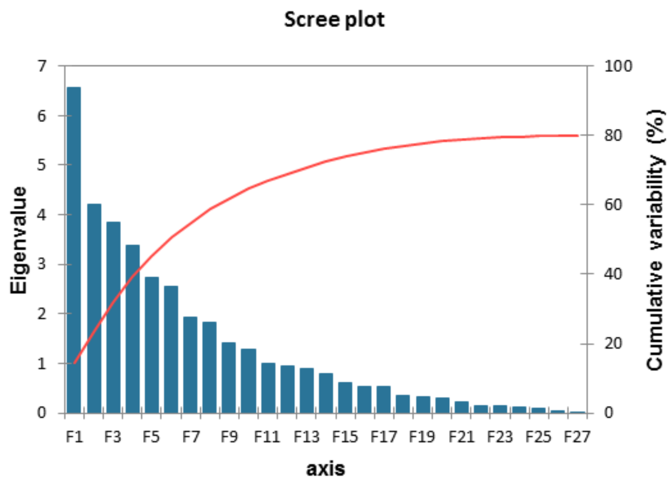

Figure 5. Eigenvalues.

both micro and macro scales. However, this understanding contrasts with the prevalent lack of comprehension in many Nigerian communities concerning the roles of organizations overseeing waste management at local and state government levels. This knowledge gap could significantly contribute to the country's overall poor waste management situation. Factor 6 reveals a lack of consensus regarding everyone's accountability for environmental sanitation and waste management (Ayomoh et al., 2008; Kalogo et al., 2007).

As stated in Table 7, Factor 7 supports Factor 6 on everyone's obligation to maintain environmental cleanliness. Figure 5 illustrates the findings of a factor analysis using eigenvalues for each piece of data and a scree plot to show them. It shows respondents' perspectives on the attitudinal scale evaluated based on variable communalities. To illustrate the structure and relationship between the component variables, an eigenvalue greater than one (**λ** = 1) and subjected to subsequent cluster analyses as shown in Figure 6.

Essentially, the factor analysis underscores substantial gaps in both understanding and compliance with laws and regulations governing waste management. These gaps notably influence people's waste disposal practices, resulting in the improper disposal of waste in non-designated areas. Figure 7 illustrates the distribution of factors and their correlations with the variables. The primary latent factor (F1) emphasizes generating heat and energy from waste and utilizing waste byproducts as soil conditioners, both pivotal contributing elements. On the other hand, Factor (F2) indicates a lack of concern regarding the adverse health effects stemming from improper waste disposal.

The varimax rotation signifies subsequent iterations aimed at isolating crucial factors and their relationships (Figure 7). In D1, factor loadings highlight latent factors such as deriving energy from waste, converting waste into fuel for heating and power generation, utilizing energy byproducts as bio-fertilizer for food production, and generating income from waste. On the other hand, the discriminative power (D2) identifies factors linked to indiscriminate waste disposal, irrespective of its health consequences, and potential penalties imposed by authorities.

The key observations from the summary of factors were depicted in Figure 8. Among the prevalent traits, attitudes favoring waste management norms and regulations were notably lacking. Additionally, there was a limited understanding of waste's potential for energy production, which consequently hindered the perception of generating revenue from waste. Despite the absence of considerations for energy efficiency or gas emissions, there was substantial support for some form of plastic recycling, aligning with previous studies (Ajieh et al., 2021b; Babaei et al., 2015; Kofoworola, 2007).

Strength weakness opportunities and threats

The potential strengths and latent opportunities for Municipal Solid Waste (MSW) applications were evaluated based on the findings derived from both factor and SWOT analyses, outlined in Table 8.

There's a substantial volume of Municipal Solid Waste (MSW) available for potential energy utilization. The utilization of biomass or waste as a fuel source in power plants has been extensively documented worldwide (Consonni et al., 2011; Ferronato and Torretta, 2019; Makarichi et al., 2019; Valizadeh, 2020). Additionally, pretreating waste for use as an alternative to inorganic fertilizers or for producing biogas, contributing to heat and electricity generation, has gained attention (Franke-Whittle et al., 2014; Isagba et al., 2023; Ren et al., 2018).

The utilization of MSW offers multiple advantages such

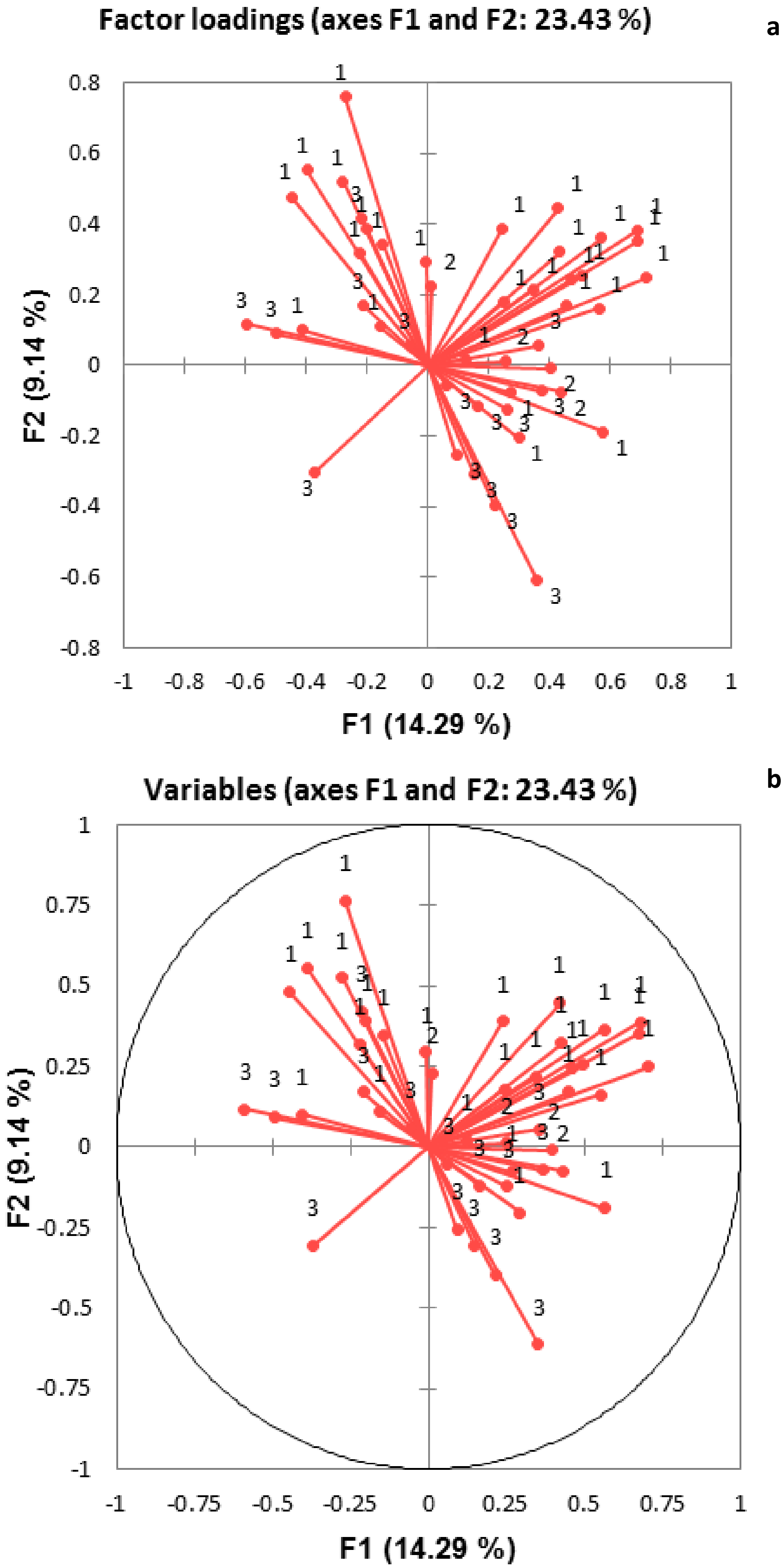

Figure 6. (a) Factor pattern. (b) Correlations between variables and factors.

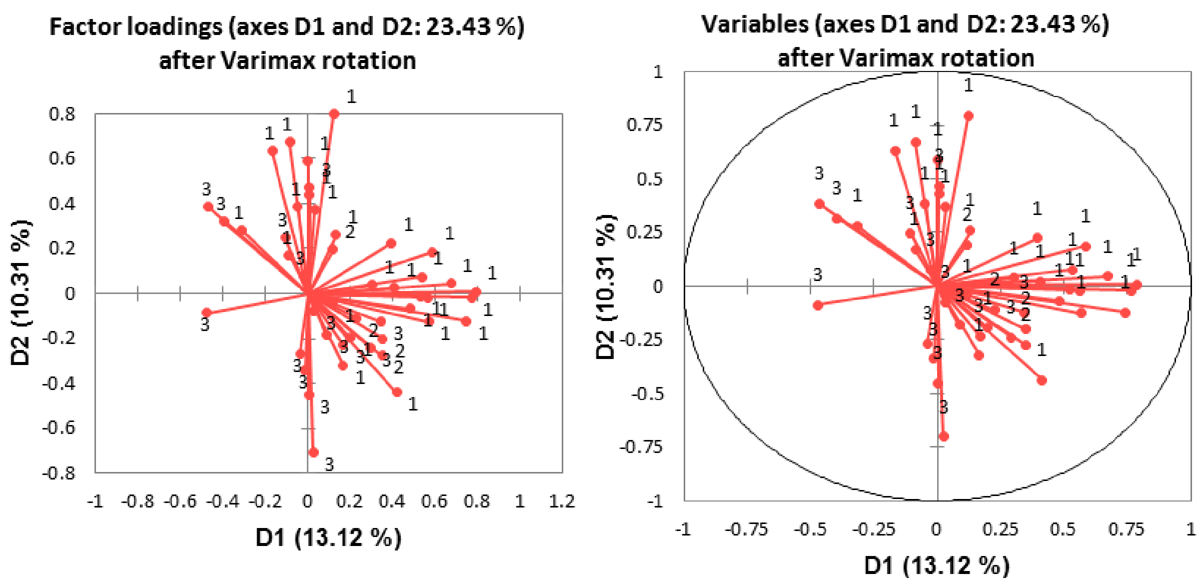

Figure 7. Factor loadings after varimax rotation.

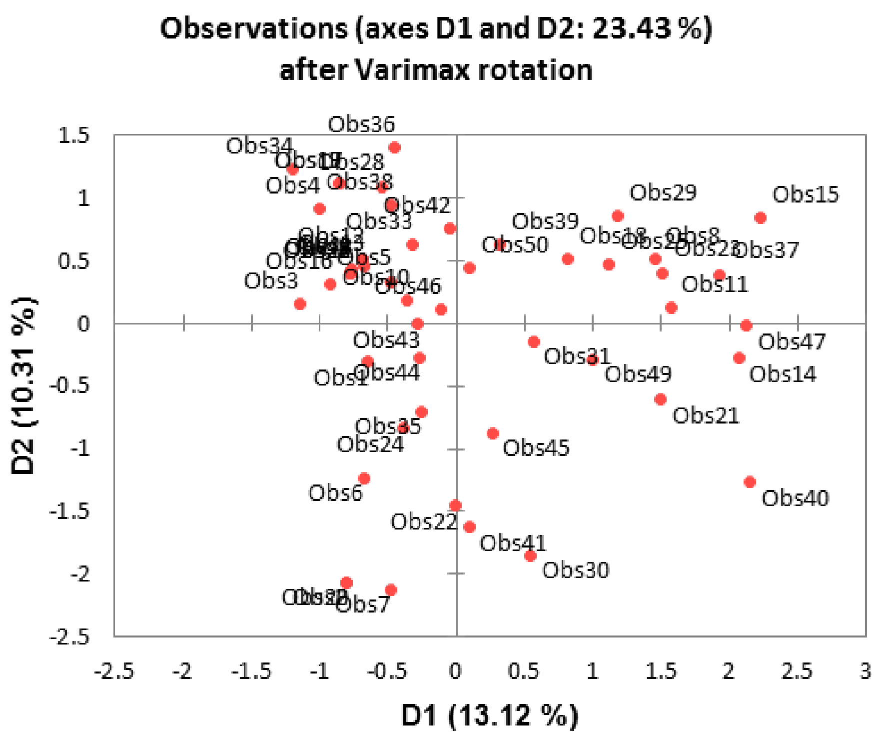

Figure 8. Summary of observations.

as job creation, economic opportunities, and alignment with policies. However, the lack of understanding regarding waste management causes deficiencies, leading to environmental concerns (Ezechi et al., 2017; Igoni et al., 2007; Uwadiegwu and Chukwu, 2013). Challenges encompass improper waste disposal and non-compliance with regulations, which pose health risks (Ferronato and Torretta, 2019), inadequate staffing and training for waste managers, and insufficient funding for waste management facilities. Uncontrolled burning of

Table 8. SWOT analysis for MSW.

Parameter	Positive	Negative
	Strengths	**Weaknesses**
Internal forces	There is an abundance of MSW particularly food waste	Poor awareness
	Digestate for soil conditioning	Poor waste disposal due to apathy or Poor compliance to regulations
	Available human resources	Health implications such as high rate of disease spread.
	Available knowhow/technology transfer	Poor waste management and insufficient waste managers
	Huge employment opportunity	Absence of waste sorting and segregation culture
	Revenue generation	Unclear and not well-defined roles/responsibility for individuals, organizations, and various levels of government in waste management
	Energy generation	Inadequate funding
	Recycling	Poor infrastructure
	Government policies/regulations	Land fills
		Unregulated burning
	Opportunities	**Threats**
External forces	Bio-fertilizer	Climate change/global warming
	Technology transfer	Effects from toxic waste
	Knowledge transfer	
	Sustainable/Green production	

unsorted MSW exacerbates garbage-related air pollution, contributing to climate change (Emodi et al., 2015). A waste management model was devised to synthesize the gaps, strengths, opportunities, weaknesses, and threats hindering effective MSW management. Figure 8 illustrates the separation of waste at its source into biodegradable and non-biodegradable components, emphasizing the importance of recycling recoverable waste and effectively managing non-combustible waste to avoid exposure to potentially hazardous contaminants. Furthermore, the potential for using food waste and feces to generate biogas and employing the residuals as soil conditioners for agriculture is recognized (Ajieh et al., 2020; Ihoeghian et al., 2023; Isagba et al., 2023; Ren et al., 2018). However, in the presence of hazardous materials, pyrolysis and gasification stand as valuable conversion options to maximize energy yields while minimizing pollution-related consequences (Ionescu et al., 2013; Venderbosch et al., 2010). It is crucial to establish coordination among government policies, individual behavioral changes, and concerted efforts by waste managers to drive and implement a robust waste management system.

Oguntoyinbo (2012) emphasized the pivotal roles of waste managers in both environmental and socioeconomic domains. As depicted in Figure 9, the consequential outcomes of these roles lead to sustainable waste recycling, energy production, and biofertilizer creation, exerting a multiplier effect on fostering a cleaner environment, ensuring energy security, and bolstering food security. Similarly, the National Social Register (NSR) compiled by the National Social Safety Nets Coordinating Office (NASSCO) under the Federal Ministry of Humanitarian Affairs, Disaster Management, and Social Development has enumerated 12,828,135 Poor and Vulnerable Households (PVHHs), encompassing 52,838,729 individuals residing across 128,249 villages in 737 local government areas (LGAs) in Nigeria, as of September 30th, 2022. A strategically designed and well-maintained waste management program, with an emphasis on waste-to-wealth initiatives, could uplift these PVHHs from poverty. Engaging these households in waste sorting and recycling could potentially generate approximately N10,000 per week, translating to N40,000 monthly income for a single household—surpassing Nigeria's current minimum wage (Figure 10 for an illustration of this

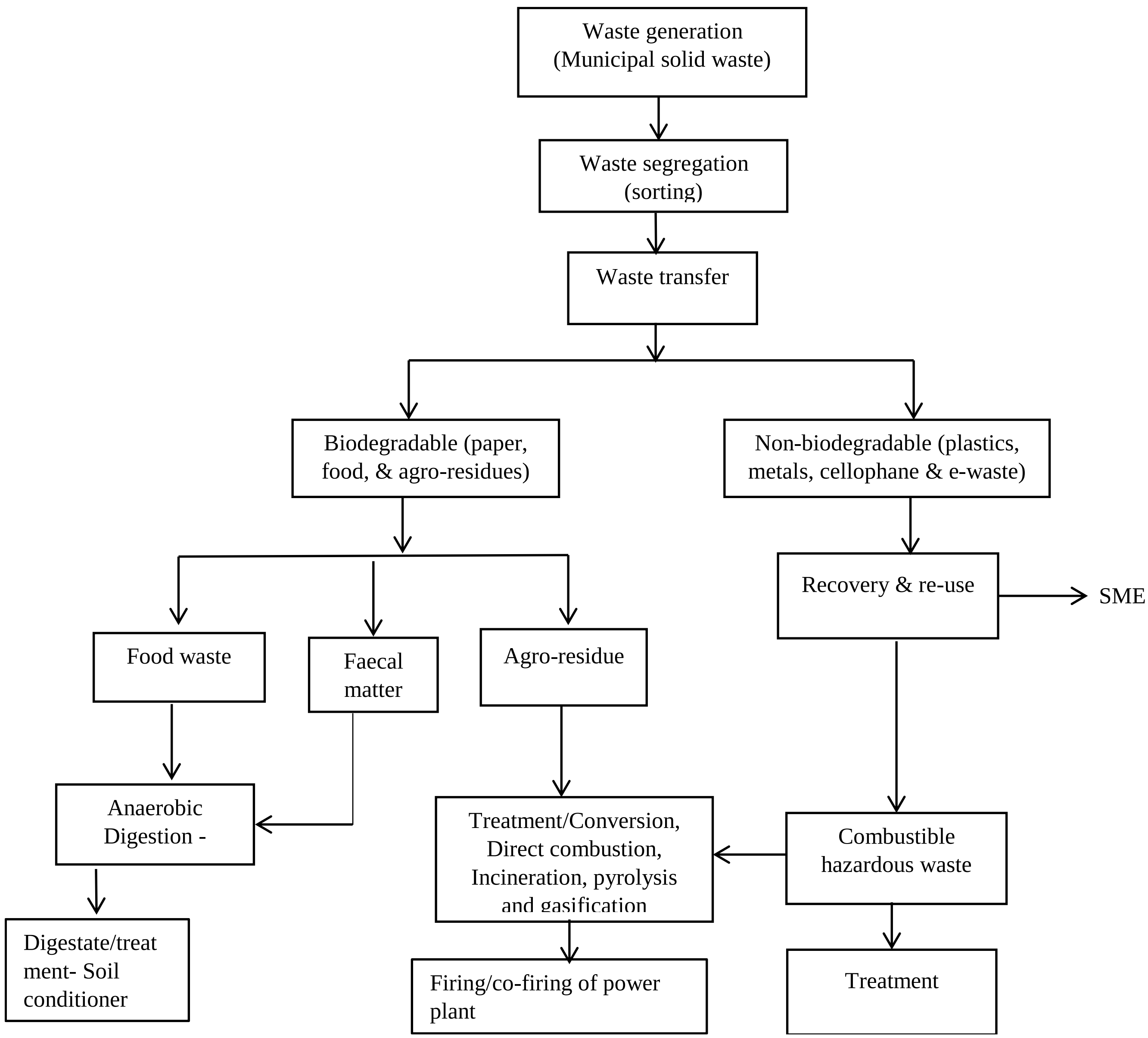

Figure 9. Flow chart of proposed waste management model.

concept).

Sustainable waste management holds the promise of enhanced income, a cleaner environment, and an upsurge in Gross Domestic Product (GDP). The outcomes of this research robustly underscore the lack of awareness concerning the economic prospects entailed in recycling waste, harnessing it for energy, and utilizing it as biofertilizer to enrich soil for enhanced food production, despite the implementation of policies. The conversion process, depending on the intended objective, primarily involves biochemical and thermochemical pathways. Waste with a substantial amount of biodegradable organic matter and high moisture content undergoes biochemical treatment, as depicted in Figure 11 (Ajieh et al., 2020).

Waste to energy

Several studies highlight that biochemical techniques represent the most feasible and environmentally conscientious methods for converting waste into energy (Ravi et al., 2017; Shobana et al., 2021). The interaction of biomass derived from waste (fuel) with air at specific temperatures often results in heat release, as illustrated in Figure 12. The combustible elements of Municipal Solid Waste (MSW) consist of carbon (C), hydrogen (H), and oxygen (O), as demonstrated in Equations 5 and 6.

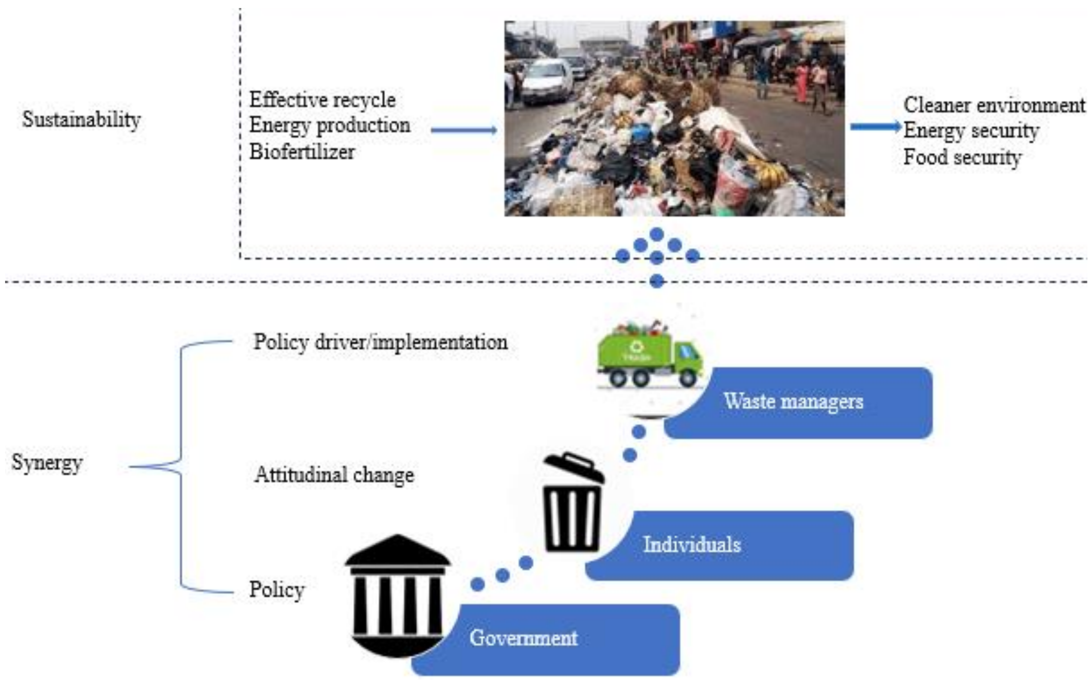

Figure 10. Sustainable waste recovery.

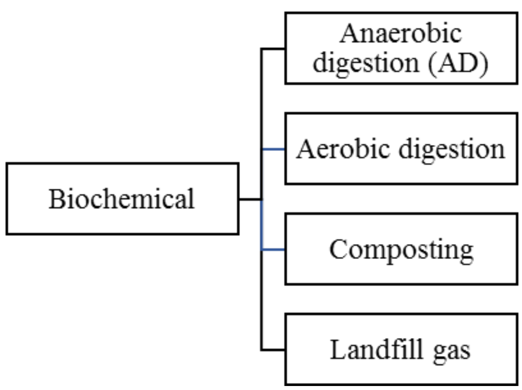

Figure 11. Biochemical treatment.

$$C + O_2 \rightarrow CO_2 \quad (5)$$

$$2H_2 + O_2 \rightarrow 2H_2O \quad (6)$$

In incineration, carbon dioxide is obtained from carbon and water from hydrogen as shown in reactions 5 and 6. Temperature, pressure, biomass particle size, heating rate, residence time, heat loss, and catalysts collectively influence the outcomes of pyrolysis. Char is a nonvolatile substance with high carbon content, remains after the process.

The composition of the substance and the rate of heating significantly impact the gases produced during pyrolysis. Gaseous pyrolysates commonly resulting from the pyrolysis of cellulosic materials include carbon dioxide (CO_2), carbon monoxide (CO), ammonia (NH_3), methane (CH_4), hydrogen (H_2), hydrogen cyanide (HCN), and water vapor (H_2O). Additionally, the hydrocarbon fraction may contain methane, polycyclic aromatic hydrocarbons (PAHs), and a tar mixture composed of oxygenated species such as phenols, acids, light aromatics, and heavy tars (C1-C36 components) like pyrene and anthracene (Ayomoh et al., 2008). During cellulose degradation, the process may involve cleavage of the glucosidic bond or dehydration, typically occurring below 300°C. This results in gradual charring and depolymerization of the macromolecules. Higher temperatures lead to rapid glucosidic bond cleavage and evaporation of products. Cellulosic pyrolysis follows two pathways: one involves depolymerization forming levoglucosan, which further decomposes into flammable volatiles, and the other leads to complete dehydration to produce water and char.

The energy content in the char from pyrolysis ranges from 20 to 60%, contingent on the raw solid feedstock type and process parameters (Ionescu et al., 2013; Makarichi et al., 2019). Gasification involves transforming volatile hydrocarbons and char into syngas or producer gas. It's a crucial step in converting solid biomass into gaseous products and effectively harnessing the energy within biomass. While pyrolysis and gasification recover the chemical value of waste for secondary fuels, incineration mainly recovers the waste's energy value (Ionescu et al., 2013; Makarichi et al., 2019), as shown in Figure 13.

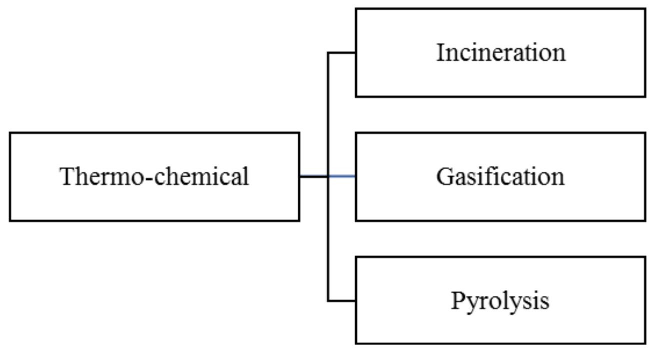

Figure 12. Thermo-chemical treatment methods.

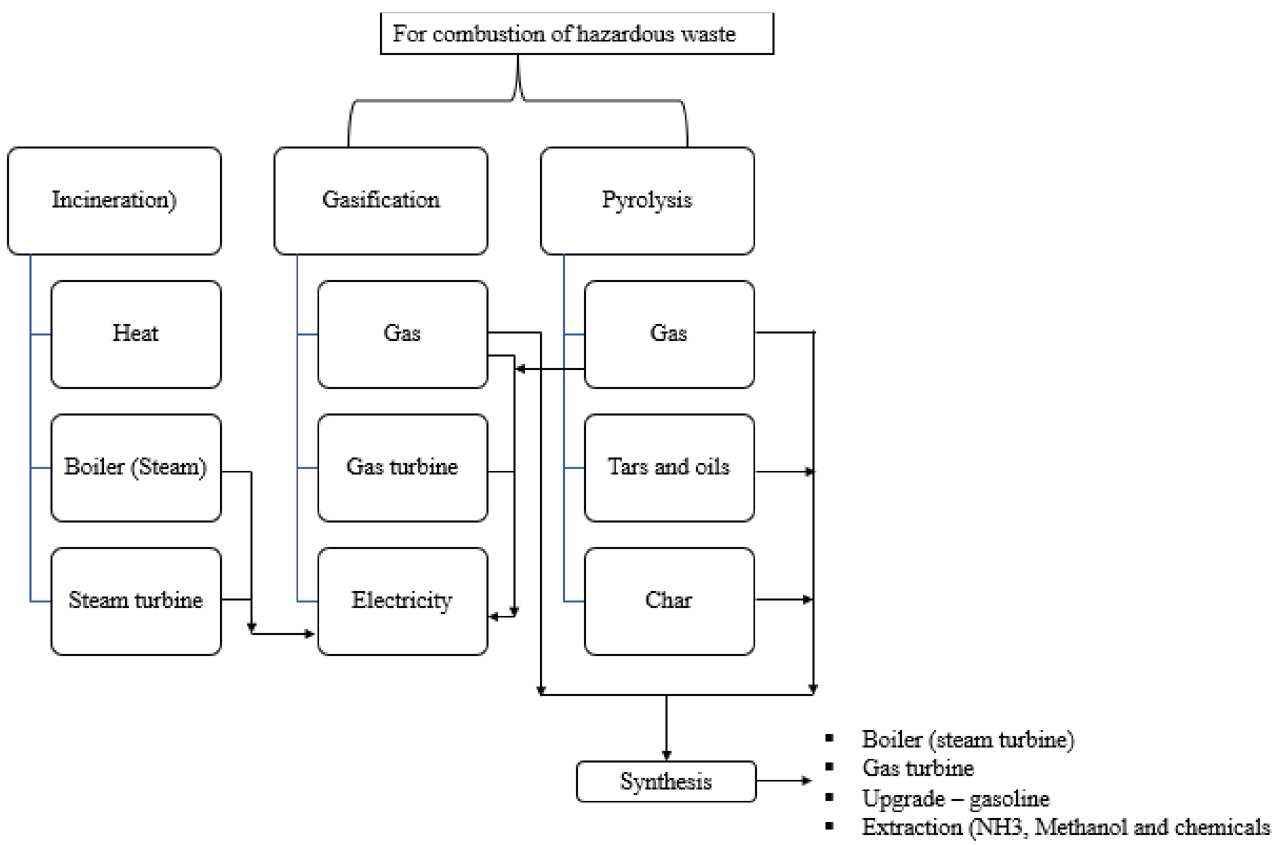

Figure 13. Energy values of MSW.

Converting Municipal Solid Waste (MSW) into energy offers numerous advantages, such as a higher calorific value, consistent physical and chemical compositions, reduced levels of pollutants like particulate matter (PM) emissions, decreased surplus air requirement for combustion, and easier storage, processing, and transportation. These benefits have been highlighted in studies (Ajieh et al., 2023; Ionescu et al., 2013). Moreover, sustainable waste recovery yields further advantages, including enhanced food production, a more pristine environment, and versatile energy generation encompassing both heat and electricity.

Conclusion

MSW management in Nigerian cities is emerging as a critical environmental challenge, contributing significantly to the spread of diseases and causing issues such as the blockage of waterways due to improper waste disposal and non-compliance with waste management regulations.

The identified weaknesses in the current scenario include inadequate waste management infrastructure, insufficient training, and a lack of clear delineation of roles among individuals, organizations, and government entities. Failure to address these issues can lead to severe consequences in terms of environmental pollution and its impact on climate change.

The study emphasizes the importance of recognizing the strengths and opportunities within the waste management sector to mitigate potential environmental hazards. The findings reveal a notable gap in understanding the potential of waste as an energy resource, despite its proven benefits in recycling industries and as a soil conditioner. Factor analysis and SWOT analysis were employed to elucidate these aspects, forming the basis for a waste management model that synthesizes gaps, opportunities, weaknesses, and potential threats.

Importantly, the study underscores the positive aspects of MSW utilization, particularly in creating numerous employment opportunities within the developing sectors of MSW management and small and medium enterprises (SMEs), while also bolstering energy security. Harnessing the strengths and possibilities within MSW management is crucial for addressing environmental challenges, promoting sustainable practices, and capitalizing on the economic and employment potential of this evolving sector.

RECOMMENDATIONS

Additionally, and from the foregoing, the following recommendations are suggested:

a) Advocacy on the 4R (reduce, reuse, recover and recycle) of waste management for mass education of human population.
b) Promote circularity concept in waste management hierarchy for improved environment, energy and soil conditioning for enhanced crop and/or food production.
c) Collaboration/partnership engagement among stakeholders including governmental, non-governmental, private and community-based organizations in creating awareness on waste management.
d) Incentivize waste collection and segregation into the waste management value chain to boost income generation and waste management at source.
e) Introduction of advance waste management technology for enhanced waste management outcomes that is, clean environment and sustainable energy
f) Build operational synergy among stakeholders in waste management and emerging business to create employment and overall addition to Gross Domestic Product (GDP).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Ackerman F (2000). Waste management and climate change. Local Environment 5(2):223-229.

Ajieh MU, Isagba ES, Ihoeghian N, Edosa VIO, Amenaghawon A, Oshoma CE, Erhunmwunse N, Obuekwe IS, Tongo I, Emokaro C, Ezemonye LIN (2021a). Assessment of sociocultural acceptability of biogas from faecal waste as an alternative energy source in selected areas of Benin City, Edo State, Nigeria. Environment, Development and Sustainability.

Ajieh MU, Isagba ES, Ihoeghian N, Edosa VIO, Amenaghawon A, Oshoma CE, Erhunmwunse N, Obuekwe IS, Tongo I, Emokaro C, Ezemonye LIN (2021b). Assessment of sociocultural acceptability of biogas from faecal waste as an alternative energy source in selected areas of Benin City, Edo State, Nigeria. Environment, Development and Sustainability 23(9):13182-13199.

Ajieh MU, Ogbomida TE, Onochie UP, Akingba O, Kubeyinje BF, Orerome OR, Ogbonmwan SM (2020). Design and construction of fixed dome digester for biogas production using cow dung and water hyacinth. African Journal of Environmental Science and Technology 14(1):15-25.

Ajieh MU, Owamah HI, Edomwonyi-Otu LC, Ajieh GI, Aduba P, Owebor K, Ikpeseni SC (2023). Characteristics of fuelwood perturbation and effects on carbon monoxide and particulate pollutants emission from cookstoves in Nigeria. Energy for Sustainable Development 72:151-161.

Albanna M (2012). Solid waste management options and their impacts on climate change and human health. In Environmental Protection Strategies for Sustainable Development (pp. 499-528). Springer Netherlands.

Ali I, Ahmad M, Ganat T (2021). Development of a new formulation for enhancing the rheological and filtration characteristics of low-solids WBMs. Journal of Petroleum Science and Engineering 205.

Alzate S, Restrepo-Cuestas B, Jaramillo-Duque Á (2019). Municipal solid waste as a source of electric power generation in Colombia: A techno-economic evaluation under different scenarios. Resources 8(1).

Amasuomo E, Baird J (2016). The Concept of Waste and Waste Management. Journal of Management and Sustainability 6(4):88.

Amuda OS, Adebisi SA, Jimoda LA, Alade AO (2014). Journal of Sustainable Development Studies Challenges and Possible Panacea to the Municipal Solid Wastes Management in Nigeria 6(1):64-70.

Ayomoh MKO, Oke SA, Adedeji WO, Charles-Owaba OE (2008). An approach to tackling the environmental and health impacts of municipal solid waste disposal in developing countries. Journal of Environmental Management 88(1):108-114.

Babaei AA, Alavi N, Goudarzi G, Teymouri P, Ahmadi K, Rafiee M (2015). Household recycling knowledge, attitudes and practices towards solid waste management. Resources, Conservation and Recycling 102:94-100.

Bagherian MA, Mehranzamir K, Rezania S, Abdul-Malek Z, Pour AB, Alizadeh SM (2021). Analyzing utilization of biomass in combined heat and power and combined cooling, heating, and power systems. In Processes 9(6). MDPI AG.

Barr S, Gilg AW, Ford NJ (2001). A conceptual framework for understanding and analysing attitudes towards household-waste management. Environment and Planning A 33(11):2025-2048.

Consonni S, Giugliano M, Massarutto A, Ragazzi M, Saccani C (2011). Material and energy recovery in integrated waste management systems: Project overview and main results. Waste Management 31(9-10):2057-2065.

Desa A, Ba'yah Abd Kadir N, Yusooff F (2011). A study on the knowledge, attitudes, awareness status and behaviour concerning solid waste management. *Procedia* - Social and Behavioral Sciences 18:643-648.

Doaemo W, Dhiman S, Borovskis A, Zhang W, Bhat S, Jaipuria S, Betasolo M (2021). Assessment of municipal solid waste management system in Lae City, Papua New Guinea in the context of sustainable development. Environment, Development and Sustainability 23(12):18509-18539.

Drimili E, Herrero-Martin R, Suardiaz-Muro J, Zervas E (2020). Public views and attitudes about municipal waste management: Empirical evidence from Athens, Greece. Waste Management and Research 38(6):614-625.

Emodi NV, Dauda SY, Yusuf SD (2015). Addressing Climate Change Impact on the Energy System View project Radiation Physics View project Improving Electricity Access in Nigeria: Obstacles and the Way Forward. International Journal of Energy Economics and Policy 5(1):335-351. www.econjournals.com

Ezechi EH, Nwabuko CG, Enyinnaya OC, Babington CJ (2017). Municipal solid waste management in Aba, Nigeria: Challenges and prospects. Environmental Engineering Research 22(3):231-236.

Ezemonye LIN, Ogbomida ET, Ajieh MU (2018). CHAPTER EIGHT THE PROBLEM OF ENERGY SECURITY IN AFRICA: PROSPECTS AND CHALLENGES. Contemporary Issues in Africa's Development: Whither the African Renaissance? 152 p.

Fernández-Nava Y, Del Río J, Rodríguez-Iglesias J, Castrillón L, Marañón E (2014). Life cycle assessment of different municipal solid waste management options: A case study of Asturias (Spain). Journal of Cleaner Production 81:178-189.

Ferronato N, Torretta V (2019). Waste mismanagement in developing countries: A review of global issues. In International Journal of Environmental Research and Public Health 16(6). MDPI AG.

Franke-Whittle IH, Confalonieri A, Insam H, Schlegelmilch M, Körner I (2014). Changes in the microbial communities during co-composting of digestates. Waste Management 34(3):632-641.

Hou G, Chen T, Ma K, Liao Z, Xia H, Yao T (2019). Improving social acceptance ofwaste-to-energy incinerators in China: Role of place attachment, trust, and fairness. Sustainability (Switzerland) 11(6).

Igboanugo A, Ajieh M, Azi S (2015). Performance Evaluation of a Biomass Stove Using Particulate Matter and Carbon Monoxide Emission from Briquette and Fuel Wood. Nigerian Journal of Technology 34(3):484.

Igoni AH, Ayotamuno MJ, Ogaji SOT, Probert SD (2007). Municipal solid-waste in Port Harcourt, Nigeria. Applied Energy 84(6):664-670.

Ihoeghian NA, Amenaghawon AN, Ogofure A, Oshoma CE, Ajieh MU, Erhunmwunse NO, Obuekwe IS, Edosa VIO, Tongo I, Emokaro C, Ezemonye LIN, Semple KT, Martin AD (2023). Biochar-facilitated batch co-digestion of food waste and cattle rumen content: An assessment of process stability, kinetic studies, and pathogen fate. Green Technologies and Sustainability 1(3):100035.

Ionescu G, Rada EC, Ragazzi M, Mărculescu C, Badea A, Apostol T (2013). Integrated municipal solid waste scenario model using advanced pretreatment and waste to energy processes. Energy Conversion and Management 76:1083-1092.

Isagba ES, Ajieh MU, Oshoma CE, Amenaghawon A, Ogofure A, Obatusin V, Obuekwe IS, Tongo I, Ihoeghian N, Edosa VIO, Erhunmwunse N, Lag-Brotons AJ, Emokaro C, Ezemonye LIN, Semple KT (2023). Assessment of Anaerobic Digestate Amended with Wood Ash and Green Vegetable Matter and Impacts on Microbial Growth. Waste and Biomass Valorization.

Jetter J, Zhao Y, Smith KR, Khan B, Yelverton T, Decarlo P, Hays MD (2012). Pollutant emissions and energy efficiency under controlled conditions for household biomass cookstoves and implications for metrics useful in setting international test standards. Environmental Science and Technology 46(19):10827-10834.

Kalogo Y, Habibi S, Maclean HL, Joshi SV (2007). Environmental implications of municipal solid waste-derived ethanol. Environmental Science and Technology 41(1):35-41.

Kofoworola OF (2007). Recovery and recycling practices in municipal solid waste management in Lagos, Nigeria. Waste Management 27(9):1139-1143.

Liu RX, Kuang J, Gong Q, Hou XL (2003). Principal component regression analysis with SPSS. Computer Methods and Programs in Biomedicine 71(2):141-147.

Lohri CR, Diener S, Zurbrügg C (2014). Anaerobic Digestion of Biowaste in Developing Countries-Practical Information and Case Studies.

Luoranen M, Horttanainen M (2007). Feasibility of energy recovery from municipal solid waste in an integrated municipal energy supply and waste management system. Waste Management and Research 25(5):426-439.

Makarichi L, Kan R, Jutidamrongphan W, Techato KA (2019). Suitability of municipal solid waste in African cities for thermochemical waste-to-energy conversion: The case of Harare Metropolitan City, Zimbabwe. Waste Management and Research 37(1):83-94.

Nabegu AB (2010). An Analysis of Municipal Solid Waste in Kano Metropolis, Nigeria. Journal of Human Ecology 31(2):111-119.

Nikolaou IE, Evangelinos KI (2010). A SWOT analysis of environmental management practices in Greek Mining and Mineral Industry. Resources Policy 35(3):226-234.

Oguntoyinbo OO (2012). Informal waste management system in Nigeria and barriers to an inclusive modern waste management system: A review. In Public Health 126(5):441-447.

Ogwueleka TC (2013). Survey of household waste composition and quantities in Abuja, Nigeria. Resources, Conservation and Recycling 77:52-60.

Okey EN, Umana EJ, Markson AA, Okey PA (2013). Municipal solid waste characterization and management in Uyo, Akwa Ibom State, Nigeria. Transactions on Ecology and The Environment 173:1743-3541.

Owamah IH, Izinyon OC, Igbinewekan P (2017). Characterization and quantification of solid waste generation in the Niger Delta Region of Nigeria: a case study of Ogbe-Ijoh community in Delta State. Journal of Material Cycles and Waste Management 19(1):366-373.

Owebor K, Oko COC, Diemuodeke EO, Ogorure OJ (2019). Thermo-environmental and economic analysis of an integrated municipal waste-to-energy solid oxide fuel cell, gas-, steam-, organic fluid- and absorption refrigeration cycle thermal power plants. Applied Energy 239:1385-1401.

Oyelola OT, Babatunde (2008). Characterization of domestic and market solid wastes at source in Lagos metropolis, Lagos, Nigeria. In African Journal of Environmental Science and Technology 3(12).

Pandyaswargo AH, Onoda H, Nagata K (2012). Energy recovery potential and life cycle impact assessment of municipal solid waste management technologies in Asian countries using ELP model. International Journal of Energy and Environmental Engineering 3(1):1-11.

Rachid G, El Fadel M (2013). Comparative SWOT analysis of strategic environmental assessment systems in the Middle East and North Africa region. Journal of Environmental Management 125:85-93.

Rahardyan B, Matsuto T, Kakuta Y, Tanaka N (2004). Resident's concerns and attitudes towards Solid Waste Management facilities. Waste Management 24(5):437-451.

Ravi R, Vinu R, Gummadi SN (2017). Coulson and Richardson's Chemical Engineering, Fourth Edition Volume 3A Chemical and Biochemical Reactors and Reaction Engineering.

Ren C, Wang T, Xu Y, Deng J, Zhao F, Yang G, Han X, Feng Y, Ren G (2018). Differential soil microbial community responses to the linkage of soil organic carbon fractions with respiration across land-use changes. Forest Ecology and Management 409:170-178.

Shobana C, Rangasamy B, Hemalatha D, Ramesh M (2021). Bioaccumulation of silver and its effects on biochemical parameters and histological alterations in an Indian major carp Labeo rohita. Environmental Chemistry and Ecotoxicology 3:51-58.

Stratton SJ (2021). Population Research: Convenience Sampling Strategies. In Prehospital and Disaster Medicine 36(4):373-374). Cambridge University Press.

Tan RBH, Khoo HH (2006). Impact Assessment of Waste Management Options in Singapore. Journal of the Air and Waste Management Association 56(3):244-254.

Tucker P, Speirs D (2003). Attitudes and behavioural change in household waste management behaviours. Journal of Environmental Planning and Management 46(2):289-307.

Ugwu CO, Ozoegwu CG, Ozor PA (2020). Solid waste quantification and characterization in university of Nigeria, Nsukka campus, and recommendations for sustainable management. Heliyon 6(6).

Uwadiegwu BO, Chukwu KE (2013). STRATEGIES FOR EFFECTIVE URBAN SOLID WASTE MANAGEMENT IN NIGERIA. In European Scientific Journal 9(8).

Valizadeh J (2020). A novel mathematical model for municipal waste collection and energy generation: case study of Kermanshah city. Management of Environmental Quality: An International Journal 31(5):1437-1453.

Venderbosch RH, Ardiyanti AR, Wildschut J, Oasmaa A, Heeres HJ (2010). Stabilization of biomass-derived pyrolysis oils. Journal of

Chemical Technology and Biotechnology 85(5):674-686.
Wang S, Xiao F (2004). AHU sensor fault diagnosis using principal component analysis method. Energy and Buildings 36(2):147-160.