

Climate-smart healthcare waste management in urban primary health care facilities in Abuja, Nigeria: A situation analysis, proof-of-concept comparative baseline assessment of environmental sustainability practices and system readiness across four facilities

Glory Nwakaogor

glory.nwakaogor@ehealthnigeria.org

eHealth Africa <https://orcid.org/0009-0008-9058-0227>

Dominic Gulak

eHealth Africa

Loveth Metiboba

eHealth Africa <https://orcid.org/0000-0003-1001-0723>

Joshua Ogundairo

eHealth Africa

Onche Ogbole

eHealth Africa

Adedayo Odukoya

eHealth Africa

Fatimah Howeidy

eHealth Africa

Gift Abudar

eHealth Africa

David Akpan

eHealth Africa

Ota Akhigbe

eHealth Africa

Atef Fawaz

eHealth Initiative

Nemi Ishaku

eHealth Africa

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Abstract

Background

Unsafe healthcare waste management in primary health care (PHC) facilities contributes to healthcare-associated infections, occupational injuries, and environmental degradation, including greenhouse gas emissions from open burning. Despite growing global emphasis on climate-smart health systems, evidence on integrating environmental sustainability into PHC waste management in sub-Saharan Africa remains sparse. As a pilot proof-of-concept, this study assessed the baseline status of climate-smart and environmentally sustainable healthcare waste management practices across four PHC facilities in Abuja, Nigeria, to test the assessment approach and inform intervention design.

Methods

We conducted a proof-of-concept comparative baseline assessment across four purposively selected PHC facilities (Apo PHC, Kagini PHC, EHA Clinics, and Lugbe PHC) in Abuja, Federal Capital Territory. This pilot was designed to establish the feasibility of a structured facility audit approach and to generate baseline data ahead of the ClimateSENSE intervention, rather than to produce population-level prevalence estimates. Using a structured 14-domain audit tool, data were collected through direct observation, staff interviews, and document review. Composite scores were computed for each domain, and an overall readiness score (maximum 275) was derived for each facility. Facility-level waste-related carbon dioxide (CO₂) emissions were estimated using a WHO-aligned approach (0.2 kg of waste per patient per day; emission factor 0.8 kg CO₂ per kg of waste). Findings are reported across all domains, with emphasis on environmental and climate practices, waste treatment, and disposal.

Results

Composite readiness scores ranged from 43.6% (Kagini PHC, low-to-moderate) to 84.7% (EHA Clinics, high readiness). Waste segregation was the strongest domain (75–100% across facilities), but data systems were weak: 50% of facilities did not measure waste quantities, and 75% kept no records. Half of the facilities stored waste for more than 48 hours. Environmental and climate practices were the weakest domain: only one facility (25%) used renewable energy for waste treatment, 75% did not track carbon emissions, and open burning was the primary disposal method in 75% of facilities, with all facilities (100%) using fuel accelerants. Functional autoclave capacity was limited to 50% of facilities. Estimated baseline waste-related emissions totalled approximately 7.7 tonnes CO₂ per year across the four facilities (WHO patient-load basis); self-reported waste volumes were substantially higher and internally inconsistent with patient load. Over two years, facilities reported an average of 1.5 needle-stick injuries and 1.5 staff exposure incidents, despite universal Hepatitis B vaccination coverage.

Conclusions

Healthcare waste management in these facilities is partially functional but uneven, with the most critical failures concentrated at treatment and disposal, where environmental sustainability remains peripheral. Open burning, absent emission tracking, and the non-use of renewable energy represent critical gaps in climate-smart practice. The ClimateSENSE intervention, which deploys solar-powered autoclaves, strengthens segregation systems, and builds frontline capacity, is well-positioned to address these gaps. These proof-of-concept findings support the feasibility of the assessment approach and motivate larger, representative studies of environmentally sustainable PHC waste management across Nigeria and comparable low- and middle-income country settings.

Background

Primary health care (PHC) facilities generate diverse categories of waste during routine service delivery, including infectious waste, sharps, pharmaceutical residues, and laboratory materials. The World Health Organization (WHO) estimates that approximately 15% of all healthcare waste is hazardous, with the potential to cause infectious, toxic, or environmental harm when improperly managed [1]. Unsafe disposal of this fraction exposes healthcare workers, patients, waste handlers, and surrounding communities to preventable health risks, including sharps injuries, blood-borne pathogen transmission, and toxic exposure from chemical and pharmaceutical waste.

Beyond immediate infection risks, healthcare waste management carries significant environmental and climate implications. Open burning is one of the most prevalent disposal methods in low- and middle-income country (LMIC) settings, releasing toxic emissions, including dioxins, furans, and fine particulate matter, and contributing to air pollution, environmental degradation, and greenhouse gas (GHG) emissions [1, 2]. If the global healthcare sector were a country, it would rank among the world's five largest carbon emitters [3]. Conventional waste treatment methods, including non-renewable-energy-powered incineration and autoclaving, further contribute to the sector's carbon footprint, underscoring the need for climate-smart alternatives [4].

Globally, the WHO/UNICEF Joint Monitoring Programme (JMP) reports that, as of 2023, only a quarter of health care facilities in fragile contexts had basic waste management services, with over half lacking basic hygiene services [5]. Sub-Saharan Africa bears a disproportionate burden of healthcare-associated infections (HAIs), accounting for an estimated 4.8 million cases and 500,000 deaths annually, with inadequate waste management a key contributing factor [6].

Despite growing international emphasis on climate-resilient and environmentally sustainable health systems, reflected in the WHO Global Strategy on Infection Prevention and Control (2023) and the WHO Guidance for Climate-Resilient and Environmentally Sustainable Health Care Facilities, empirical evidence on the integration of climate-smart practices into PHC waste management in Nigeria remains limited [4, 7]. Most published studies focus on waste segregation or treatment infrastructure, with few

systematically assessing renewable energy use, emission tracking, and efforts to reduce open burning as composite indicators of environmental sustainability.

In Nigeria, deficiencies in healthcare waste management are well documented. Studies consistently report poor waste segregation, reliance on open burning and indiscriminate dumping, limited functional treatment infrastructure, and weak governance systems, particularly at the PHC level [8, 9, 10]. Nationally, sharp and non-sharp healthcare waste was found to be burned in protected pits in fewer than half of all sampled facilities, with functional incinerators present in only 2.06% of healthcare facilities [11]. These system failures are compounded by staff knowledge gaps, inadequate training, weak institutional accountability, and insufficient financing [9, 10].

This paper reports a proof-of-concept comparative baseline assessment of the readiness of healthcare waste management systems in four PHC facilities in Abuja, Federal Capital Territory, Nigeria, conducted as part of the Climate-Smart Environmental Sanitation for Enhanced Health System (ClimateSENSE) project by eHealth Africa. The assessment was conceived as a pilot with two purposes: to test the feasibility and utility of a structured 14-domain audit tool for characterising climate-smart waste management at the PHC level, and to generate facility-level baseline data to inform the design and monitoring of the ClimateSENSE intervention. Given the small, purposive sample, it is intended as a feasibility and baseline exercise and a comparative case study across contrasting facility types, rather than as an epidemiological study designed to estimate the prevalence of practices across the wider PHC system. We report baseline findings across the full healthcare waste management chain, with particular emphasis on environmental and climate practices, waste treatment, and disposal, to characterise the current state of climate-smart practice and identify critical intervention targets. Although the small sample is not intended to support population-level inference, the study was designed and reported following the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement, adapted to this facility-level assessment; a completed STROBE checklist is provided as Additional file 1.

Methods

Study design and setting

This was a pilot, proof-of-concept comparative baseline assessment carried out in April 2026 across four purposively selected PHC facilities in Abuja, Federal Capital Territory (FCT), Nigeria: Apo PHC, Kagini PHC, EHA Clinics (a private-sector facility operated by eHealth Africa), and Lugbe PHC. Consistent with the aims of a feasibility and baseline exercise, the four facilities were not intended to constitute a statistically representative sample; instead, they were selected as contrasting cases spanning a range of facility types, service-delivery capacities, and geographic catchment areas within the FCT. The facilities differ in infrastructure availability, staffing levels, patient volume, and operational context, enabling a comparative case-study analysis of system performance across the healthcare waste management chain and testing whether the audit approach could discriminate between higher- and lower-readiness

settings. Because the sample was small and purposive, the assessment characterises these facilities and the assessment method rather than estimating the distribution of practices across the wider PHC system.

Data collection tool and domains

Data were collected using a structured facility audit tool (adapted from WHO healthcare waste management assessment frameworks) [2] organised into 14 thematic sections (Domains A-N), covering facility characteristics and staffing; infrastructure and utility availability; waste generation and tracking; waste segregation; collection and transport; storage; treatment (autoclave systems); disposal; waste burning composition; occupational health and safety; policies, standard operating procedures (SOPs), and training; environmental and climate practices; and infection prevention and control (IPC) compliance audit indicators.

The tool incorporated binary (Yes/No) compliance questions directly linked to the composite score, as well as categorical, multi-select, quantitative, and perception-based items for contextual depth. Data were collected using an Open Data Kit (ODK)-based digital tool deployed on mobile devices, with built-in validation checks, skip logic, GPS tagging, and time stamps to support data quality. Trained assessors conducted direct observation of facility areas, reviewed relevant documentation (logbooks, policy documents, SOPs), and conducted structured interviews with facility in-charges, health workers, laboratory personnel, and waste handlers, consistent with the WHO multimodal strategy for IPC implementation.

Composite scoring

Composite scores for each domain were calculated by summing item scores, with each domain assigned a defined maximum (Domain D, waste generation = 10; E, segregation = 40; F, collection and transport = 15; G, storage = 20; H, treatment = 35; J, environmental risk/burning = 15; K, occupational health and safety = 30; L, policies and training = 20; M, environmental practices = 15; N, IPC compliance audit = 75). Compliant binary indicators were scored 5 and non-compliant 0; reverse scoring was applied to undesirable practices (e.g., open burning); categorical and multi-select responses were scored against predefined performance levels. An overall facility readiness score (maximum 275) was derived by aggregating scores across all domains. Facilities were categorised as High Readiness ($\geq 75\%$), Moderate Readiness (55–74%), or Low-to-Moderate Readiness ($< 55\%$), consistent with thresholds established for this assessment. Where necessary, section scores were expressed as percentages of the maximum to enable cross-section comparison.

Quantitative variables (e.g., number of injuries or exposures) were not included in the composite scoring; instead, they were analysed separately using averages, minimum, and maximum values, as they represent outcome measures rather than compliance indicators.

Estimation of waste-related CO emissions

Facility-level waste-related carbon dioxide (CO₂) emissions were estimated using the WHO-aligned approach adopted in the ClimateSENSE measurement framework. Total daily waste was estimated from patient load using a generation rate of 0.2 kg of healthcare waste per patient per day. This rate corresponds to the WHO benchmark for low-income settings, which generate, on average, approximately 0.2 kg of hazardous healthcare waste per occupied bed per day [1, 2]; in the absence of inpatient bed-day data, and given the outpatient orientation of the assessed facilities, it was applied on a per-patient basis as the facility-level generation rate. Waste was apportioned to WHO category benchmarks (general 85%; infectious 10%; sharps 2%; anatomical 1%; pharmaceutical/chemical 2%) [2]. Baseline emissions were estimated under the prevailing all-waste-burned scenario by applying an emission factor of 0.8 kg CO₂ per kg of waste, consistent with combustion emission factors applied in GHG inventory methodology and healthcare-waste carbon-footprint studies [12, 13], and adopted in the project measurement framework. Daily estimates were annualised by multiplying by 365.

Because most facilities did not weigh or record waste (a key finding of this assessment), two bases for estimation are reported transparently. First, a WHO patient-load basis applied the 0.2 kg/patient/day generation rate to each facility's average daily outpatient attendance, obtained from the assessment dataset, and is presented as the primary, per-facility estimate. Second, a reported-volume basis was used, where, for each facility, the self-reported daily waste-volume band was the waste input. The two bases are compared, and their divergence is interpreted as a measure of waste-data reliability rather than concealment.

Ethical considerations

This study was a pilot, facility-level baseline assessment conducted to inform the design and monitoring of the ClimateSENSE programme. Data were obtained through direct observation of facility infrastructure and waste-management practices, review of facility records (logbooks, policy documents, and SOPs), and structured key-informant interviews with facility in-charges, health workers, laboratory personnel, and waste handlers. No patient-level data, clinical records, or personally identifiable information were collected, and no procedures were performed on patients. Full details of ethics approval and consent are provided in the Declarations section. No generative artificial intelligence or large language model was used to generate or analyse the data reported in this study.

Results

Overview of assessed facilities

The four assessed facilities serve diverse patient populations across the FCT of Abuja. EHA Clinics operates as a private-sector facility with relatively high resource availability; Apo PHC and Lugbe PHC are government-operated facilities serving high-density peri-urban communities; Kagini PHC is a government

facility in a lower-density area with more limited infrastructure. All four facilities deliver outpatient, maternal and child health, immunization, and basic diagnostic services, and generate daily volumes of infectious waste, sharps, and pharmaceutical materials.

Overall facility readiness scores

Composite readiness scores (maximum 275) showed substantial inter-facility variation, ranging from low-to-moderate readiness at Kagini PHC (43.6%) to high readiness at EHA Clinics (84.7%) (Table 1). On average, facilities scored approximately 60% before the intervention. The variation was driven primarily by differences in treatment capacity, disposal practices, and system integration.

Table 1
Overall facility readiness scores

Facility	Overall score (/275)	Percentage (%)	Readiness category
EHA Clinics	232.9	84.7	High readiness
Apo PHC	209.0	76.0	High readiness
Lugbe PHC	163.1	59.3	Moderate readiness
Kagini PHC	119.9	43.6	Low-moderate readiness

Service delivery and staffing profile

All facilities were actively delivering primary healthcare services, with variation in volume and staffing capacity (Table 2). Facilities reported a mean of 32.8 outpatient visits per day (range 15–50) and 106.5 antenatal care visits per month (range 11–165). Deliveries averaged 16.5 per month (range 0–45); the presence of facilities reporting zero deliveries indicates that not all assessed PHCs routinely conduct delivery services. Immunization sessions averaged 2.25 per week (range 1–3), and facilities conducted a mean of 28.8 laboratory tests per day (range 15–40). This volume and diversity of services indicate continuous generation of both general and hazardous waste, including sharps, infectious materials, and laboratory waste.

Staffing composition varied across facilities. Facilities had a mean of 1.75 doctors (range 0–7); three of the four facilities operated without a doctor, with all medical-officer posts concentrated at EHA Clinics. The mean was 3.75 nurses or midwives (range 1–7) and 6.5 Community Health Extension Workers (CHEWs/JCHEWs) (range 0–12), the largest cadre overall. Support staff included a mean of 4.75 cleaners or waste handlers (range 2–8). Notably, facilities had a mean of only 0.5 Environmental Health Officers (range 0–1): only two facilities (Kagini PHC and Lugbe PHC) had a dedicated officer, indicating that half lacked the specialist expertise to oversee waste management and environmental compliance.

Table 2
Facility service-delivery and staffing profile (n = 4)

Facility measure	Mean	Minimum	Maximum
Outpatient (OPD) visits per day	32.75	15	50
Antenatal care (ANC) visits per month	106.5	11	165
Deliveries per month	16.5	0	45
Immunization sessions per week	2.25	1	3
Laboratory tests per day	28.75	15	40
Doctors	1.75	0	7
Nurses or midwives	3.75	1	7
CHEWs/JCHEWs	6.5	0	12
Laboratory staff	3.25	1	5
Cleaners/waste handlers	4.75	2	8
Environmental Health Officers	0.5	0	1

Infrastructure and utility readiness

Facilities had basic infrastructure to support service delivery and waste management, but reliability varied. Most facilities (75%) relied on solar power as their primary electricity source, while one facility (25%) depended on the national grid supplemented by a generator. Power reliability was variable: half of the facilities (50%) reported moderate availability (4–12 hours per day), and half (50%) reported high reliability (> 18 hours per day). Inconsistent power may compromise the continuous operation of waste treatment systems such as autoclaves, which require stable energy.

Water supply was consistently available: all facilities (100%) used boreholes, described as always available, supporting hygiene and IPC practices. For waste-management infrastructure, three of four facilities (75%) reported adequate waste bins, while one (25%) reported a gap; all facilities (100%) had designated waste storage areas and secure rooms suitable for installing treatment equipment. Structurally, therefore, facilities were largely equipped to support waste management, though not uniformly.

Waste generation and tracking

While healthcare waste was actively generated across all facilities, systems for measuring, recording, and managing it were largely underdeveloped. Only two of four facilities (50%) measured or estimated the amount of waste generated, and only one facility (25%) maintained records of waste quantities; the remaining 75% kept no formal records. This is a critical weakness in waste-data systems, limiting the ability to plan operations, monitor trends, assess environmental impact, and allocate resources.

Reported daily waste volumes varied: 50% of facilities generated less than 10 kg per day, 25% generated 10–25 kg per day, and 25% generated 51–100 kg per day. At the facility level, Apo PHC reported the highest volume (51–100 kg/day), Lugbe PHC had a low-to-moderate volume (10–25 kg/day), and both Kagini PHC and EHA Clinics had less than 10 kg/day. The laboratory was identified as the primary source of waste in 50% of facilities, the maternity ward in 25%, and multiple departments in 25%. Composite scoring (maximum 10) revealed marked disparities: EHA Clinics achieved 100%, reflecting consistent estimation, documentation, and categorisation; Apo PHC scored 50%; and Kagini PHC and Lugbe PHC both scored 0%, indicating a complete absence of formalised waste-quantification systems. A benchmark of 70% denotes minimum acceptable performance, met only by EHA Clinics.

Waste segregation

Waste segregation was the strongest-performing domain across facilities. All facilities (100%) reported availability of colour-coded bins, disposal of sharps in puncture-proof containers, and placement of bins at the point of care, and all reported that staff were trained on segregation. However, only two of four facilities (50%) had clearly labelled bins, and one facility (25%) reported sharps observed in general waste, indicating a breach in segregation. Bins were not frequently overflowing in any facility (100%), but the use of plastic liners was inconsistent (50%). Composite scores (maximum 40) were high but varied: EHA Clinics 40/40 (100%); Apo PHC 35/40 (87.5%); and Kagini PHC and Lugbe PHC each 30/40 (75%). Despite this relative strength, sustainability is threatened by gaps in training reinforcement and supervision, particularly in lower-performing facilities.

Waste collection and internal transport

Collection and transport systems were functionally present, with strong compliance in some core practices but important operational gaps. Training recency was uneven: half of the facilities (50%) had trained staff within the previous six months, while half (50%) had not trained in over 12 months. Collection frequency varied: only one facility (25%) collected waste once daily (the recommended practice), two facilities (50%) collected twice daily, and one facility (25%) collected only when bins were full, a reactive approach. Waste collection was assigned to cleaners in 75% of facilities, with a dedicated waste-management officer in only one facility (25%).

Transport relied on manual carrying in 75% of facilities, with one facility (25%) using a wheelbarrow; manual handling increases the risk of spillage, injury, and exposure. All facilities (100%) transported waste categories separately and provided PPE to waste handlers, though PPE completeness ranged from gloves only to full sets (gloves, masks, boots, aprons). Composite scores (maximum 15) were moderate to strong: Kagini PHC 15/15 (100%), and Apo PHC, EHA Clinics, and Lugbe PHC each 10/15 (66.7%). Variation was driven mainly by collection frequency rather than the absence of basic systems.

Waste storage

All facilities (100%) had a designated waste storage area, but storage conditions, duration, and segregation varied considerably. Only one facility (25%) met all recommended conditions (fenced,

locked, and protected from animals); the remainder demonstrated partial compliance, including one storage area demarcated with wood as an improvised barrier. Storage duration was concerning: only one facility (25%) stored waste for less than 24 hours, one (25%) for 24–48 hours, and half of the facilities (50%) for more than 48 hours, increasing the risk of contamination, odour, pest infestation, and environmental exposure. Three of four facilities (75%) stored infectious waste separately from general waste, while one (25%) did not. Composite scores (maximum 20) varied substantially: EHA Clinics 20/20 (100%); Apo PHC 16/20 (80%); Lugbe PHC 13/20 (65%); and Kagini PHC 5/20 (25%). The low score at Kagini PHC reflects poor storage conditions, prolonged storage duration, and gaps in within-storage segregation.

Domain composite scores across facilities and comparison with known domain scores

Composite scores across all scored domains are summarised in Table 3. The pattern is consistent: facilities perform comparatively well in early-stage handling (segregation, collection, storage at the better-resourced sites) and in protective systems, but performance declines sharply at treatment, disposal-related environmental risk, and environmental practices. EHA Clinics performed strongly across most domains, whereas Kagini PHC scored lowest in most domains except collection and transport and burning practices.

Table 3
Composite domain scores by facility (% of domain maximum)

Domain (maximum)	**WHO required standard (%)	**Minimum WHO required standard (%)	Apo PHC	EHA Clinics	Kagini PHC	Lugbe PHC
Waste generation & tracking (10)	100	70–75	50.0	100	0	0
Waste segregation (40)	100	70–75	87.5	100	75.0	75.0
Collection & transport (15)	100	70–75	66.7	66.7	100	66.7
Waste storage (20)	100	70–75	80.0	100	25.0	65.0
Waste treatment - autoclave (35)	100	70–75	65.7	51.4	14.3	0
Burning practices / environmental risk (15)	100	70–75	33.3	33.3	66.7	33.3
Occupational health & safety (30)	100	70–75	100	100	50.0	100
Policies & training (20)	100	70–75	50.0	100	50.0	75.0
Environmental practices (15)	100	70–75	33.3	66.7	0	33.3
IPC compliance audit (75)	100	70–75	93.3	93.3	40.0	73.3
Overall readiness (275)	100	70–75	76.0	84.7	43.6	59.3
<i>Note. Domain percentages are derived from the facility audit composite scores. Overall readiness percentages correspond to the aggregate scores reported in Table 1.</i>						
<i>Source **:</i> WHO 2023						

Waste treatment: autoclave availability and utilization

Three of four facilities (75%) had autoclave equipment installed; however, only two (50%), Apo PHC and EHA Clinics, had functional autoclaves at the time of assessment. The autoclave at Kagini PHC was non-functional, and Lugbe PHC had none. Even where functional autoclaves existed, utilization was limited: 50% of facilities reported low use (1–2 cycles per day), and 25% reported that their autoclave had never been used.

Monitoring and quality assurance practices were critically weak. Only one facility monitored both temperature and pressure; no facility monitored all required parameters, including cycle time; and only

one facility used biological indicators to verify sterilization effectiveness. Documentation practices were similarly inadequate, with only one facility maintaining an autoclave logbook. These gaps mean that even when autoclaves are used, there is no assurance that sterilization is effective. Composite scores (maximum 35) were low overall: Apo PHC 23/35 (65.7%), EHA Clinics 18/35 (51.4%), Kagini PHC 5/35 (14.3%), and Lugbe PHC 0/35 (0%) (Table 4).

Table 4
Waste treatment (autoclave system) indicators by facility

Indicator	Apo PHC	EHA Clinics	Kagini PHC	Lugbe PHC
Autoclave available	Yes	Yes	Yes	No
Autoclave functional	Yes	Yes	No	-
Treats key waste types (lab, infectious, sharps)	Yes	Other	No	-
Frequency of use	1–2 cycles/day	1–2 cycles/day	Not used	-
Biological indicators used	Yes	No	No	-
Logbook maintained	No	Yes	No	-
Treatment domain score (/35)	23 (65.7%)	18 (51.4%)	5 (14.3%)	0 (0%)

Waste disposal: dominance of open burning

Open burning was the primary disposal method in three of four facilities (75%), while only one facility (25%) relied on incineration. In three facilities (75%), soot marks and ash residues provided physical confirmation that open burning was routine, embedded in daily operations rather than exceptional. Disposal frequency was split, with half of the facilities (50%) disposing of waste daily and half on a weekly cycle, implying extended on-site accumulation.

A key structural driver was the weak linkage to formal waste systems. Municipal waste collection was used by only half of the facilities (Apo PHC and EHA Clinics), and only these two had a formal agreement with municipal authorities. Reported collection was largely irregular; three of four facilities (75%) described municipal collection as irregular, and only EHA Clinics reported a regular (weekly) schedule. Even for general (non-infectious) waste, only half of the facilities benefited from municipal or private collection. The absence of reliable downstream disposal infrastructure effectively forces facilities to burn on-site as a default rather than a choice.

Waste burning composition

All facilities (100%) reported segregating waste before disposal, yet the final burning step was largely uncontrolled. Burning frequency ranged from once per week to daily (6–7 times per week). The scale of

waste generation in bags was modest; 75% of facilities generated 0–5 bags per day, and 25% generated 6–10 bags per day, but frequent burning sustained persistent environmental exposure.

Critically, only one facility (25%) could estimate the composition of waste being burned (a mix of 30% plastic/rubber and 70% organic/paper); the remaining 75% operated without knowledge of composition, burning mixed materials whose plastic and synthetic fractions release highly toxic combustion by-products. All facilities (100%) used fuel accelerants, petrol, diesel, or used engine oil, to initiate fires, transforming routine burning into a high-emission activity. Composite scores (maximum 15) reflected this vulnerability: only Kagini PHC reached a moderate 66.7%, while Apo PHC, EHA Clinics, and Lugbe PHC each scored 33.3%.

Estimated waste-related CO₂ emissions per facility

Because open burning was the dominant disposal method, baseline waste-related CO₂ emissions were estimated under an all-waste-burned scenario. Using the WHO patient-load basis (daily outpatient attendance x 0.2 kg waste per patient per day x 0.8 kg CO₂ per kg of waste), estimated baseline emissions totalled approximately 21 kg CO₂ per day, or about 7.7 tonnes CO₂ per year, across the four facilities (Table 5). The two higher-attendance facilities, Kagini PHC and Lugbe PHC (50 outpatients per day each), accounted for the largest estimated emissions on this basis.

Table 5
Estimated baseline waste-related CO₂ emissions by facility (WHO patient-load basis)

Facility	OPD/day	Est. waste (kg/day)	CO ₂ (kg/day)	CO ₂ (t/year)	Self-reported band (kg/day)
Apo PHC	15	3.0	2.4	0.88	51–100
Kagini PHC	50	10.0	8.0	2.92	< 10
EHA Clinics	16	3.2	2.6	0.93	< 10
Lugbe PHC	50	10.0	8.0	2.92	10–25
Total (4 facilities)	131	26.2	21.0	7.65	-

Waste is estimated as average daily OPD attendance x 0.2 kg/patient/day; CO₂ applies an emission factor of 0.8 kg CO₂/kg under an all-waste-burned baseline; annual figures = daily x 365. OPD attendance is used as the patient-load measure; other service contacts (ANC, deliveries, immunization, laboratory) are not added. The final column shows each facility's self-reported waste volume for comparison. Figures are indicative planning estimates, not measured emissions.

Self-reported volumes are internally inconsistent. The facilities' self-reported waste volumes diverge sharply from their patient load. Apo PHC recorded the lowest outpatient attendance (15 patients per day) yet self-reported the highest waste volume (51–100 kg/day), a volume that, at the WHO generation rate,

would correspond to 255–500 patients per day. Conversely, Kagini PHC and Lugbe PHC, the busiest facilities, self-reported low-to-moderate volumes. Aggregated across the four facilities, self-reported volumes imply roughly 30 tonnes of CO₂ per year, about four-fold higher than the patient-load estimate. This inconsistency is consistent with the finding that most facilities do not weigh or record waste, and indicates that self-reported volumes are unreliable. We therefore present the standardised patient-load estimate as the primary figure and recommend that prospective emissions monitoring under the intervention use this method, validated against weighed-waste samples.

Occupational health and safety

Protective systems were widely established, yet occupational risk persisted. All facilities (100%) reported Hepatitis B vaccination for staff, needle-stick injury management protocols, and availability and appropriate use of PPE. However, over a two-year reference period, facilities reported a mean of 1.5 needle-stick injuries (range 0–5) and 1.5 staff exposures to infectious waste (range 0–6). Preventive systems were less consistent: three of four facilities (75%) had conducted waste-management safety training, and 25% lacked a hazardous-waste spill response procedure. Staff perception of safety was generally positive (75% felt safe; 25% neutral; none felt unsafe), facility cleanliness was rated very good (50%), good (25%), or fair (25%), and no facility (0%) had received patient complaints about waste or cleanliness. Composite scores (maximum 30) were strong but uneven: Apo PHC, EHA Clinics, and Lugbe PHC each achieved 100%, while Kagini PHC scored 50%. The persistence of injuries despite protective infrastructure, alongside overfilled sharps containers in 75% of facilities, indicates a breakdown in routine adherence rather than a knowledge or equipment gap (Table 6).

Table 6
Occupational health and safety indicators across facilities

Indicator	Value	Interpretation
Mean needle-stick injuries (last 2 years)	1.5 (0–5)	Ongoing occupational risk across facilities
Mean staff exposure to infectious waste (2 years)	1.5 (0–6)	Continued exposure risk during handling
Staff vaccinated against Hepatitis B	4/4 (100%)	Strong protection system in place
Safety training conducted	3/4 (75%)	Training exists but not consistently implemented
Needle-stick injury protocol	4/4 (100%)	Strong response system available
Hazardous-waste spill procedure	3/4 (75%)	Preparedness gap in one facility
Staff perception of safety	3/4 safe, 1/4 neutral	Confidence generally high but not universal
Patient complaints on waste/cleanliness	0/4 (0%)	No reported external dissatisfaction

Governance, policies, and training

Governance structures were partially established but inconsistently institutionalised. Three of four facilities (75%) had a formal healthcare waste management policy and a waste management committee, and SOPs were displayed in 75% of facilities. However, only 50% conducted staff training at the recommended bi-annual frequency; 25% trained annually, and 25% did not train at all. Composite scores (maximum 20) reflected partial institutionalisation: EHA Clinics 20/20 (100%); Lugbe PHC 15/20 (75%); and Apo PHC and Kagini PHC each 10/20 (50%). Policy frameworks, therefore, exist in most facilities, but their influence on daily practice is uneven.

Environmental and climate practices

Environmental and climate practices were the weakest domain across all facilities (maximum domain score 15). Only one facility (25%), Apo PHC, reported using renewable energy to power waste treatment; notably, this was despite three facilities (75%) using solar power as their main electricity source, indicating that available clean energy was generally not harnessed for waste treatment. A majority of facilities (75%) did not track carbon emissions; only EHA Clinics had initiated emission monitoring. Efforts to reduce open burning were limited to two facilities (50%): EHA Clinics, through a quality-improvement and community-sensitisation initiative, and Lugbe PHC, through repeated but as-yet-unanswered requests to municipal waste authorities. Neither had produced consistent change at the time of assessment, and the actions were largely indirect rather than structural.

Composite scores reflected this gap: EHA Clinics scored highest (66.7%, reflecting emission tracking and burning-reduction efforts), Apo PHC and Lugbe PHC each scored 33.3% (renewable-energy use and burning-reduction efforts, respectively), and Kagini PHC scored 0% (Table 7). Environmental and climate considerations have not yet been institutionalised within healthcare waste management; they exist at the margins, recognised in principle but not embedded in practice, and are distributed unevenly rather than concentrated in the highest-performing facility.

Table 7
Environmental and climate practice indicators by facility

Indicator	Apo PHC	EHA Clinics	Kagini PHC	Lugbe PHC
Renewable energy used for waste treatment	Yes	No	No	No
Carbon emissions tracked	No	Yes	No	No
Action taken to reduce open burning	No	Yes	No	Yes
Environmental/climate score (/15)	5 (33.3%)	10 (66.7%)	0 (0%)	5 (33.3%)

IPC compliance

Core IPC structural elements were well established: waste storage areas were rated clean, adequate, and secure across all facilities (100%); sharps were reported as handled safely (100%); PPE was universally available and used (100%); and no facility received complaints from surrounding communities (100%). However, these strengths were offset by gaps at high-risk control points. Overfilled sharps containers were observed in 75% of facilities, labelled bins were absent in one facility, and only 50% of facilities had operational autoclaves or disposal meeting recommended standards. Visible open burning was present in 75% of facilities.

Overall IPC composite scores (maximum 75) ranged from 40% (Kagini PHC) to 93.3% (Apo PHC and EHA Clinics), with Lugbe PHC at 73.3% (Table 8). The pattern reflects not an absence of IPC systems but inconsistency in application: performance declined precisely where risk was highest- sharps management, treatment, and disposal.

Table 8
Facility-level IPC compliance mapping

Indicator	Apo PHC	Kagini PHC	EHA Clinics	Lugbe PHC
Waste bins properly labelled	Yes	No	Yes	Yes
Sharps containers not overfilled	Yes	No	No	No
Storage area clean and maintained	Yes	Yes	Yes	Yes
Storage adequate and secure	Yes	Yes	Yes	Yes
Autoclave operational	Yes	No	Yes	No
Waste properly segregated	Yes	No	Yes	Yes
Appropriate bins in all service areas	Yes	No	Yes	Yes
Visible open burning	Yes	Yes	No	Yes
Sharps handled safely	Yes	Yes	Yes	Yes
PPE available and used appropriately	Yes	Yes	Yes	Yes
SOPs available	Yes	No	Yes	Yes
SOPs followed	Yes	No	Yes	Yes
Disposal meets standards	Yes	No	Yes	No
No community complaints	Yes	Yes	Yes	Yes
IPC composite score (/75)	70 (93.3%)	30 (40%)	70 (93.3%)	55 (73.3%)

Discussion

As a proof-of-concept pilot, this study provides one of the first facility-level, multi-domain baseline assessments of healthcare waste management and climate-smart, environmentally sustainable practices at the PHC level in Abuja, Nigeria. Although based on only four purposively selected facilities, and therefore not generalisable to the wider PHC system, it demonstrates that a structured 14-domain audit can feasibly capture and discriminate readiness across contrasting facility types, and it yields baseline data to guide a targeted intervention. The findings reveal a system that demonstrates partial capacity across early-stage waste handling but fails structurally at the most consequential stages—treatment, disposal, and environmental sustainability integration, where cumulative risks are greatest. The domain composite scores (Table 3) make this attenuation explicit: relatively strong segregation, collection, and storage at the better-resourced sites give way to weak treatment, high disposal-related environmental risk, and near-absent environmental practices.

The dominance of open burning as the primary disposal method (75% of facilities), combined with universal use of fuel accelerants, positions these facilities as active contributors to localised air pollution and greenhouse gas emissions. This is consistent with national-level evidence from Nigeria, where burning in protected pits and open areas remains the most common disposal method [11]. The WHO emphasises that open burning of healthcare waste, particularly plastics and contaminated materials, generates toxic emissions including dioxins, furans, and particulate matter, with serious consequences for human health and environmental safety [1]. The normalisation of burning as a system default, driven by absent or unreliable municipal waste collection, represents a structural rather than a behavioural failure: facilities burn because there is no viable alternative.

Our emissions estimates make the climate dimension tangible while exposing a data-quality problem. On the standardised WHO patient-load basis, the four facilities generate an estimated 7.7 tonnes of CO₂ per year from waste burning; their self-reported waste volumes imply roughly four-fold more (about 30 tonnes per year) and are internally inconsistent with patient load, most strikingly at Apo PHC, which had the lowest outpatient attendance yet reported the highest waste volume. This divergence is itself a finding: because facilities do not weigh or record waste, self-reported volumes are unreliable, and standardised, patient-load-based estimation validated against weighed samples is required for credible monitoring. It reinforces calls to embed routine waste quantification within PHC information systems as a prerequisite for both environmental accountability and operational planning.

The limited integration of climate-smart practices, only one facility using renewable energy for waste treatment, 75% not tracking emissions, and environmental actions largely absent or reactive, reflects a broader challenge identified globally. In many PHC settings, environmental sustainability is recognised conceptually but remains operationally peripheral, disconnected from day-to-day waste system management [4, 14]. The findings align with the WHO Global IPC Strategy (2023) call for health actors to invest in WASH and waste services as integral to IPC, and to address the environmental consequences of waste management alongside infection control [7].

The autoclave functionality gap is particularly instructive. While 75% of facilities had autoclaves, only 50% were functional; utilization among functional units was low, no facility achieved comprehensive monitoring of sterilization parameters, and only one maintained a logbook. This pattern reflects a documented regional challenge: the presence of equipment does not translate into effective treatment capacity without maintenance systems, reliable power, trained operators, and quality assurance [6, 14]. Without functional treatment, waste bypasses the essential decontamination step, compelling reliance on open burning and sustaining the cycle of environmental harm.

The occupational safety findings reveal a persistent paradox. Despite universal Hepatitis B vaccination coverage, PPE availability, and needle-stick injury response protocols, 1.5 needle-stick injuries and 1.5 staff exposure incidents occurred per facility over two years. This is consistent with published evidence that needle-stick injuries average 2.5 per healthcare worker annually in developing countries [15], and that globally, approximately three million healthcare workers experience percutaneous exposure to blood-borne pathogens annually, more than 90% occurring in developing countries [16]. The rate of overfilled sharps containers (75% of facilities) suggests these injuries arise not from absent protective infrastructure but from breakdowns in routine operational adherence, a governance and supervision challenge.

The wide inter-facility variation in composite readiness scores (43.6–84.7%) underscores that high performance is attainable within the Nigerian PHC context, as demonstrated by EHA Clinics, whose waste quantification and record-keeping, emission tracking, full IPC compliance, and comprehensive governance systems offer a practical model for replication. Climate-smart elements were, however, distributed unevenly rather than concentrated in the highest-performing facility: renewable energy for waste treatment was reported only at Apo PHC, and the strongest treatment-domain performance was also at Apo PHC, not EHA Clinics. The 41.1 percentage-point gap between EHA Clinics and Kagini PHC suggests that facility type, resource availability, and institutional capacity are important structural determinants that interventions must address differentially.

These findings have direct implications for the ClimateSENSE intervention design. The deployment of solar-powered autoclaves addresses the twin challenges of treatment capacity and renewable energy integration. Standardised waste segregation systems and frontline health worker capacity building target the governance and training gaps that allow upstream achievements in segregation to be lost at treatment and disposal. Engagement of recycling and licensed waste-disposal actors addresses the structural absence of downstream disposal pathways that currently forces reliance on burning. More broadly, the study supports the need for integrated, climate-smart approaches to PHC waste management in sub-Saharan Africa, recognising waste management as an interconnected chain in which failures in any one domain propagate downstream.

Limitations

This study has several limitations that follow directly from its design as a pilot, proof-of-concept assessment. Most importantly, the sample of four purposively selected facilities is small and non-representative; it was chosen to test the assessment approach and to span contrasting facility types, not to estimate the prevalence of practices across the Abuja PHC system or Nigeria as a whole. The percentages reported here therefore describe these four facilities only and should not be read as population estimates; with four facilities, each facility corresponds to 25% and small differences can appear large, so the findings are best interpreted as illustrative and hypothesis-generating rather than definitive. The single-time-point design captures a snapshot and may not reflect seasonal or operational variation in practices. Composite scores are based on self-reported data and direct observation, which may be subject to social desirability bias, particularly for sensitive practices such as open burning, and the composite scoring tool itself has not yet been formally validated. Quantitative emission data were unavailable, and environmental impact was assessed using proxy indicators rather than measured carbon outputs; the emissions figures are indicative planning estimates rather than measured values. Building on this proof-of-concept, future work should employ larger and more representative samples, longitudinal designs, formal validation of the audit tool, and objective environmental measurement to test and extend these baseline findings.

Conclusions

This proof-of-concept pilot shows that healthcare waste management in these four Abuja PHC facilities is partially functional and uneven, and that a structured multi-domain audit can feasibly surface where the system succeeds and fails. Strengths in early-stage waste handling, particularly segregation and occupational protective systems, are not sustained through the full waste management chain. The most critical failures occur at treatment and disposal, where limited autoclave functionality and open burning on a large scale generate concentrated health, occupational, and environmental risks. Environmental sustainability remains at the margins of current practice: unmeasured, under-resourced, and largely absent from operational systems.

The ClimateSENSE project is well-positioned to address these gaps through a differentiated, evidence-based intervention that targets the treatment-disposal interface, integrates climate-smart innovations, including solar-powered autoclaves, and strengthens governance and accountability mechanisms across facilities. The performance of EHA Clinics illustrates that high-quality, climate-smart PHC waste management is achievable in this context and offers a promising model that warrants testing in larger, more representative studies. As a feasibility and baseline exercise, this pilot is best read as generating hypotheses and intervention targets rather than definitive evidence; nonetheless, it points to environmentally sustainable healthcare waste systems as a public health and climate-resilience priority for Nigeria and comparable LMIC settings, and provides an assessment approach that can be scaled to build that evidence base.

Abbreviations

ANC: Antenatal care

CHEW/JCHEW: Community Health Extension Worker/Junior Community Health Extension Worker

ClimateSENSE: Climate-Smart Environmental Sanitation for Enhanced Health System

CO₂: Carbon dioxide

FCT: Federal Capital Territory

GHG: Greenhouse gas

HAI: Healthcare-associated infection

IPC: Infection prevention and control

JMP: WHO/UNICEF Joint Monitoring Programme

LMIC: Low- and middle-income country

ODK: Open Data Kit

OPD: Outpatient department

PHC: Primary health care

PPE: Personal protective equipment

SOP: Standard operating procedure

STROBE: Strengthening the Reporting of Observational Studies in Epidemiology

WASH: Water, sanitation and hygiene

WHO: World Health Organization

Declarations

Ethics approval and consent to participate

Because health-facility staff participated as key informants, the assessment was submitted to the Federal Capital Territory Health Research Ethics Committee, which determined that it constituted a service and programme evaluation posing minimal risk to participants and granted approval with the reference number FHREC/2026/01/371/13-07-26. The study was conducted in accordance with the principles of the Declaration of Helsinki. Participation was voluntary. Institutional consent was obtained from the officer in charge of each facility, and verbal informed consent was obtained from each staff

participant before data collection, following an explanation of the assessment's purpose, the voluntary nature of participation, and the confidential handling of responses. Verbal consent was approved by the ethics committee given the minimal-risk, facility-level nature of the assessment. No patient-level or personally identifiable data were collected.

Consent for publication

Not applicable. The manuscript does not contain data from any person in any form.

Availability of data and materials

The datasets generated and analysed during the current study are not publicly available because they form part of an ongoing programme evaluation, but are available from the corresponding author on reasonable request. The baseline dataset and the structured facility audit tool are maintained in the ClimateSENSE project repository.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

DG conceptualised the study and contributed to the manuscript. LM reviewed the manuscript. GN drafted the manuscript. JO supervised field assessment and data validation. OO contributed to study design and data collection. and AO conducted data analysis and composite scoring. FH and GA supervised field assessment and data validation. DA and OA contributed to emissions estimation and interpretation. AF and NI contributed to study design and critical revision. All authors read and approved the final manuscript.

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