

Evaluation of Waste Generation Patterns and Composition in Tertiary Healthcare Facilities: A Comparative Study of UITH and Kwasuth Ilorin, Nigeria

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Abstract

Healthcare waste management remains a critical public health and environmental challenge in developing countries, particularly in tertiary healthcare facilities where large patient volumes and intensive clinical activities generate diverse hazardous waste streams. This study evaluated waste generation patterns and composition at the Kwara State University Teaching Hospital and the University of Ilorin Teaching Hospital in Nigeria. Waste generated by 20 departments at UITH and their corresponding units at Kwasuth was segregated into general (non-hazardous) and hazardous categories over four weeks and weighed daily. Results showed that UITH recorded a higher waste generation rate (2.0 kg/patient/day) compared to Kwasuth (1.75 kg/patient/day). Hazardous waste constituted approximately 42% of total waste generated in UITH, significantly higher than the 25% recorded in Kwasuth. Waste composition analysis indicated that general waste predominated in both hospitals (58–75%); however, UITH generated higher proportions of infectious, sharps, and pathological waste than Kwasuth. The findings align with previous studies reporting hazardous waste fractions of 10–25% in healthcare facilities, although the proportion observed in UITH exceeded the typical WHO range, suggesting inadequate waste segregation practices. The higher waste generation and hazardous waste proportion observed in UITH indicate increased environmental and occupational health risks. The study recommends stricter waste segregation protocols, regular staff training, and improved investment in treatment technologies such as autoclaves and incinerators to enhance compliance with healthcare waste management guidelines. The findings provide empirical data to support healthcare waste management planning and policy development in Kwara State, Nigeria.

Keywords: Healthcare waste; Waste generation; Waste composition; Tertiary healthcare facilities; Waste management

1. INTRODUCTION

Healthcare facilities generate a wide range of waste types, including infectious, pathological, chemical, and general waste. When improperly managed, healthcare waste poses risks of disease transmission, environmental pollution, and occupational hazards. Developing countries often face infrastructural, financial, and regulatory constraints that hinder effective healthcare waste management.

Healthcare waste in facilities can be classified based on the volume generated, with major sources including laboratories, mortuaries, and research centres. Minor sources encompass small private laboratories, health centres, dental clinics, pharmacies, veterinary practices, maternity homes, bone-setting centres, tattoo parlours, acupuncture clinics, and traditional medicine homes [1].

Healthcare facilities generate substantial volumes of waste during patient care, diagnostics, and research activities. This healthcare waste (also called medical or biomedical waste) includes materials like soiled dressings, sharps, body fluids, chemicals, and infectious agents. According to WHO [2], approximately 85% of hospital waste is classified as non-hazardous, predominantly originating from administrative and housekeeping functions within healthcare facilities. This category may also include waste generated from the maintenance of healthcare premises. 10-25% of hospital waste is considered hazardous, comprising infectious, pathological, chemical, sharp, and radioactive materials [3].

Globally, the number of hospitals and healthcare facilities is steadily increasing to meet the rising demand for healthcare services among growing populations. This expansion, coupled with an increased reliance on disposable medical products, has resulted in a significant surge in healthcare waste generation [4]. Healthcare waste generation is influenced by factors such as waste management systems, type and specialization of healthcare facilities, level of use of disposable or reusable materials, patient load, and institutional policies [4]. Fig. 1 shows the production rates of hazardous refuse in various countries.

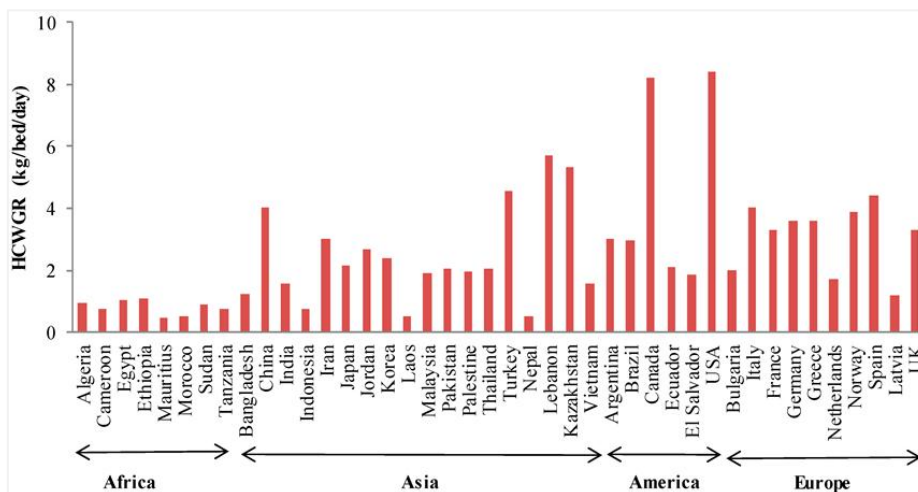


Fig. 1: Healthcare Waste Generation Rates in some countries [5]

Healthcare waste management involves different stages from the production of medical waste to its disposal. The purposeful actions taken to generate, segregate, quantify, store, handle, collect, transport, treat, and dispose of healthcare waste [6]. Improper segregation, handling, transportation, and disposal of healthcare waste pose serious health and environmental risks to healthcare workers, patients, visitors, and the general public [7, 8]. Availability of a healthcare waste management committee, adequate personal protective equipment (PPE), and past experience of waste-related injuries all influence the efficiency of healthcare waste management practices [9]. Poor healthcare waste management may lead to air, water, and soil pollution, unpleasant odour, disease transmission, and contamination of underground water sources [10]. Effective healthcare waste management, therefore, requires proper segregation, minimization, safe disposal practices, and the adoption of environmentally sustainable technologies [11].

Studies in developing countries report waste generation rates in health facilities range from 1.0–2.2 kg/patient/day [12, 13]. The generation rate in developed nations such as Italy, the USA, and Portugal is more than the rates generated in developing nations [14].

Nigeria has established national healthcare waste management guidelines, yet implementation remains inconsistent across health institutions. Tertiary hospitals, due to their complex clinical services and high patient turnover, are major contributors to medical waste. However, reliable data on waste- type composition, generation rates, and management practices remain limited. In Nigeria, healthcare service provision is structured across three tiers of government: Federal, State, and Local. The Federal Government manages most tertiary healthcare facilities, while state health systems tailor programs to address the specific needs of their populations. Despite this division, there is a collaborative effort between federal and state institutions to meet national healthcare requirements.

In August 2006, the Federal Ministry of Environment (FMOEnv) and the Federal Ministry of Health (FMOH) established a National Healthcare Waste Management Plan (NHCWMP) working committee, supported by various international organizations, including the World Bank, United Nations Children's Fund (UNICEF), and the WHO. According to the draft of the NHCWMP (2007), the generation of healthcare waste is influenced by multiple factors, including established waste management practices, the types of healthcare facilities, daily patient volumes, and the complexity and specialization level of health services [15].



In Nigeria, rapid hospital expansion and increased use of disposable products have led to growing waste streams. Studies report that Nigerian hospitals generate hundreds of tons of waste annually, much of which is improperly disposed of (e.g., dumped or burned openly). Tertiary hospitals can produce over 1 kg of waste per bed per day, with significant hazardous fractions if segregation is poor. The national guidelines, including the Federal Environmental Protection Agency Act (FEPA) [16] and the National Environmental Standards and Regulations Enforcement Agency regulations (NESREA) [17], emphasize staff training, waste segregation at source, and proper waste tracking practices.

Despite the existence of national healthcare waste management regulations in Nigeria, comparative empirical studies between federal and state-owned tertiary hospitals in Kwara State remain limited. Understanding differences in waste generation patterns between healthcare facilities is essential for informing state-level policy harmonization, infrastructure planning, and budgetary allocation for sustainable healthcare waste management systems. Despite the implementation of the National Healthcare Waste Management Plan (NHCWMP), challenges persist in adhering to proper waste segregation, disposal methods, and regulatory compliance.

This study focuses on two tertiary institutions in Ilorin, Kwara State, Nigeria: University of Ilorin Teaching Hospital (UITH) and Kwara State University Teaching Hospital (KWASUTH). Both hospitals provide extensive clinical services and thus generate diverse waste. Despite national guidelines on healthcare waste that mandate tracking, segregation, and safe disposal, many Nigerian hospitals struggle with implementation due to limited resources and training. By comparing their waste generation patterns and management systems, the study provides empirical evidence to inform policy improvements and strengthen institutional practices.

Healthcare waste management remains a major public health and environmental concern, particularly in developing countries where inadequate segregation, treatment, and disposal practices persist. In Nigeria, Abalaku et al. [18] reported inconsistencies in healthcare waste handling across tertiary hospitals in Lafia, with incineration, pit burning, and open dumping serving as the dominant disposal methods. Similarly, Obubu et al. [19] observed that although many healthcare facilities in Lagos State adopted color-coded segregation systems, compliance with recommended waste management standards remained inadequate. Abah [20] further noted that only a small proportion of healthcare facilities in Nigeria possess functional incineration capacity, with significant deficiencies existing at primary and secondary healthcare levels.

Several studies have also highlighted poor awareness and inadequate training among healthcare workers regarding biomedical waste management. Golandaj and Kallihal [21] found that more than half of healthcare workers surveyed in Karnataka, India, lacked proper biomedical waste management training, resulting in poor segregation and disposal practices. Similar findings were reported by Ibrahim et al. [22] in Ethiopia, where only 56.4% of healthcare professionals adhered to recommended waste segregation practices.

Studies on healthcare waste generation rates indicate considerable variation across healthcare facilities and regions. Jimoh and Abdullahi [23] reported that infectious and sharps waste constituted a substantial proportion of biomedical waste generated in hospitals in Akure, Nigeria. In Iran, Sadeghi et al. [24] recorded an average waste generation rate of 2.12 kg/bed/day, while Alwabr et al. [25] reported 2.5 kg/bed/day in hospitals in Yemen. Comparable studies in Morocco and Qatar documented generation rates ranging from 0.76 to 4.64 kg/bed/day depending on hospital type and specialization [26, 27]. Likewise, Anicetus et al. [28] observed substantial variations in healthcare waste quantities among hospitals in Tanzania due to differences in patient load and specialization.

Poor waste management practices have also been linked to environmental pollution and increased public health risks. Khalid et al. [29] observed that many teaching hospitals in Pakistan lacked effective waste segregation systems and relied heavily on open dumping and poorly operated incinerators. Shabani et al. [30] similarly reported that rural hospitals in Zimbabwe depended mainly on open burning and low-level disposal methods due to financial and technical limitations. Furthermore, Parida et al. [31] emphasized the growing environmental risks associated with untreated hospital wastewater and biomedical waste, particularly following the COVID-19 pandemic.

Despite increasing global concern regarding healthcare waste management, comparative studies involving tertiary healthcare facilities in Nigeria remain limited. This study, therefore, evaluates waste generation patterns and composition in UITH and KWASUTH to provide data necessary for improved healthcare waste management planning and policy formulation.



2. MATERIALS AND METHODS

2.1. Research Design

The study was conducted in UITH and KWASUTH in Ilorin, Nigeria. A cross-sectional mixed-methods approach was adopted, integrating quantitative waste measurement with qualitative observations and interviews. Quantitative data were collected through surveys and waste-type measurement, while qualitative insights were gathered via observational studies and in-depth interviews with healthcare professionals, waste managers, and administrative staff. UITH's study was carried out from March to June, 2025, while KWASUTH's study was carried out from July to October, 2025.

2.2. Data Collection Methods

2.2.1. Survey Study

A survey study was conducted using structured questionnaires to capture data on waste generation patterns, quantities, and waste management practices among healthcare staff, patients, and visitors. The survey consisted of seven sections: Background information, waste generation patterns, waste quantities, waste management practices, challenges and concerns, suggestions and ideas, and additional comments.

i. Questionnaire Development

The questionnaire was developed following existing frameworks and instruments in healthcare waste management literature to ensure alignment with the study's objectives. The questionnaires were designed to capture comprehensive data on waste generation patterns, categorization practices, and management challenges specific to healthcare settings. Existing studies emphasize that using structured questionnaires ensures data consistency and reliability [32, 33]. Questions were adapted from validated sources to enhance content relevance and validity within the study's specific context [34].

ii. Participant Selection

A purposive sampling approach was employed to select a representative sample of healthcare staff, patients, and visitors, given their varying degrees of involvement in or impact on waste management. Healthcare professionals were chosen based on their roles in waste handling and patient care, while patients and visitors were included to account for waste generated from their presence and activities within healthcare facilities. The importance of representative sampling in achieving accurate insights into healthcare waste practices is widely documented in the literature [35].

iii. Administration

To optimize accessibility and maximize response rates, the questionnaires were administered in paper format. Studies show that paper distribution was effective in healthcare settings where digital access was inconsistent or limited [36]. The distribution process was tailored to minimize workflow disruptions within hospital departments while ensuring broad participation [37]. Paper-based surveys were accommodated for respondents who may prefer non-digital formats, supporting both accuracy and completion rates [38].

iv. Data Analysis

The responses were coded and analysed using the Statistical Package for the Social Sciences (SPSS), focusing on both descriptive and inferential statistical methods to identify key themes related to waste generation, handling, and disposal [39]. Coding procedures were aligned with thematic analysis principles to allow systematic categorization of responses, an approach widely endorsed for analysing qualitative and quantitative data in healthcare research [40]. SPSS was selected due to its robustness in managing and analysing large datasets efficiently, a capability commonly utilized in healthcare research [41].

2.2.2. Observational Studies

Direct observation was conducted to evaluate waste handling and categorization practices within the facilities, focusing on waste sorting, storage, and disposal areas. All procedures conformed to ethical standards; consent was obtained from hospital administrators and staff, and safety protocols (PPE for waste handlers) were strictly followed. The following procedures were followed:

i. Waste collection and measurement

In each hospital, wastes were collected from a representative set of clinical departments daily. Following established protocols, waste segregation bins (two-colour-coded bags, black for general waste and yellow for infectious/hazardous waste) were placed in each department. Medical staff were instructed to dispose of waste in the appropriate bin. Every 24 hours, the contents of each bin were collected and weighed using a calibrated 50 kg-capacity scale. Both general (non-infectious) and hazardous categories were recorded. Hazardous waste was defined per WHO/National guidelines to include infectious materials (soiled dressings, swabs), sharps, pathological waste, chemical/pharmaceutical residues, and other regulated waste. Data recorded included the daily weight of each category per department.

ii. Waste Sorting and Categorization



Waste was systematically classified into categories, including hazardous, non-hazardous, and recyclable materials. This classification followed established protocols for healthcare waste to ensure consistent categorization and allow for a comparative analysis of waste types. Hazardous waste, including sharps, infectious materials, pathological waste, and chemical residues, was segregated using color-coded containers. Recyclable materials such as plastics, paper, metals, and glass were separated from the waste stream during segregation. The recyclable fraction was weighed, and its proportion relative to the total waste generated was calculated. Organic waste, primarily food remnants, garden waste, and biodegradable materials, was collected separately and weighed daily. Studies highlight the importance of systematic sorting in reducing cross-contamination and supporting proper disposal practices in healthcare settings [42, 43].

iii. Waste Measurement

The generation rate of each waste type category was quantified in terms of kilograms per day and per hospital bed, using calibrated scales and standardized containers. This method enables accurate tracking of waste generation rates, a practice widely adopted in healthcare facilities for effective waste management [44]. Previous studies have shown that waste quantification provides critical data for assessing the effectiveness of waste reduction efforts [45].

To ensure reliability and consistency in data collection, all measurement activities followed WHO guidelines alongside ASTM standards, specifically ASTM D5231-92 (2019), which is the established protocol for determining the composition of waste in healthcare settings. These standards are widely recognized for their robustness and have been used in multiple studies to maintain high-quality data collection and reporting, enabling cross-comparisons among diverse facilities [46]. Following the WHO and ASTM protocols provided methodological rigor to the study, ensuring that findings are reliable and repeatable. The standardized approach also facilitates integration with global datasets on healthcare waste, adding value to international efforts aimed at managing waste-related risks in healthcare settings [47].

The total quantity of healthcare waste generated was measured using calibrated digital weighing scales placed at designated waste collection points in both facilities. Waste was collected and weighed daily, and values were recorded in kilograms (kg). Daily averages and cumulative totals were subsequently computed for comparative analysis. Calibrated scales are fundamental in healthcare waste studies for obtaining precise measurements of weight, which directly affects disposal methods, environmental impact assessments, and cost analyses [48]. Volume measurement tools were also employed to quantify liquid waste streams, which are particularly prevalent in laboratory and medical waste categories.

iv. Photographic Documentation

Photographs were taken at each stage of waste generation, storage, and disposal to visually document handling practices. Photographic documentation has been used in similar studies to enhance data accuracy and provide visual evidence for analysis [49]. This approach provided a clear, visual record of adherence to waste management protocols and facilitated an assessment of compliance with established standards [50].

v. Data Analysis

Data were analysed using SPSS Version 26. Descriptive statistics summarized waste quantities and practices, while inferential tests (Welch's t-test) were carried out to compare institutional differences.

2.3. Data Availability

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to ethical reasons.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Waste Generation Rates

Table 1 compares the descriptive Statistics of the waste generation rates of UITH and KWASUTH.



Table 1. Descriptive Statistics of the Waste Generation Rates of UITH and Kwasuth

Statistic	UITH	Kwasuth	Units
Sample size (n)	16	16	Weeks
Mean (\bar{X})	85.04	70.27	kg/week
Standard deviation (s)	46.538	37.536	kg/week
Variance (s^2)	2165.73	1409.00	(kg/week) ²

Source: Field Survey, 2025

The analysis of weekly waste generation across the two tertiary healthcare facilities reveals notable contrasts in absolute waste output, although these differences do not reach statistical significance. As shown in Table 1, the University of Ilorin Teaching Hospital (UITH) produced a higher mean weekly waste quantity of 85.04 kg, compared to 70.27 kg recorded at the Kwara State University Teaching Hospital (Kwasuth). This difference of approximately 15 kg suggests that UITH handles a larger operational load, which may be attributed to its broader service coverage, higher patient inflow, and more extensive diagnostic and treatment activities. In most healthcare settings, such structural and functional differences typically translate to increased waste generation, particularly in high-volume departments such as surgery, laboratory services, and emergency care.

The Welch's t-test of Weekly Waste Generation of UITH and Kwasuth is outlined below.

Formulation of Hypotheses

- Null Hypothesis (H_0): $\mu_1 = \mu_2$ — There is no significant difference between the mean weekly waste generation of UITH and Kwasuth.
- Alternative Hypothesis (H_1): $\mu_1 \neq \mu_2$ — There is a significant difference between their mean weekly waste generation.

Test Statistic and Formula

The Welch's t-test formula is given as:

$$t = \frac{(\bar{X}_1 - \bar{X}_2)}{\sqrt{\left(\frac{s_1^2}{n_1}\right) + \left(\frac{s_2^2}{n_2}\right)}} \quad (1)$$

Substituting the given data:

$$t = \frac{(85.04 - 70.27)}{\sqrt{\left(\frac{46.538^2}{16}\right) + \left(\frac{37.536^2}{16}\right)}} = 0.981$$

Degrees of Freedom (df)

Degrees of freedom for Welch's test are computed using the following formula:

$$df = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{1}{n_1 - 1} \left(\frac{s_1^2}{n_1}\right)^2 + \frac{1}{n_2 - 1} \left(\frac{s_2^2}{n_2}\right)^2} \quad (2)$$

$$df = ((135.36 + 88.06)^2) / ((135.36^2/15) + (88.06^2/15)) = 28.72 \approx 29$$

Decision Rule

At a 5% level of significance ($\alpha = 0.05$) for a two-tailed test with $df = 29$, the critical t-value from statistical tables is ± 2.045 . Since the computed $|t| = 0.981 < 2.045$, we fail to reject the null hypothesis (H_0).

Based on the above result, there is no statistically significant difference in mean weekly waste generation between UITH and Kwasuth. Although UITH recorded a higher mean (85.04 kg/week) compared to Kwasuth (70.27 kg/week), the observed difference is within the limits of random variation ($p > 0.05$). This implies that both hospitals have comparable average waste generation rates.

Table 2 presents the comparative waste generation rates per patient per day for UITH and Kwasuth. The results indicate that UITH produces a higher waste generation rate (2.0 kg/patient/day) compared to Kwasuth (1.75 kg/patient/day). This difference reflects variations in facility size, service complexity, and patient turnover between the two tertiary institutions. UITH, with a daily patient load of approximately 750 individuals, generates about 1,500 kg of waste per day, suggesting a more resource-intensive service delivery system that aligns with the operational characteristics of larger teaching hospitals. Kwasuth, on the other hand, records a lower patient volume (500 patients daily) and a corresponding waste output of 875 kg/day, resulting in a slightly lower generation rate of 1.75



kg/patient/day. UITH operates as a larger tertiary referral centre with a broader range of specialized clinical services, which likely contributed to its higher waste output. These variations are influenced by patient volume [12], facility size, and regulatory enforcement [51]. The waste generation rates obtained from both institutions are comparable to values reported in previous studies conducted in tertiary healthcare facilities in developing countries, which indicate waste generation rates of approximately 1.0–2.2 kg/patient/day [12, 13]. Despite the quantitative difference between the two facilities, the variation in per-patient waste generation is relatively small (0.25 kg/patient/day). This may be attributed to similar clinical activity patterns and comparable levels of consumables usage in both institutions, even though UITH handles a larger caseload. The higher waste-to-patient ratio at UITH may further reflect broader diagnostic services, a wider range of surgical procedures, or more advanced therapeutic interventions that inherently generate more waste.

Table 2. Comparative waste generation rates per patient per day for UITH and KWASUTH

Facility	Number of patients per day	Waste generated per day (kg)	Waste Generation Rate (kg/patient/day)
UITH	750	1500	2.00
KWASUTH	500	875	1.75

From a waste management perspective, these findings highlight the importance of aligning waste control strategies with patient flow and service intensity. Facilities with higher waste generation rates, such as UITH, may require more robust segregation protocols, increased storage capacity, and more frequent waste collection cycles to prevent operational and environmental hazards. KWASUTH, although generating less waste per patient, still produces substantial daily volumes requiring sustained attention to handling efficiency. The comparative analysis of waste generation rates per patient underscores the need for both facilities to optimize resource use, implement waste minimization strategies, and strengthen institutional policies aimed at reducing per-capita waste output, particularly among departments with high clinical activity.

When expressed per bed capacity, UITH recorded approximately 0.20 kg/bed/day, whereas KWASUTH recorded approximately 0.30 kg/bed/day (based on official bed capacity records). Although UITH generated more waste in absolute terms, differences in operational intensity and waste handling efficiency between the two facilities may influence the disparity in waste per bed results.

3.1.2. Waste Composition

Table 3 shows the detailed breakdown of waste type by category for each hospital. General (non-infectious) waste was the largest component: 58% of UITH’s waste and 75% of KWASUTH’s. Infectious waste (soiled dressings, swabs) constituted for 20% at UITH and 10% at KWASUTH. Sharps waste (needles, blades) comprised 5% and 5%, respectively; pathological waste constitutes 5% and 3%; and chemical/pharmaceutical waste constitutes 12% and 7%. UITH’s share of each hazardous subtype (42%) which comprises infectious, sharps, pathological, chemical wastes was uniformly higher than that of KWASUTH (25%).

Table 3. Composition of healthcare waste by category in UITH and KWASUTH

Category	UITH(%)	KWASUTH(%)
General (non-hazardous)	58	75
Infectious	20	10
Sharps	5	5
Pathological	5	3
Chemical/pharmaceutical	12	7
Total	100	100

Source: Field Survey, 2025.

The proportion of hazardous waste in UITH (42%) far exceeds WHO benchmark (10–25%), and only 58% of waste generated at UITH was classified as general waste (e.g., food and paper), which is lower than the WHO’s estimate that approximately 85% of hospital waste is non-hazardous [2]. These results align with findings from other tertiary healthcare facilities in Africa. For example, Ho Teaching Hospital in Ghana reported waste fractions of 56.3% general waste and 43.7% hazardous waste [12], while hospitals surveyed in Ethiopia generated 58.7% general waste and 41.3% hazardous waste [52]. These similarities suggest that higher hazardous waste proportions may be associated with more specialized service profile, particularly the presence of extensive surgical units, advanced diagnostic



laboratories, and higher patient turnover. These operational characteristics typically produce larger quantities of infectious, pathological, and sharps waste, thus increasing total hazardous waste output typically provided by tertiary healthcare institutions. Similar deviations from the WHO benchmark have been reported in some healthcare facilities in developing countries where poor waste segregation practices contribute to increased hazardous waste proportions [53, 54]. The findings therefore suggest the need for improved waste segregation, staff training, and continuous monitoring to reduce the volume of waste requiring specialized treatment and disposal.

KWASUTH, although smaller in capacity, also exceeded the national threshold, indicating systemic shortcomings in waste segregation practices. The elevated percentage may likely result from contamination of non-hazardous waste streams such as paper, food residues, and packaging materials with infectious materials due to improper point-of-care separation. This is consistent with earlier findings from staff surveys showing limited compliance with color-coded segregation and inadequate training in waste identification. Exceeding the benchmark has significant implications for operational cost, environmental safety, and occupational health. Hazardous waste is more expensive to manage and poses greater risks to waste handlers, patients, and the broader community. The results, therefore, underscore the urgent need for reinforced segregation protocols, improved training, and regular compliance monitoring in both facilities.

These findings have practical implications. The excessive hazardous fraction at UITH poses health risks to staff and the community. Biomedical waste in this category can harbour pathogens or toxins; as noted, inadequate management is linked to infection outbreaks and pollution. To address this, UITH should strengthen source segregation. For instance, retraining staff (especially in high-output departments) to separate purely general waste (food wrappers, packaging) from clinical waste would reduce the load on hazardous waste streams. The dominance of non-hazardous waste indicates potential for improved segregation to reduce hazardous treatment burdens.

3.1.3. Waste Density

The assessment of waste density across the two tertiary healthcare facilities revealed notable differences that reflect variations in waste composition, handling practices, and spatial constraints. The average waste density was estimated at 140 kg/m³ for UITH and 120 kg/m³ for KWASUTH, indicating that waste generated at UITH is comparatively more compact and heavier per unit volume. The higher density recorded at UITH can be attributed to the greater presence of mixed waste streams, particularly the combination of high-moisture infectious waste, compacted general waste, and laboratory residues. This mixture increases the overall mass within a limited volume, thereby elevating density values. Additionally, UITH's restricted temporary storage areas necessitate more frequent manual compaction by waste handlers to optimize available space. Such compacting practices, though operationally convenient, inadvertently raise density measurements by reducing void spaces within waste bags and containers.

In contrast, KWASUTH's lower density value of 120 kg/m³ suggests a comparatively less compacted waste stream, potentially influenced by better segregation efficiency and a higher proportion of lightweight general waste. The availability of slightly larger or less congested storage zones in KWASUTH may also reduce the need for informal compacting, allowing waste to retain more of its natural bulk.

From a waste management standpoint, higher waste density at UITH may place additional pressure on downstream processes, particularly transportation and incineration, as denser waste typically increases handling difficulty and fuel consumption during thermal treatment. Conversely, KWASUTH's lower density may indicate more aerated waste, which may require volume-based management solutions such as increased collection frequency. The observed density patterns highlight the operational implications of storage limitations, segregation practices, and waste composition in shaping physical waste characteristics. These findings underscore the need for improved spatial planning and reinforced segregation protocols to minimize unnecessary compaction and optimize waste handling efficiency across both facilities.



3.1.4. Recyclable and Organic Waste Analysis

Fig. 2 presents the recyclable and organic wastes generated in both facilities.

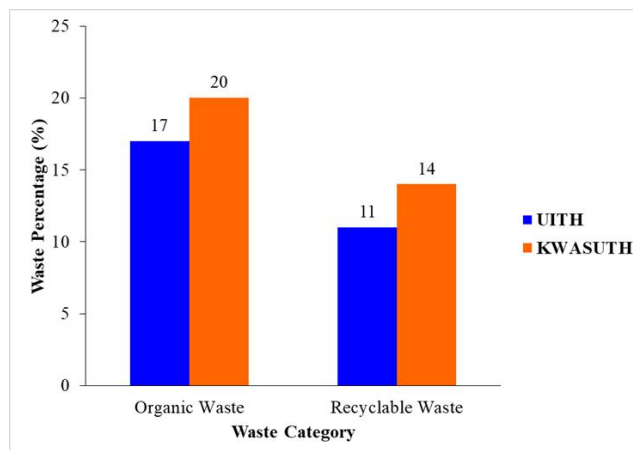


Fig. 2: Recyclable and organic waste generated in both facilities (Data Source: Field Survey, 2025).

The recyclable waste fraction was estimated at 14% in KWASUTH and 11% in UITH, reflecting relatively low levels of recyclable material recovery in both hospitals (Fig. 3). Plastics constituted the largest recyclable component, followed by paper materials and limited glass waste originating from laboratories and pharmacies. KWASUTH exhibited a slightly higher recyclability percentage due to a marginally lower proportion of hazardous and moisture-laden waste streams in its total output. The lower percentage recorded at UITH corresponds with its higher hazardous waste generation, which reduces the relative proportion of clean recyclable materials.

Despite the presence of recyclables, both facilities demonstrated poor recycling performance. This inefficiency may be attributed to inadequate sorting at source, the absence of clearly labelled bins for recyclable categories, and the lack of formal partnerships with accredited recycling companies. The absence of structured recycling systems results in valuable materials being mixed with hazardous waste, rendering them contaminated and unsuitable for recovery. The low recycling rates represent a missed opportunity for waste minimization, resource recovery, and cost reduction in waste management. Hospitals with effective recycling programs have been shown to achieve up to 30–40% reduction in general waste volume. Therefore, establishing structured recycling mechanisms could substantially improve environmental sustainability across both institutions.

Organic waste constituted 17% of total waste at UITH and 20% at KWASUTH, with both facilities generating biodegradable waste primarily from inpatient wards, staff cafeterias, and ancillary service areas (Fig. 3). The relatively higher organic waste fraction observed in KWASUTH reflects its lower proportion of infectious and pathological waste, allowing food and biodegradable materials to make up a larger share of total waste. Conversely, the slightly lower organic fraction at UITH is consistent with its higher output of hazardous waste resulting from specialized clinical activities such as surgical procedures, obstetric services, and laboratory diagnostics. These high-risk waste categories reduce the proportional share of biodegradable materials in the overall waste composition. Organic waste represents an important component from a sustainability perspective. High organic fractions can lead to odour, leachate formation, and rapid decomposition if not handled promptly, thereby requiring daily evacuation and proper containment. The findings indicate that both hospitals would benefit from integrating controlled composting or digestion initiatives for biodegradable waste, as implemented in similar tertiary hospitals globally. Such strategies could reduce landfill pressure and enhance sustainable waste management practices.

3.1.5. Departmental Waste Generation

Fig. 3 presents the departmental waste analysis of both institutions. Surgical units accounted for the largest share of waste, generating 32–35% of total output in both facilities. This dominance aligns with the inherently waste-intensive nature of surgical procedures, which involve high volumes of disposable drapes, gowns, syringes, packaging materials, and sharps. Laboratory units contributed the second-largest proportion, ranging between 21% and 24%, consistent with high usage of reagents, sample containers, test kits, and diagnostic consumables. General wards followed with 18–20%, influenced by patient admissions, drug administration, and daily ward activities. Outpatient and administrative units contributed the least waste, reaffirming that short-stay patient interactions and non-clinical



functions produce minimal waste relative to highly technical departments. This pattern shows that surgery and diagnostic services represent critical hotspots for targeted waste reduction, improved segregation, and enhanced treatment interventions.

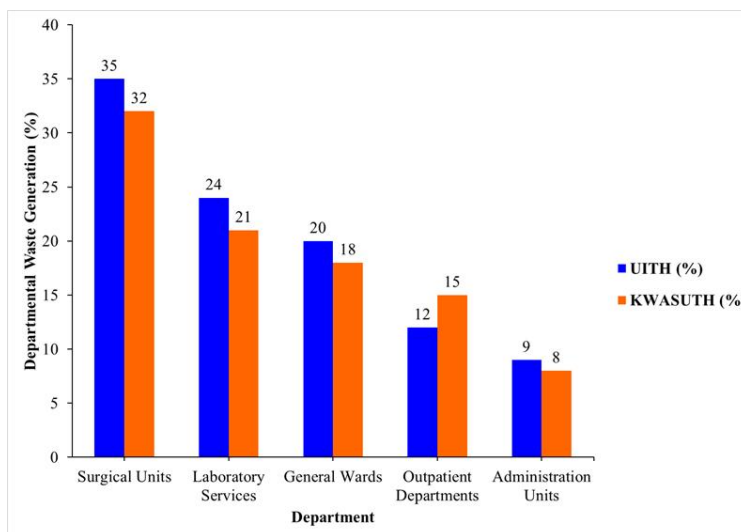


Fig. 3: Departmental Contribution to Total Waste Output in UITH and KWASUTH

3.1.6. Patient-to-Waste Ratio

Fig. 4 presents the Patient-to-Waste Generation Ratios for UITH and KWASUTH. The estimated patient-to-waste ratios show that UITH generated 2.0 kg/patient/day, whereas KWASUTH recorded 1.75 kg/patient/day. These findings indicate that patient attendance is a major determinant of waste output, consistent with global evidence that patient-dependent procedures such as diagnostics, admissions, surgical interventions, and ward-based care account for the bulk of hospital waste generation. UITH’s higher ratio can be attributed to its role as a tertiary referral centre receiving more critically ill patients who require resource-intensive procedures and prolonged hospitalization. This naturally leads to increased use of consumables such as intravenous sets, surgical drapes, laboratory materials, and disposable gloves, ultimately increasing total waste production. The difference also reflects variations in service complexity, as KWASUTH handles a smaller proportion of high-risk and highly specialized procedures. The results underscore the need for patient-adjusted waste forecasting models to optimize waste storage capacity, collection frequency, and treatment scheduling in both institutions.

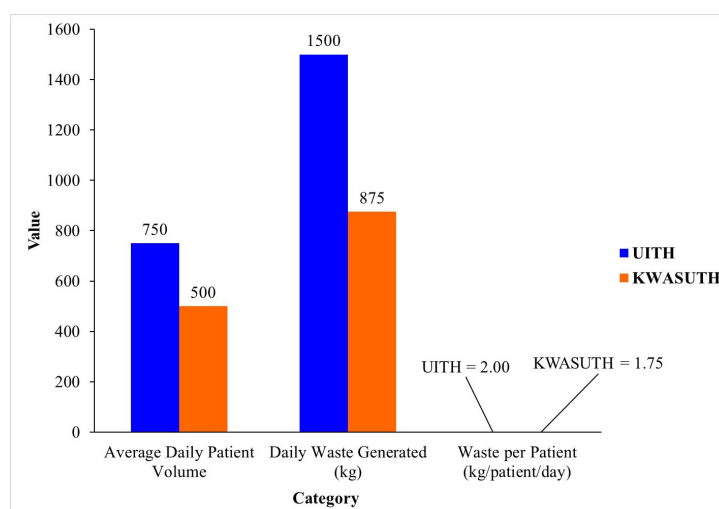


Fig. 4: Patient-to-Waste Ratio in UITH and KWASUTH (Waste Audit and Patient Records, 2025)



3.1.7. Staff-to-Waste Ratio

Fig. 5 presents the Staff-to-Waste Generation Ratios for UITH and KWASUTH. The staff-to-waste analysis revealed waste generation rates of 0.65 kg/staff/day in UITH and 0.58 kg/staff/day in KWASUTH. The higher value in UITH corresponds with its more intensive clinical operations, including higher surgical throughput, advanced imaging services, and broader inpatient capacity, all of which require substantial use of consumables handled directly by staff. This metric is particularly useful because it reflects waste generated from clinical decision-making, diagnostic procedures, sanitation activities, and workplace practices. The higher ratio at UITH may be attributed to a greater per-staff workload, potentially increased use of disposables during infection-control procedures, and more frequent handling of hazardous items. Such variation between the two facilities emphasizes the influence of workforce size and clinical intensity on waste output. Strengthening training, supervision, and adherence to waste minimization principles could reduce these ratios, particularly in high-waste departments such as surgery and laboratory units.

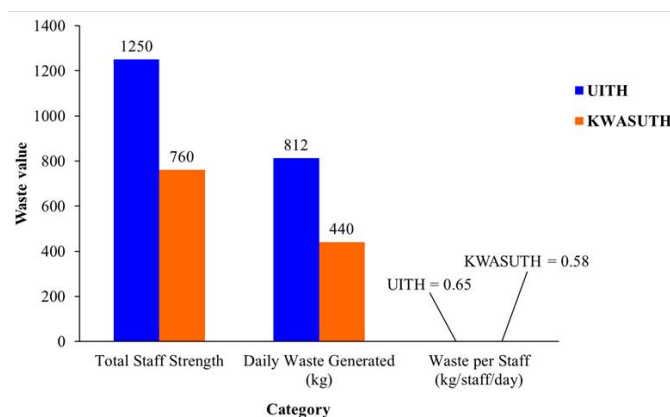


Fig. 5: Staff-to-Waste Ratio in UITH and KWASUTH (Field Survey and HR Records, 2025)

3.1.8. Comparative Descriptive Statistics on Staff Knowledge and Training in KWASUTH and UITH

Table 4 presents a comparative descriptive analysis of staff knowledge and training on healthcare waste management practices between KWASUTH and UITH. The comparison highlights key areas of strength and weakness in the staff’s understanding, participation in training programs, adherence to safety measures, and involvement in institutional waste management policies.

Table 4. Comparative Descriptive Statistics on Staff Knowledge and Training in KWASUTH and UITH

Variable	Groups	KWASUTH	KWASUTH	UITH	UITH
		(frequency)	(%)	(frequency)	(%)
1. Have you been trained	Yes	65	59.1	50	65.8
	No	45	40.9	26	34.2
	Total	110	100	76	100
2. Place of training	KWASUTH	110	100	0	0
	UITH	0	0	76	100
	Total	110	100	76	100
3. Is biomedical waste segregated?	Yes	85	77.3	65	85.5
	No	18	16.4	6	7.9
	Don’t know	7	6.4	5	6.6
	Total	110	100	76	100
4. Who segregates BMW?	Medical staff	61	55.5	44	57.9
	Cleaning worker	36	32.7	25	32.9
	Don’t know	13	11.8	7	9.2
	Total	110	100	76	100
5. Are color-coded containers identified & distinguished?	Yes	45	40.9	29	38.2
	No	55	50.0	35	46.1
	Don’t know	10	9.1	12	15.8
	Total	110	100	76	100



Variable	Groups	KWASUTH (frequency)	KWASUTH (%)	UITH (frequency)	UITH (%)
6. Are biomedical waste bags subject to tears?	Yes	52	47.3	44	57.9
	Sometimes	32	29.1	24	31.6
	Rarely	10	9.1	3	3.9
	No	6	5.5	3	3.9
	Don't know	10	9.1	2	2.6
	Total	110	100	76	100
7. Are biomedical waste sacks/bags fastened properly?	Yes	72	65.5	52	68.4
	Sometimes	14	12.7	9	11.8
	Rarely	8	7.3	6	7.9
	No	9	8.2	4	5.3
	Don't know	7	6.4	5	6.6
	Total	110	100	76	100
8. Are there provisional measures to prohibit liquid from waste?	Yes	61	55.5	44	57.9
	Sometimes	27	24.5	19	25.0
	Rarely	10	9.1	7	9.2
	No	6	5.5	3	3.9
	Don't know	6	5.5	3	3.9
	Total	110	100	76	100
9. Is healthcare waste treated before final disposal?	Yes	82	74.5	60	78.9
	No	19	17.3	9	11.8
	Don't know	9	8.2	7	9.2
	Total	110	100	76	100
10. What kind of HCW treatment system do you use?	Chemical disinfection	10	9.1	7	9.2
	Incinerator	25	22.7	17	22.4
	Open fire/landfill	75	68.2	52	68.4
	Total	110	100	76	100

Source: Field Survey, 2025

Staff training in biomedical waste management was moderate in both hospitals, with 59.1% of respondents in Kwara State University Teaching Hospital and 65.8% in University of Ilorin Teaching Hospital reporting that they had received formal training. This suggests a fair level of awareness of biomedical waste handling practices, although a substantial proportion of staff in both facilities remain untrained.

Waste segregation was mainly carried out by medical personnel, accounting for 55.5% of respondents in KWASUTH and 57.9% in UITH, while cleaning staff also contributed significantly to the process. Although awareness of waste segregation practices was relatively high in both hospitals (77% in KWASUTH and 86% in UITH), compliance with color-coded segregation systems remained poor, with only 41% and 38% adherence respectively. This indicates weaknesses in practical implementation despite reasonable awareness levels.

The study also revealed shortcomings in waste containment and handling practices. Nearly half of respondents in KWASUTH (47.3%) and more than half in UITH (57.9%) reported frequent tearing of waste bags, largely attributed to overfilling and the use of low-quality liners. Compliance with proper fastening of waste bags before transportation was only moderate, reported by 65.5% of respondents in KWASUTH and 68.4% in UITH. Similarly, liquid waste containment practices were inadequate, as only about 56% of KWASUTH staff and 58% of UITH staff applied recommended measures such as double-bagging or the use of leak-proof containers.

Waste treatment prior to final disposal showed moderate compliance in both hospitals, with treatment rates of 75% in KWASUTH and 79% in UITH. While these values indicate some level of adherence to recommended treatment practices, the untreated fraction still poses potential health and environmental risks.



Open burning was identified as the predominant disposal method in both facilities, accounting for about 68% of waste disposal practices. Similar observations have been reported in several healthcare facilities across developing countries [12, 53, 55], where inadequate waste management infrastructure and limited funding often result in the use of open burning as a low-cost disposal alternative [56]. Open burning remains a major environmental and public health concern because of the release of harmful pollutants associated with uncontrolled burning, as it releases toxic pollutants like dioxins, furans, and heavy metals, contributing to respiratory diseases [57] and climate change [58]. Overall, the findings show that although both hospitals demonstrate moderate strengths in staff training and awareness, important gaps remain in segregation compliance, waste containment, liquid waste control, and environmentally safe disposal practices. Addressing these deficiencies will require improved staff training, closer supervision, better waste handling facilities, and investment in safer treatment technologies, including on-site treatment systems such as double-chamber incinerators [59].

These deficiencies point to systemic vulnerabilities that heighten the risks of leakage, contamination, and occupational exposure. Torn bags, improperly fastened liners, and poorly managed liquid waste compromise containment integrity and increase the likelihood of environmental spills and staff contact with hazardous materials. The findings emphasize the need for improved training, stricter adherence to handling protocols, and the procurement of stronger waste bags and appropriate liquid-holding containers to enhance the overall safety and effectiveness of waste management operations.

3.1.9. Waste Management Costs

Table 5 presents the analysis of the monthly waste management expenditure in UITH and KWASUTH. The financial analysis revealed that UITH allocates approximately ₦1.85 million monthly to healthcare waste collection, internal transport, and final disposal, while KWASUTH commits ₦1.25 million monthly. This expenditure gap aligns with the relative operational capacities of both facilities, reflecting UITH’s broader clinical coverage, higher patient volume, and more frequent waste evacuation schedules. Despite these differences, both institutions allocate less than 2% of their total recurrent expenditure to waste management, substantially lower than the 5% minimum threshold recommended by WHO for safe, sustainable biomedical waste handling. Underinvestment of this kind is often associated with inadequate procurement of color-coded bags, substandard storage infrastructure, insufficient staff training programs, and limited adoption of non-incineration treatment technologies. The results, therefore, highlight a structural financial gap that undermines the ability of both hospitals to achieve optimal waste segregation, storage, treatment, and environmentally compliant disposal. An increase in budget allocation is essential to reduce reliance on open burning, improve PPE availability, and sustain long-term waste minimization initiatives.

Table 5. Monthly Waste Management Expenditure in UITH and KWASUTH

Facility	Monthly Waste Management Cost (₦)	Estimated Annual Cost (₦)	% of Total Recurrent Budget	WHO Recommended Minimum
UITH	1,850,000	22,200,000	< 2%	5%
KWASUTH	1,250,000	15,000,000	< 2%	5%

Source: Administrative Records, 2025.

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

The study concludes that both UITH and KWASUTH demonstrate moderate levels of biomedical waste management training among staff; however, nearly 40% of personnel remain untrained, leading to inconsistent compliance with standard waste handling procedures. Although awareness of waste segregation practices is relatively high, poor adherence to color-coding systems indicates inadequate compliance with national healthcare waste management guidelines. The frequent occurrence of torn waste bags and insufficient liquid waste control measures further reflects weaknesses in waste packaging and monitoring practices. While both hospitals carry out some form of waste treatment prior to disposal, the continued reliance on open burning as the dominant disposal method poses significant environmental and public health concerns. Furthermore, no significant difference was observed between the two institutions in terms of staff training coverage and waste generation rates, suggesting that the variations identified are largely operational rather than structural.



4.2. Recommendations

Based on the key findings and in alignment with the study objectives, the following recommendations are made:

- i. Establish mandatory and periodic staff training on biomedical waste management across all departments, emphasizing segregation, labelling, and safe disposal techniques.
- ii. Enforce strict color-coded segregation using standardized containers and conduct regular internal audits to ensure compliance with the National Healthcare Waste Management Guidelines (FMEnv, 2022).
- iii. Replace open burning with eco-friendly technologies such as autoclaving and incineration with emission controls to minimize environmental pollution and health risks.

Future studies should examine seasonal variations in healthcare waste generation, particularly differences between wet and dry seasons. They should also assess how patient load and hospital specialization influence the quantity and composition of waste generated. In addition, future research could develop predictive or machine learning models to improve waste management efficiency and enhance environmental safety within Nigerian healthcare facilities.

Conflicts of Interest

The authors declare no conflict of interest.

References

- [1] Yong, Z., Gang, X., Guanxing, W., Tao, Z., and Dawei, J. "Medical waste management in China: A case study of Nanjing." *Journal of Waste Management*, 29, 1376-1382 (2009). doi:10.1016/j.wasman.2008.10.023.
- [2] World Health Organization. "Safe management of wastes from health-care activities" (2nd ed.). (2017). doi:10.1201/9781315141532.
- [3] Glenn, M., and Agarwal, R. "Clinical waste in developing countries: An analysis with a case study of India, and a critique of the Basle TWG Guidelines." (2019).
- [4] Janik-Karpinska, E., Brancaloni, R., Niemcewicz, M., Wojtas, W., Foco, M., Podogrocki, M., and Bijak, M. "Healthcare waste—A serious problem for global health." *Healthcare (Basel, Switzerland)*, 11(2), 242 (2023). doi:10.3390/healthcare11020242.
- [5] Minoglou, M., Gerassimidou, S., and Komilis, D. "Healthcare waste generation worldwide and its dependence on socio-economic and environmental factors." *Sustainability*, 9(2), 220 (2017). doi:10.3390/su9020220.
- [6] World Health Organization. "Safe management of wastes from health-care activities" (2nd ed.). (2014).
- [7] Ansari, M., Ehrampoush, M. H., Farzadkia, M., and 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; A state of the art of review." *Environment International*, 132 (2019). doi:10.1016/j.envint.2019.105073.
- [8] Odonkor, S., and Mahami, T. "Healthcare waste management in Ghanaian hospitals: Associated public health and environmental challenges." *Waste Management & Research*, 00(0), 1-9 (2020). doi:10.1177/0734242X20914748.
- [9] Berhanu, S., Beyamo, A., and Desalegn, T. "Health care waste management and associated factors during Covid-19 pandemic among public health facilities in Hadiya Zone, Southern Ethiopia: A cross-sectional study." *Risk Management and Healthcare Policy*, 15, 1553-1559 (2022). doi:10.2147/RMHP.S370438.
- [10] Ghali, H., Ben Cheikh, A., Bhiri, S., Bouzgarrou, L., Ben Rejeb, M., Gargouri, I., and Said Latiri, H. "Health and environmental impact of hospital wastes: Systematic review." *Dubai Medical Journal*, 6(2), 67–80 (2023). doi:10.1159/000529432.
- [11] Raji, M. O., and Adeogun, A. G. "Healthcare waste management: An overview." *ABUAD Journal of Engineering Research and Development*, 7(1), 14-27 (2024). doi:10.53982/ajerd.
- [12] Afesi-Dei, C., Appiah-Brempong, M., and Awuah, E. "Health-care waste management practices: The case of Ho Teaching Hospital in Ghana." *Heliyon*, 9(4), Article e15514 (2023). doi:10.1016/j.heliyon.2023.e15514.
- [13] Manga, V. E. "Hospital waste generation and management in tertiary health care facilities: A comparative assessment. Fako Division, Cameroon." *European Journal of Applied Sciences*, 13(02), 59–71 (2025). doi:10.14738/aivp.1302.18383.
- [14] Ghafari, Y., and Nabizadeh, R. "Composition and quantity of cytotoxic waste from oncology wards: A survey of environmental characterization and source management of medical cytotoxic waste." *Bioscience Biotechnology Research Communications*, 10(3) (2017). Available from: <https://bit.ly/2wVZqub>
- [15] Federal Ministry of Environment. "National Healthcare Waste Management Guidelines." (2022).
- [16] Federal Environmental Protection Agency (FEPA). "National Interim Guidelines and Standards for Industrial Effluents, Gaseous Emissions and Hazardous Wastes Management in Nigeria." (1991).
- [17] National Environmental Standards and Regulations Enforcement Agency (NESRA). "National Environmental (Healthcare Waste Control) Regulations." Lagos. (2021).
- [18] Abalaku, S. A., Ogwueleka, T. C., Samson, B., and Idris, A. "Generation and composition of medical waste in Lafia." *International Journal of Computing and Engineering*, 6(4), 39–53 (2024). doi:10.47941/ijce.2218.
- [19] Obubu, M., Chuku, N., Ananaba, A., Sadiq, F. U., Sambo, E., Kolade, O., Oyekanmi, T., Olaosebikan, K., and Serrano, O.



- "Lagos State hospital waste management practices: A descriptive overview with stakeholders' role and key recommendations." *Journal of Environmental Protection*, 14(2), 108-125 (2023). doi:10.4236/jep.2023.142008.
- [20] Abah, R. C. "Assessment of healthcare facilities location and medical waste generation and handling in Nigeria." *Journal of Public Health and Epidemiology*, 12(1), 50–62 (2020). doi:10.5897/JPHE2020.1204.
- [21] Golandaj, M., and Kallihal, S. S. "Awareness, attitude, and practices regarding biomedical waste management among healthcare staff in Karnataka, India." *International Journal of Engineering Applied Sciences and Technology*, 5(2), 89-94 (2020).
- [22] Ibrahim, M., Kebede, M., and Mengiste, B. "Healthcare waste segregation practice and associated factors among healthcare professionals working in public and private hospitals, Dire Dawa, Eastern Ethiopia." *Journal of Environmental and Public Health*, Volume 2023, Article ID 8015856 (2023). doi:10.1155/2023/8015856.
- [23] Jimoh, U. U., and Abdullahi, W. O. "Generation and composition of biomedical waste in selected hospitals in Akure South Local Government Area, Nigeria." *African Journal of Biomedical Research*, 25, 73–81 (2022).
- [24] Sadeghi, M., Fadaei, A., and Ataee, M. "Assessment of hospitals medical waste management in Chaharmahal and Bakhtiari Province in Iran." *Archives of Agriculture and Environmental Science*, 5(2), 157-163 (2020). doi:10.26832/24566632.2020.0502011.
- [25] Alwabr, G. M. A., Al-Mikhlaifi, A. S., Al-Hakimi, S. A., and Dughish, M. A. "Determination of medical waste composition in hospitals of Sana'a city, Yemen." *Journal of Applied Science and Environmental Management*, 20(2), 343-347 (2016). doi:10.4314/jasem.v20i2.15.
- [26] Al Naemi, H., Izuka, K., Edquibal, C., Al-Korbi, N., Al Kuwari, N., and Al Homaid, M. "Quantitative assessment of medical waste management in Hamad Medical Corporation—Qatar." *Occupational Diseases and Environmental Medicine*, 9, 112-126 (2021). doi:10.4236/odem.2021.93009.
- [27] El Gueriri, S. A., El Mansouri, F., Achemlal, F., Lachaal, S., Brigui, J., and Fakhri Lanjri, A. "Healthcare waste characteristics and management in regional hospital and private clinic." *Global Journal of Environmental Science and Management*, 9(4), 805-818 (2023). doi:10.22034/gjesm.2023.391234.36.
- [28] Anicetus, H., Saria, J., and Mohamed, H. "Estimation of different categories of healthcare waste generated at two different hospital categories in four hospitals in Dar es Salaam City." *Journal of Environmental Protection*, 11, 872-888 (2020). doi:10.4236/jep.2020.1110055.
- [29] Khalid, S., Haq, N., Sabiha, Z.-u.-A., Latif, A., Khan, M. A., Iqbal, J., and Yousaf, N. "Current practices of waste management in teaching hospitals and presence of incinerators in densely populated areas." *Journal of Physics: Conference Series*, 1804, 012147 (2024). doi:10.1088/1742-6596/1804/1/012147.
- [30] Shabani, T., Mutekwa, T. V., and Shabani, T. "Solid waste characteristics and management strategies at St. Theresa and Holy Cross hospitals in Chirumanzu rural District, Zimbabwe." *Environmental Sciences Europe*, 36(57) (2024). doi:10.1186/s12302-024-00882-0.
- [31] Parida, V. K., Sikarwar, D., Majumder, A., and Gupta, A. K. "An assessment of hospital wastewater and biomedical waste generation, existing legislations, risk assessment, treatment processes, and scenario during COVID-19." *Journal of Environmental Management*, 308, 114609 (2022). doi:10.1016/j.jenvman.2021.114609.
- [32] Malkawi, A. I., Al-Batain, M. A., and Basuni, S. "Designing questionnaires for healthcare waste research: A systematic approach." *Journal of Environmental Management*, 288, 112323 (2021). doi:10.1016/j.jenvman.2021.112323.
- [33] Zhang, Y., Chen, Y., and Wang, X. "Trends in healthcare waste management practices: A comparative study." *Waste and Biomass Valorization*, 11(7), 3719-3731 (2020). doi:10.1007/s12649-020-01088-6.
- [34] Kerdlap, P., van den Berg, M., and Pearson, L. "Healthcare waste management frameworks: A global analysis." *International Journal of Environmental Research and Public Health*, 18(15), 7613 (2021). doi:10.3390/ijerph18157613.
- [35] Gupta, S., Basu, S., and Yadav, R. "Waste management in healthcare facilities: Current trends and future directions." *Waste Management & Research*, 37(12), 1235-1244 (2019). doi:10.1177/0734242X19887414.
- [36] Li, W., and Zhang, J. "Optimizing paper-based survey distribution in healthcare settings." *Healthcare*, 9(3), 236-244 (2021). doi:10.3390/healthcare9030236.
- [37] Choi, J., and Yi, J. "Methods for improving response rates to healthcare surveys." *Health Services Research*, 54(5), 1065-1080 (2019). doi:10.1111/1475-6773.13299.
- [38] Chen, H., Xu, J., and Shi, L. "The application of paper-based surveys in healthcare research: A literature review." *Journal of Nursing Management*, 28(4), 552-559 (2020). doi:10.1111/jonm.12936.
- [39] Alzoubi, M. H., and Al-widyan, M. I. "Healthcare waste management: Types, quantities, and management practices in selected hospitals." *Journal of Environmental Health Science & Engineering*, 19(1), 101-113 (2021). doi:10.1007/s40201-021-00623-1.
- [40] Patwary, M. A., Sarker, M. H., and Uddin, S. "A comprehensive review on healthcare waste management systems: Evidence from developing countries." *Journal of Environmental Management*, 307, 114-126 (2022). doi:10.1016/j.jenvman.2022.114126.
- [41] Kim, H. J., and Oh, S. H. "Advantages of using SPSS in healthcare research: A review." *Healthcare Informatics Research*, 27(2), 115-121 (2021). doi:10.4258/hir.2021.27.2.115.
- [42] Azage, M., and Kumie, A. "Healthcare waste management practices among healthcare workers in healthcare facilities of Gondar town, Northwest Ethiopia." *BMC Public Health*, 18(1), 1-8 (2018). doi:10.1186/s12889-018-5318-5.
- [43] Hossain, M. S., Santhanam, A., Norulaini, N. N., and Omar, A. M. "Clinical solid waste management practices and its impact on human health and environment—A review." *Waste Management*, 99, 39-48 (2022).



- doi:10.1016/j.wasman.2022.03.003.
- [44] Bassey, B. E., Benka-Coker, M. O., and Aluyi, H. S. "Characterization and management of solid medical wastes in selected hospitals in Nigeria." *African Health Sciences*, 18(1), 1-8 (2019). doi:10.4314/ahs.v18i1.1.
- [45] Moghadam, F. M., Mokhtarani, N., and Mokhtarani, B. "Survey of medical waste disposal methods and its relation to health and environment." *Environmental Health Engineering and Management Journal*, 7(3), 201-207 (2020). doi:10.34172/ehemj.2020.20.
- [46] ASTM. "ASTM D5231-92(2019): Standard test method for determination of the composition of unprocessed municipal solid waste." ASTM International. (2019). doi:10.1520/D5231-92R19.
- [47] Caniato, M., Tudor, T., and Vaccari, M. "International governance structures for healthcare waste management: A systematic review of scientific literature." *Journal of Environmental Management*, 203(2), 240-250 (2018). doi:10.1016/j.jenvman.2017.08.013.
- [48] Nema, A. K., and Gupta, S. K. "Waste management: The global concept." *Springer Series in Waste Management*. (2020).
- [49] Park, J., Kim, H., and Lee, D. "Visual documentation in healthcare studies: Use and benefits in waste management research." *Health & Place*, 70, 102587 (2021). doi:10.1016/j.healthplace.2021.102587.
- [50] Risse, B., Munodawafa, D., and Kaluza, P. "Visualizing waste management practices: A photographic analysis of waste handling in healthcare facilities." *Journal of Environmental Management*, 231, 214-223 (2019). doi:10.1016/j.jenvman.2018.10.054.
- [51] Khan, B. A., Khan, A. A., Ahmed, H., Shaikh, S. S., Peng, Z., and Cheng, L. "A study on small clinics waste management practice, rules, staff knowledge, and motivating factor in a rapidly urbanizing area." *International journal of environmental research and public health*, 16(20), 4044 (2019). doi:10.3390/ijerph16204044.
- [52] Debere, M. K., Gelaye, K. A., Alamdo, A. G., and Trifa, Z. M. (2013). "Assessment of the health care waste generation rates and its management system in hospitals of Addis Ababa, Ethiopia, 2011," *BMC Public Health*, 13(10), 1-9(2013). doi: 10.1186/1471-2458-13-28.
- [53] Gashaw, A. K., Pitta, S. & Jifera, L. D. "Assessment of medical waste generation, disposal practices and health implications at Bule Hora University Teaching Hospital, West Guji, Ethiopia." *Discov Health Systems*, 4(91), 1-25 (2025). doi:10.1007/s44250-025-00261-3.
- [54] Kanno, G., Mengesha, A. & Wondimagegn, M. "Status of hospital waste management and associated environmental risks in Ethiopia." *J Public Health Epidemiol*, 13(5), 85-97 (2021). doi:10.5897/JPHE2021.1367.
- [55] Tesfahun, E., Esubalew, G. & Kassaye, H. "Healthcare waste generation rate and disposal practices in Addis Ababa hospitals." *Waste Manag Res*, 37(5), 675-688 (2019).
- [56] Abah, S. O. & Ohimain, E. I. "Healthcare waste management in Nigeria: a case study." *J Public Health Epidemiol*, 3(3), 99-110 (2011).
- [57] Manyele, S. V. & Mujuni, C. M. "Healthcare waste management in Tanzania: current situation and challenges." *Environ Health Insights*, 4, 55-60 (2010).
- [58] Mekonnen, D. & Besufekad, A. "The impact of improper healthcare waste management on public health in developing countries: a case study from Ethiopia." *Waste Manag Res*, 40(3), 225-239 (2022).
- [59] Mokuolu, O. A., Akindele, R. S., and Olawumi, H. O. "Development of improved solid hospital waste management practices in a Nigerian tertiary hospital." *Nigerian Journal of Technology*, 35(3), 674-680 (2016).

