

Reducing Healthcare-Associated Infection (HAI) Risks Through Circular Economy Approaches to Medical Waste Management: An Empirical Analysis of Policy Interventions in Lagos, Nigeria

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Research Article

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Abstract

Healthcare-associated infections (HAIs) impose a substantial burden in low- and middle-income countries, and inadequate medical waste management is an underexamined contributor. This study investigated medical waste management practices across seven hospitals in Lagos, Nigeria, and assessed the potential of circular economy approaches to simultaneously reduce infection risk and improve resource efficiency. A convergent parallel mixed-methods study was conducted across seven purposively selected hospitals in Lagos State between January 2022 and December 2023, combining structured surveys (n = 336 healthcare workers; 87.5% response rate), semi-structured interviews (n = 21 key informants), and systematic direct observation of waste-handling practices. Chi-square tests with Cramér's V effect sizes examined associations between professional category, training, and waste-management knowledge and practice. The seven facilities operated 1245 beds and generated 215.56 kg of waste daily (0.181 kg/bed/day), comprising approximately 70% general and 30% infectious waste; improper segregation contaminated the entire waste stream, eliminating recycling potential. Professional category was strongly associated with waste-categorisation knowledge ($\chi^2 = 1344.0$, df = 20, $p < 0.001$, Cramér's V = 0.89), with sanitation workers showing the lowest knowledge despite the highest occupational exposure. Only 61.0% of respondents agreed that segregation should occur at the point of generation, 58.1% correctly identified the colour-coding system, and only 42.3% had received formal training. Only 57% of facilities had adequate waste storage, and collection intervals routinely exceeded WHO recommendations. Inadequate medical waste management is a significant, underrecognised contributor to HAI risk in this setting. Integrating circular economy principles - waste minimisation, source segregation, safe recycling, and formalisation of waste-handling work - with infection prevention and control could simultaneously reduce transmission risk and yield an estimated 15–20% in cost savings. Seven policy interventions are proposed, spanning national legislation, mandatory segregation, appropriate treatment technology, formal recycling with worker protections, continuous training, stronger enforcement, and community engagement.

Background

Healthcare-associated infections (HAIs) remain one of the most persistent threats to patient safety worldwide, affecting an estimated 7–10% of hospitalised patients in developing countries and contributing to prolonged hospital stays, increased antimicrobial resistance, elevated costs, higher mortality, and reduced quality of life [1, 2]. The burden is disproportionately severe in low- and middle-income countries (LMICs), where infection rates can exceed those of high-income settings by a factor of two to twenty, reflecting infrastructural constraints, inadequate supplies, workforce shortages, and weak governance [3]. Although considerable research attention has focused on established infection control interventions such as hand hygiene, antimicrobial stewardship, and environmental disinfection, the contribution of medical waste management to HAI transmission has received comparatively little attention, particularly in resource-constrained settings where it may represent a more tractable point of intervention [4, 5].

In Nigeria, Africa's most populous country with over 200 million inhabitants, inadequate medical waste management has been identified as a significant but underexamined contributor to HAI risk [6, 7]. More than 30,000 healthcare facilities generate substantial volumes of medical waste daily, yet the country lacks comprehensive collection infrastructure, coherent regulatory frameworks, and sufficient technical and financial capacity for safe management [8, 9]. This gap creates escalating risks for healthcare workers through needlestick injuries, for informal waste pickers scavenging inadequately treated waste, and for communities near facilities and disposal sites [10].

Medical waste encompasses infectious material contaminated with blood or body fluids, sharps capable of causing percutaneous injury, pharmaceutical and chemical residues, anatomical specimens, and radioactive materials requiring specialised disposal [11, 12]. When segregation, storage, transport, or treatment is inadequate, this waste becomes a vector for disease transmission [13]. The risks are substantial: a single needlestick exposure carries an estimated transmission risk of 30% for hepatitis B, 1.8% for hepatitis C, and 0.3% for HIV [14]. Beyond bloodborne pathogens, improper waste management also facilitates transmission of respiratory infections, including tuberculosis, antimicrobial-resistant organisms, and emerging pathogens, as illustrated during the COVID-19 pandemic [15, 16]. Globally, the World Health Organization estimates that unsafe injection practices and improper disposal contribute to millions of preventable hepatitis B, hepatitis C, and HIV infections annually; research from India has linked needlestick injuries to nearly two million new hepatitis B infections, 30,000 new HIV infections, and 400,000 new hepatitis C infections in a single year [14].

Conventional medical waste management follows a linear 'take-make-dispose' model of generation, collection, transport, treatment (typically incineration or autoclaving), and landfill disposal, with minimal resource recovery [17, 18]. This model is economically inefficient, environmentally damaging, socially inequitable in the exposure it creates for marginalised communities, and perpetuates infection risk throughout the management chain [19, 20]. The circular economy offers an alternative framework that reconceives waste as a resource with residual value [21]. Its core principles - waste prevention through improved procurement, extended product life through safe reprocessing, material value retention through segregation that enables recycling, energy recovery through advanced thermal treatment, and closed-loop system design [22] - converge naturally with infection control imperatives that already require proper segregation and treatment [23, 24].

This article reports findings from a comprehensive investigation in Lagos State, Nigeria, examining current medical waste management practices, the pathways through which they may contribute to HAI risk, the adequacy of existing policy frameworks, and evidence-based interventions that integrate circular economy principles with infection control. The research addresses several gaps in the literature, including the scarcity of empirical data on medical waste practices in Nigeria, limited understanding of the gap between stated knowledge and observed practice, minimal documentation of statistical associations between worker characteristics and performance, limited analysis of circular economy applicability in this setting, and a shortage of policy-relevant evidence. Findings are intended to inform

national policy in Nigeria and to offer insights applicable to other African contexts facing similar challenges.

Healthcare-associated infections and medical waste linkages

HAIs constitute a major global health burden, with baseline prevalence in LMICs ranging from 4.4% to 88.9% and affecting hundreds of millions of patients annually [1, 14]. Contributing factors include suboptimal hand hygiene, inadequate environmental cleaning, overcrowding, and - critically - inadequate medical waste management, an area that has received limited research attention despite representing a tractable intervention point [4]. Medical waste can harbour diverse pathogens, including methicillin-resistant *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Mycobacterium tuberculosis*, hepatitis viruses, and HIV, all capable of causing severe infection [12, 25]. Studies across developing countries document high occupational exposure among healthcare workers and informal waste pickers, who often work without protective equipment, training, or occupational health support [26–28].

Circular economy principles in healthcare waste management

The circular economy is a systemic alternative to linear production and consumption, drawing on industrial ecology, cradle-to-cradle design, and regenerative principles [21]. Its core tenets are designing out waste through upstream decisions, retaining products and materials in use at their highest value, and regenerating natural systems [22]. Several African countries are exploring circular economy approaches: South Africa, for example, has incorporated resource-recovery targets exceeding 25%, extended producer responsibility, and formalisation of the informal waste sector [29]. In healthcare specifically, circular economy applications include waste minimisation through more efficient procurement, device reprocessing where clinically validated as safe, segregation that enables recycling of non-infectious material, energy recovery through advanced thermal treatment with emission controls, and pharmaceutical take-back schemes [18]. Where properly implemented, these approaches can deliver environmental benefits (reduced landfill use and greenhouse gas emissions), economic benefits (estimated cost savings of 15–20% alongside new revenue streams), and social benefits (improved occupational health and more dignified employment for waste workers) [23, 30].

Medical waste management in Nigeria and Lagos State

Lagos State generates over 200 metric tonnes of medical waste daily from an estimated population of 20 million [31]. The Lagos Waste Management Authority (LAWMA) Medical Waste Unit coordinates collection, treatment, and disposal through a system in which healthcare facilities segregate waste using a colour-coded system (yellow for infectious waste, black for general waste, red for sharps), Private Sector Participation (PSP) operators collect from more than 2000 registered facilities, and a centralised

hydroclave facility - located along the Oshodi Expressway and operating ECODES 1000 equipment with a nominal capacity of 24 metric tonnes per day - sterilises waste using high-temperature, pressurised steam before landfill disposal [17, 9]. Despite this infrastructure, previous studies document persistent non-compliance with segregation protocols, storage facilities that lack adequate ventilation and drainage, insufficient provision of personal protective equipment, and inadequate training, particularly for sanitation workers who face the highest exposure [6, 32]. Targeted interventions by LAWMA and John Snow Incorporated have produced temporary improvements in segregation and handling practices, but these gains have proved difficult to sustain without ongoing reinforcement, adequate resourcing, and institutional commitment [33, 10].

Methods

This study employed a convergent parallel mixed-methods design, combining quantitative surveys, qualitative semi-structured interviews, and systematic direct observation, conducted in Lagos State, Nigeria's commercial capital (population exceeding 20 million), between January 2022 and December 2023.

Study setting and sampling

Seven hospitals were purposively selected using a maximum-variation sampling strategy to capture the full spectrum of healthcare delivery in Lagos State: two tertiary teaching hospitals (380–450 beds), two secondary general hospitals (150–180 beds), two primary health centres (20–25 beds), and one private hospital (40 beds).

Quantitative survey

Structured questionnaires, adapted from validated WHO instruments, were distributed to 384 healthcare workers; this sample size was calculated using Yamane's formula, assuming 95% confidence and a 5% margin of error. Participants were selected through stratified random sampling across professional categories: nurses ($n = 280$), sanitation workers ($n = 30$), laboratory scientists ($n = 35$), pharmacists ($n = 24$), and doctors ($n = 15$). A total of 336 completed questionnaires were returned (87.5% response rate). The questionnaire assessed demographic characteristics, knowledge of waste categorisation, management practices, personal protective equipment (PPE) use, training history, and perceived occupational risk.

Qualitative interviews

Semi-structured interviews (45–90 minutes) were conducted with 21 key informants, comprising hospital administrators ($n = 7$), infection control nurses ($n = 4$), waste management supervisors ($n = 3$), LAWMA representatives ($n = 3$), and PSP operators ($n = 4$). Interview guides explored operational

challenges, resource constraints, regulatory compliance, and opportunities for improvement. Interviews were audio-recorded, transcribed verbatim, and translated from Yoruba where necessary.

Direct observation

Systematic direct observations documented waste generation, segregation, storage, transportation, and treatment practices, with photographic evidence collected where permitted. Waste generation rates were determined from facility records and direct weighing, using calibrated scales, over consecutive seven-day periods, and are expressed as kg/bed/day.

Data analysis

Quantitative data were analysed in SPSS version 26. Descriptive statistics characterised demographic and survey responses. Chi-square tests examined associations between categorical variables, with significance set at $\alpha = 0.05$; effect sizes were calculated using Cramér's V (0.1 = small, 0.3 = medium, 0.5 = large). Qualitative data underwent thematic analysis in NVivo 12; two researchers independently coded 20% of transcripts, achieving a Cohen's kappa of 0.82. Findings were triangulated across the three data sources to enhance validity.

Ethical considerations

The study was approved by the Institutional Review Board of Brandenburg University of Technology (reference BTU-ENV-2021-047) and by the ethics committees of the participating facilities. All participants provided written informed consent. Confidentiality was maintained through anonymous questionnaires, pseudonyms for interview participants, password-protected data storage, and aggregate reporting.

Results

Participant characteristics

Of the 336 healthcare workers who completed the questionnaire, 179 (53.3%) were female and 157 (46.7%) were male. Mean age was 35.46 years (SD = 1.66; range 22–58) and mean professional experience was 9.73 years (SD = 6.91; range 1–32). Nurses comprised the largest professional group ($n = 233$, 69.3%), followed by sanitation workers ($n = 30$, 8.9%), laboratory scientists ($n = 29$, 8.6%), pharmacists ($n = 24$, 7.1%), doctors ($n = 10$, 3.0%), and other support staff ($n = 10$, 3.0%) (Table 1).

Table 1
Demographic characteristics of survey respondents (N = 336)

Characteristic	n	% / mean $\pm$ SD
Gender – female	179	53.3%
Gender – male	157	46.7%
Age, years	–	35.46 $\pm$ 1.66
Professional experience, years	–	9.73 $\pm$ 6.91
Doctors	10	3.0%
Nurses	233	69.3%
Laboratory scientists	29	8.6%
Pharmacists	24	7.1%
Sanitation workers	30	8.9%
Other support staff	10	3.0%

SD, standard deviation. Source: authors' primary survey data, 2022–2023.

Waste generation and composition

The seven hospitals operated 1245 beds and generated 215.56 kg of waste daily, an average of 0.181 kg/bed/day. Generation rates varied by facility type: 0.183–0.193 kg/bed/day in tertiary hospitals, 0.116–0.175 kg/bed/day in secondary hospitals, and 0.063–0.183 kg/bed/day in smaller facilities (Table 2). Waste composition averaged 70% general and 30% infectious material; however, improper segregation contaminated general waste streams, such that entire volumes required treatment as infectious waste.

Table 2
Daily medical waste generation by facility

Facility	Type	Beds	Daily waste (kg)	Rate (kg/bed/day)
Hospital A	Tertiary	450	82.50	0.183
Hospital B	Tertiary	380	73.30	0.193
Hospital C	Secondary	180	20.88	0.116
Hospital D	Secondary	150	26.25	0.175
Hospital E	Primary	25	4.58	0.183
Hospital F	Private	40	6.80	0.170
Hospital G	Private	20	1.25	0.063
Total	–	1,245	215.56	0.181

Source: authors' direct measurement and facility records, 2022–2023.

Knowledge and self-reported practice

Knowledge assessment revealed an inconsistent pattern (Table 3). While 88.6% of respondents reported using safety boxes for sharps and 81.9% reported using colour-coded containers, only 61.0% agreed that segregation should occur at the point of generation, and only 58.1% correctly identified the colour-coding system. Critically, only 42.3% had received formal training in medical waste management, with the largest gaps observed among sanitation workers.

Table 3
Knowledge and practice indicators among respondents (N = 336)

Knowledge indicator	n	%
Agrees segregation should occur at source	205	61.0
Correctly identifies black colour code	195	58.1
Uses safety boxes for sharps	298	88.6
Uses colour-coded containers	275	81.9
Correctly categorises general waste	235	70.0
Correctly identifies infectious waste (item 1)	232	69.0
Correctly identifies infectious waste (item 2)	235	70.0
Correctly identifies infectious waste (item 3)	195	58.0
Aware of collection procedures	250	74.3
Received formal training	142	42.3

Source: authors' questionnaire responses, 2022–2023.

Statistical associations

Chi-square tests revealed highly significant associations between professional category and waste-categorisation ability, and between training and segregation practice, all with large effect sizes (Table 4). Professional category was associated with overall waste categorisation ($\chi^2 = 1344.00$, $df = 20$, $p < 0.001$, $V = 0.89$), with general waste categorisation ($\chi^2 = 856.42$, $df = 16$, $p < 0.001$, $V = 0.78$), and with infectious waste categorisation ($\chi^2 = 742.35$, $df = 18$, $p < 0.001$, $V = 0.72$). Training was similarly associated with segregation practice ($\chi^2 = 312.09$, $df = 12$, $p < 0.001$, $V = 0.61$). Doctors and nurses showed substantially higher correct-response rates than sanitation workers, who had the lowest knowledge despite the highest occupational exposure.

Table 4
Chi-square tests of association between key study variables

Variables	χ^2	df	p-value	Cramér's V
Profession vs waste categorisation	1344.00	20	< 0.001	0.89
Profession vs general waste categorisation	856.42	16	< 0.001	0.78
Profession vs infectious waste categorisation	742.35	18	< 0.001	0.72
Training vs segregation practice	312.09	12	< 0.001	0.61

df, degrees of freedom. Effect size thresholds (Cramér's V): 0.1 = small, 0.3 = medium, 0.5 = large.

Infrastructure, transportation, and treatment

Only 57% of facilities had adequate waste storage rooms. Collection frequency was inconsistent and generally fell short of WHO recommendations for daily collection: 14% of facilities were collected daily, 29% every other day, 43% twice weekly, and 14% weekly. Extended storage intervals increased vector attraction and odour nuisance. Internal transport relied on manual methods – 57% of facilities used wheelbarrows and 43% used trolleys - with workers frequently lacking adequate PPE, creating risks of worker fatigue, spillage, and exposure along transport routes. External management involved LAWMA-licensed PSP operators and centralised hydroclave treatment (24-tonne capacity); however, traffic delays, vehicle breakdowns, coordination gaps, payment delays, and periodic equipment breakdowns at the hydroclave facility contributed to service backlogs, particularly during periods of peak demand [17, 8].

Circular economy opportunities and barriers

With general waste comprising 70% of the total stream, conservative estimates suggest that 40–50% of this material - including plastics, paper, glass, and metal - could be safely recycled, potentially yielding 30–40 kg of recyclable material daily across the seven facilities and generating an estimated ₦50–75 per kilogram in revenue. Realising this potential is currently constrained by contamination of the waste stream from improper segregation (fewer than 5% of waste is currently recycled), the absence of validated decontamination protocols, a lack of specialised recycling facilities, and high upfront infrastructure costs (₦2–3 million per facility). Stakeholder perspectives varied: administrators broadly supported circular economy initiatives but emphasised resource constraints; environmental officers recognised both the infection risk and the resource waste involved; PSP operators called for clearer regulatory frameworks and financial incentives; and LAWMA representatives emphasised the need for coordinated national policy [18, 24, 30].

Occupational health among sanitation workers

Sanitation workers showed a marked inversion between exposure and knowledge: only 23.3% correctly identified appropriate segregation timing, compared with 89% of nurses and 100% of doctors. PPE compliance was low across all categories: heavy-duty gloves (40%), fluid-resistant aprons (35%), puncture-resistant footwear (45%), and face shields (15%). Although workers reported experiencing needlestick injuries, only 30% were aware of post-exposure prophylaxis procedures, reflecting the absence of structured occupational health services. Training, where provided, was minimal - typically a 30–60 minute orientation covering collection routes but with limited information on risk, PPE use, or emergency response. No systematic exposure monitoring was in place, and injuries frequently went unreported because of normalisation, fear, or the absence of clear reporting channels [2, 37, 5].

Discussion

This study demonstrates that inadequate medical waste management is a significant contributor to HAI risk in the study hospitals, operating through multiple transmission pathways. The deficiencies identified

were systemic: improper segregation despite reported knowledge, inadequate storage, insufficient treatment capacity, weak enforcement, deficient training - particularly among the highest-risk workers - and chronic resource constraints that force unsafe practice [5, 20].

The gap between reported knowledge and observed practice is a critical finding. Although 74.3% of respondents reported awareness of collection procedures and 81.9% reported using colour-coded containers, direct observation revealed substantial deviation from these self-reports. This discrepancy suggests that awareness campaigns and one-off training are insufficient without also addressing systemic barriers, including inadequate container provision, insufficient supervision, competing time pressures, and weak accountability mechanisms [34].

The strong statistical association between occupational role and waste-management knowledge ($p < 0.001$, large effect sizes throughout) points to a troubling occupational health inequity. Sanitation workers, who face the greatest exposure, demonstrated the lowest knowledge of waste categorisation, associated risks, and protective measures - an imbalance that raises serious occupational justice concerns [2]. Addressing this inequity will require targeted programmes for high-risk workers that combine intensive training with adequate PPE provision, vaccination, and post-exposure protocols.

The circular economy framework offers a promising avenue for addressing infection control, environmental sustainability, and resource efficiency through a single set of integrated interventions [21, 18]. Rigorous segregation, already essential for infection control, is also the precondition for safe recycling and the economic returns it can generate. Formalising informal waste picking, with appropriate safety protections, could convert hazardous scavenging into safer, more dignified employment. These synergies suggest that Nigeria can pursue infection control and circular economy objectives simultaneously, rather than treating them as competing priorities.

Realising this potential faces substantial implementation challenges, including resource constraints that force prioritisation of immediate clinical needs, institutional fragmentation across multiple agencies, weak regulatory enforcement, and limited technical capacity among both workers and officials. Addressing these barriers will require interventions at multiple levels: national policy frameworks, institutional capacity-strengthening, standardised operational protocols, continuous training, adequate financing, stronger enforcement, and community engagement [10]. International evidence similarly indicates that occupational health improvements require interventions that jointly address individual knowledge, organisational policy, and regulatory frameworks with clear minimum standards and enforcement mechanisms [14, 35].

Limitations

This study has several limitations. Because facilities were purposively selected, findings may not be fully generalisable to all Nigerian healthcare settings, although the maximum-variation sampling strategy was designed to capture diversity across facility types. Self-reported survey data are subject to social desirability bias, which was partially addressed through triangulation with direct observation. The cross-

sectional design precludes causal inference about the relationship between waste-management practices and HAI incidence; future longitudinal research linking waste-management indicators directly to infection surveillance data would strengthen this evidence base.

Conclusions

This study shows that inadequate medical waste management is a significant, and currently underrecognised, contributor to HAI risk in Nigerian healthcare facilities, creating avoidable exposure for workers and surrounding communities. Integrating circular economy principles - waste prevention, rigorous segregation, safe recycling, formalisation of waste-handling work with appropriate protections, and appropriate treatment - with infection prevention and control objectives offers a strategic path toward addressing both problems simultaneously.

Based on these findings, seven policy interventions are recommended: (1) a comprehensive national Medical Waste Management Act that integrates circular economy principles with infection prevention, establishes clear institutional mandates, and creates enforcement mechanisms; (2) mandatory segregation at the point of generation, using WHO-aligned, standardised colour-coded systems with adequate container provision; (3) strategic investment in treatment technologies validated for pathogen inactivation, such as hydroclaves, autoclaves, and microwave treatment, with regular efficacy monitoring; (4) formal waste recycling programmes with robust occupational safety standards, including PPE provision, vaccination, training, and post-exposure protocols; (5) institutionalised continuous professional training for healthcare workers and waste handlers, combining role-specific orientation, annual refreshers, and competency assessment; (6) strengthened regulatory oversight, including regular inspection, mandatory reporting, public disclosure, and graduated penalties; and (7) community engagement programmes that raise awareness and integrate informal waste pickers into formal systems with appropriate protections.

Implementation should be sequenced. Initial priorities include national legislation, standardised categorisation systems, mandatory segregation requirements, and basic training. Medium-term priorities include expansion of treatment capacity, investment in appropriate technology, establishment of occupational health services, and circular economy pilot projects. Long-term objectives include full circular economy integration, ambitious recycling targets, extended producer responsibility, and development of domestic technical expertise. Financing will require innovative approaches, including explicit budget allocation for medical waste management (an estimated 3–5% of facility operating budgets), results-based financing tied to performance targets, green bonds and environmental funds, and technical and concessional support from development partners [36]. Regional and international cooperation - through WHO and UNEP technical assistance and South-South learning from countries such as South Africa, India, and Brazil [29] - could further support this transition. Future research should prioritise longitudinal tracking of infection outcomes, economic evaluation of circular economy interventions, technology assessment, and social research to inform the design of worker formalisation programmes.

Declarations

Ethics Approval and Consent to Participate

Ethical approval for this study was obtained from the Lagos State Health Research Ethics Committee (LSHREC/10/06/2021). All participants provided informed consent prior to participation. This study was conducted in accordance with the principles of the Declaration of Helsinki.

Consent for Publication

Not applicable (Participants were not identifiable and no personal data was published.)

Competing Interests

The authors declare no competing interests.

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Declaration

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Author Contribution

Conceptualization: Yusuf Gbolahan Afeez; Methodology: Yusuf Gbolahan Afeez; Olaleye Oluremi Nurudeen; Data Collection: Yusuf Gbolahan Afeez; Analysis & Interpretation: Yusuf Gbolahan Afeez; Olaleye Oluremi Nurudeen; Writing - Original Draft: Yusuf Gbolahan Afeez; Writing - Review & Editing: Yusuf Gbolahan Afeez; Olaleye Oluremi Nurudeen. All authors reviewed and approved the final manuscript.

Availability of Data and Materials

The data supporting the findings of this study are available from the corresponding author upon request. Due to confidentiality agreements with participating healthcare facilities, raw data cannot be made publicly accessible.

References

1. Ansari M, Ehrampoush MH, Farzadkia M, Ahmadi E. Dynamic assessment of economic and environmental performance index and generation, composition, environmental and human health risks of hospital solid waste in developing countries. *Environ Int.* 2019;132:105073.
2. Baciú A, Negussie Y, Geller A, Weinstein JN, editors. The root causes of health inequity. *Communities in action: pathways to health equity.* Washington (DC): National Academies; 2017.
3. Abdelsalam MK, Egdair IM, Begum H, Jadi DM, Al Issa H-E, Abrika OS, et al. Key organizational factors in healthcare waste management practices of Libyan public hospitals. *Sustainability.* 2021;13(22):12785.
4. Atnafu DD, Kumie A. Healthcare waste composition and generation rate in Menellik II Referral Hospital, Addis Ababa, Ethiopia. *Int J Sustain Manag Inf Technol.* 2017;3(2):10–9.
5. Udofia EA, Fobil JN, Gulis G. Solid medical waste management in Africa. *Afr J Environ Sci Technol.* 2017;9(3):244–54.
6. Awodele O, Adewoye AA, Oparah AC. Assessment of medical waste management in seven hospitals in Lagos, Nigeria. *BMC Public Health.* 2016;16:269.
7. Obeta MC, Ogbodo GE, Nnamani CV. Medical waste management in developing countries: Nigerian perspectives. *Environ Sci Pollut Res.* 2022;29:45890–903.
8. Adetola IM. Innovative solutions to waste management: a case study of Lagos State, Nigeria [master's thesis]. Kamp-Lintfort: Rhein-Waal University of Applied Sciences; 2023.
9. Ezeudu OB, Agunwamba JC, Ezeasor IC, Madu CN. Sustainable production and consumption of polyethylene terephthalate in Nigeria: challenges and prospects. *Resour Conserv Recycl.* 2022;179:106067.
10. Kalu OK, Origbakor A. Healthcare waste management practices in Nigerian hospitals: challenges and way forward. *Environ Manag Sustain Dev.* 2023;12(2):45–60.
11. Aziz HA, Omar FM, Halim HA, Hung YT. Health-care waste management. In: Wang LK, et al. editors. *Solid waste engineering and management.* Volume 25. Cham: Springer Nature; 2022. pp. 163–229.
12. Barik KP. Health hazards of medical waste and its disposal. In: Sengupta D, Agrahari S, editors. *Modelling trends in solid and hazardous waste management.* Singapore: Springer; 2018. pp. 99–118.
13. Khan BA, Khan AA, Ahmed H, Shaikh SS, Peng Z, Cheng L. Healthcare waste management in Asian developing countries: a mini review. *Waste Manag Res.* 2021;37(9):863–75.
14. World Health Organization. Overview of technologies for the treatment of infectious and sharp waste from health care facilities. Geneva: WHO; 2021.
15. Sharma HB, Vanapalli KR, Cheela VRS, Ranjan VP, Jaglan AK, Dubey B, et al. Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic. *Resour Conserv Recycl.* 2020;162:105052.

16. Zhang H, Wen ZG, Han Y. Challenges and strategies for managing medical waste during the COVID-19 outbreak in China. *Sci Total Environ.* 2022;836:155626.
17. Olukanni DO, Azuh DE, Okwu-Delunzu VU, Ebirim CI, Akinyinka O. Medical waste management in COVID-19 era: a review. *Afr J Sci Technol Innov Dev.* 2022;14(3):749–60.
18. Antoniadou M, Varzakas T, Tzoutzas I. Circular economy in conjunction with treatment methodologies in the biomedical and dental waste sectors. *Circ Econ Sustain.* 2021;1:563–92.
19. Cook E, Velis CA. Global review on safer end of engineered life. *Waste Manag Res.* 2021;39(1):3–39.
20. Ferronato N, Torretta V. Waste mismanagement in developing countries: a review of global issues. *Int J Environ Res Public Health.* 2019;16(6):1060.
21. Ellen MacArthur Foundation. What is a circular economy? A framework for an economy that is restorative and regenerative by design [Internet]. 2020 [cited 2026 Aug 19]. Available from: <https://www.ellenmacarthurfoundation.org>
22. Belmonte-Ureña LJ, Plaza-Úbeda JA, Vazquez-Brust D, Yakovleva N. Circular economy, degrowth and green growth as pathways for research on sustainable development goals: a global analysis and future agenda proposal. *Ecol Econ.* 2021;185:107050.
23. Dissanayake DG, Weerasinghe D. Towards circular economy in fashion: review of strategies, barriers and enablers. *Circ Econ Sustain.* 2021;1:25–45.
24. Ezeudu OB, Ezeudu TS. Implementation of circular economy principles in industrial solid waste management: case studies from Nigeria. *Recycling.* 2019;4(4):42.
25. David O, Oluyeye AO, Fagade OE. Microbiological assessment of hospital waste in Nigeria. *Afr J Clin Exp Microbiol.* 2020;21(2):156–63.
26. Abanyie SK, Amuah EE, Douti NB, Amadu CC, Bayorbor M. Healthcare waste management in the Tamale Central Hospital, northern Ghana. *Environ Chall.* 2021;5:100320.
27. Manyele SV, Lyasenga TJ. Factors affecting medical waste management in low-level health facilities in Tanzania. *Afr J Environ Sci Technol.* 2019;4(5):304–18.
28. Masud MH, Rashid F, Hossain N, Dabnichki P, Akhter MS. Sustainable medical waste management in Bangladesh during COVID-19 pandemic: a case study. *J Mater Cycles Waste Manag.* 2023;25:1156–76.
29. Adeleke O, Akinlabi S, Jen TC, Dunmade I. Towards sustainability in municipal solid waste management in South Africa: a critical review. *Trans R Soc S Afr.* 2021;76(1):53–66.
30. Schröder P, Lemille A, Desmond P. Making the circular economy work for human development. *Resour Conserv Recycl.* 2020;156:104686.
31. Adeyemo O. Integrated waste management initiative of the local government: a case study of Lagos, Nigeria. Lagos: Lagos Waste Management Authority; 2019.
32. Adeoye AO, Akande EA, Lateef A. Impacts of hospital waste management on the health and environment of Ogbomoso area, Oyo State, Nigeria. *Hosp Palliat Med Int J.* 2018;2(6):386–9.

33. Alani RA, Driscoll C, Rani K, Akinyemi OO. Medical waste management in Nigeria: a case study. *J Environ Prot.* 2019;10(1):150–66.
34. Agyekum NK, Ansah EW. Medical waste management practices at healthcare facilities in Cape Coast metropolis, Ghana. *Adv J Soc Sci.* 2022;10(1):63–74.
35. Joseph B, Sanjeevi S, Thalavaipillai A, Ali M. Biomedical waste management: review and analysis. *J Environ Biol.* 2021;42(2):242–52.
36. Kondepudi SN, Ramanarayanan R, Singh GK. Integrated municipal solid waste management for smart cities. *Handbook of smart cities.* Cham: Springer; 2022. pp. 1–26.
37. Schenck CJ, Blaauw PF, Viljoen J, Swart EC. Exploring the potential health risks faced by waste pickers on landfills in South Africa: a socio-ecological perspective. *Int J Environ Res Public Health.* 2019;16(11):2059.

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