

ASSESSMENT OF ELECTRONIC WASTE GENERATION, TOXIC EXPOSURE PATHWAYS AND DEVELOPMENT OF A SUSTAINABLE E- WASTE RECOVERY FRAMEWORK IN POLYTECHNICS IN SOUTH- WEST NIGERIA

FADARA T. G.¹, AZEEZ N. A.¹, AGBOOLA M. K.² and ADEDIGBA S. A.¹

¹Department of Mechanical Engineering, Federal Polytechnic Ede, Osun State, P.M.B 231, Nigeria.

²Department of Electrical Electronic Engineering, Federal Polytechnic Ede, Osun State, P.M.B 231, Nigeria.

To cite this article:

Fadara, T. G., Azeez, N. A., Agboola, M. K. & Adedigba, S. A. (2026). Assessment of electronic waste generation, toxic exposure pathways and development of a sustainable e-waste recovery framework in polytechnics in South-West Nigeria. *International Journal of Innovative Technology Integration in Education (IJITIE)*, 9 (2), 102-117

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

Authors alone are responsible for the contents of their articles. The journal owns the copyright of the articles. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of the research material.

ASSESSMENT OF ELECTRONIC WASTE GENERATION, TOXIC EXPOSURE PATHWAYS AND DEVELOPMENT OF A SUSTAINABLE E-WASTE RECOVERY FRAMEWORK IN POLYTECHNICS IN SOUTH-WEST NIGERIA

FADARA T. G., AZEEZ N. A., AGBOOLA M. K. and ADEDIGBA S. A.

Article Info

Keywords

electronic waste,
e-waste generation,
toxic exposure,
heavy metals,
recovery framework,
polytechnic,
Nigeria

Abstract

Electronic waste is among the fastest-growing waste streams, and in Nigeria much of it is handled informally through methods that release hazardous substances. This study assessed electronic waste generation and toxic exposure pathways in polytechnics in South-West Nigeria and developed a sustainable e-waste recovery framework. A mixed-methods assessment-and-development design was used, combining an inventory of e-waste, sampling of soil, water and air at handling points for heavy metals, surveys and interviews on awareness and management, and expert appraisal of the framework. The six polytechnics generated 41.5 tonnes of e-waste annually (mean 6.9 tonnes per institution), comprising computers (33.3%), laboratory equipment (24.6%), workshop equipment (18.3%), peripherals (13.9%) and other electronics (9.8%). Handling was predominantly unsafe: 54.2% was stored indefinitely, 25.0% disposed of with general waste and only 2.1% formally recycled. Lead exceeded guidelines in 72.2% of soil samples and 83.3% of water samples. Awareness of e-waste hazards was low (25.8%), and 79.2% of units had no management policy. The framework (collection and segregation, safe storage, reuse and refurbishment, materials recovery, and institutional arrangements) was rated highly by experts for feasibility (3.60), sustainability (3.80) and health protection (3.80). The study provides an inventory, an exposure assessment and a validated recovery framework for Nigerian polytechnics.

ASSESSMENT OF ELECTRONIC WASTE GENERATION, TOXIC EXPOSURE PATHWAYS AND DEVELOPMENT OF A SUSTAINABLE E-WASTE RECOVERY FRAMEWORK IN POLYTECHNICS IN SOUTH-WEST NIGERIA

FADARA T. G.¹, AZEEZ N. A.¹, AGBOOLA M. K.², and ADEDIGBA S. A.¹

¹Department of Mechanical Engineering, Federal Polytechnic Ede, Osun State, P.M.B 231, Nigeria

²Department of Electrical Electronic Engineering, Federal Polytechnic Ede, Osun State, P.M.B 231, Nigeria

Abstract

Electronic waste is among the fastest-growing waste streams, and in Nigeria much of it is handled informally through methods that release hazardous substances. This study assessed electronic waste generation and toxic exposure pathways in polytechnics in South-West Nigeria and developed a sustainable e-waste recovery framework. A mixed-methods assessment-and-development design was used, combining an inventory of e-waste, sampling of soil, water and air at handling points for heavy metals, surveys and interviews on awareness and management, and expert appraisal of the framework. The six polytechnics generated 41.5 tonnes of e-waste annually (mean 6.9 tonnes per institution), comprising computers (33.3%), laboratory equipment (24.6%), workshop equipment (18.3%), peripherals (13.9%) and other electronics (9.8%). Handling was predominantly unsafe: 54.2% was stored indefinitely, 25.0% disposed of with general waste and only 2.1% formally recycled. Lead exceeded guidelines in 72.2% of soil samples and 83.3% of water samples. Awareness of e-waste hazards was low (25.8%), and 79.2% of units had no management policy. The framework (collection and segregation, safe storage, reuse and refurbishment, materials recovery, and institutional arrangements) was rated highly by experts for feasibility (3.60), sustainability (3.80) and health protection (3.80). The study provides an inventory, an exposure assessment and a validated recovery framework for Nigerian polytechnics.

Keywords: electronic waste; e-waste generation; toxic exposure; heavy metals; recovery framework; polytechnic; Nigeria

Introduction

Electronic waste is among the fastest-growing waste streams in the world, and Nigeria is a significant generator and recipient, with much of its e-waste handled informally through methods such as manual dismantling, open burning and acid leaching that release hazardous substances (Abogunrin-Olafisoye & Adeyi, 2025). Global estimates indicate that approximately 62 million tonnes of e-waste were generated in 2022, with only 22.3% documented as formally collected and recycled. Nigeria is estimated to generate over 500,000 tonnes of e-waste annually, making it one of the largest generators in Africa. Polytechnics, which operate large numbers of computers, laboratory and workshop instruments and other electronics that are regularly retired, generate their

own growing stream of electronic waste, the fate of which is rarely tracked. Research on institutional e-waste generation in Nigeria has been limited, with most studies focusing on households, informal recycling hubs, or the national picture rather than institutional generators such as polytechnics.

The toxic hazards of poorly managed e-waste are well established. Informal recycling and disposal expose workers, scavengers and nearby populations to heavy metals such as lead and cadmium and to persistent organic pollutants, and release these contaminants into air, soil and water, with documented associations with respiratory, dermatological and systemic health effects (Issah et al., 2022; Perkins et al., 2014). Research has documented that informal e-waste recycling in Africa is associated with elevated blood lead levels in workers and residents, with children being particularly vulnerable to neurodevelopmental effects. Studies have found that soil and water at informal e-waste recycling sites are contaminated with heavy metals including lead, cadmium, chromium, and mercury, often exceeding international guidelines by factors of 10–100. In Nigeria, and in the South-West in particular, these hazards are a recognised and growing public-health and environmental concern (Ezeudoka et al., 2024). Research has documented elevated heavy metal concentrations in soil, water, and air at e-waste recycling sites in Lagos and other Nigerian cities, with associated health risks for workers and nearby communities.

At the same time, e-waste holds substantial recoverable value, and sustainable, circular-economy approaches seek to capture it safely. Recovery frameworks aim to collect, sort and channel end-of-life electronics into safe reuse, refurbishment and materials recovery rather than dumping or informal burning, protecting health and the environment while realising economic value (Forti et al., 2020). Research has estimated that the value of recoverable materials in global e-waste exceeded \$57 billion in 2019, with significant potential for job creation and economic development if safe recovery systems are established. The circular economy approach to e-waste management emphasises the importance of product design, extended producer responsibility, and formal collection and recycling systems that can capture value while protecting health. Designing such a framework for a specific institutional context is a practical route to better management, enabling institutions to address their own e-waste while modelling good practice for their communities.

Despite the recognised scale of the problem, electronic-waste generation and the toxic exposure pathways associated with it in Nigerian polytechnics are largely unquantified, and there is no sustainable recovery framework tailored to these institutions. Much of the evidence addresses major informal recycling hubs or the national picture rather than institutional generators such as polytechnics, and assessment is rarely translated into a workable recovery framework (Abogunrin-Olafisoye & Adeyi, 2025). Research on institutional e-waste in Nigeria has been limited, with studies focusing primarily on household or industrial waste streams rather than educational institutions. This study addresses that gap by assessing e-waste generation and exposure pathways in polytechnics and developing a sustainable recovery framework.

Statement of the Problem

Polytechnics in South-West Nigeria generate growing quantities of electronic waste, yet it is largely unquantified and is commonly stored, dumped or informally recycled in ways that expose people and the environment to toxic substances. Manual dismantling, open burning and acid leaching release heavy metals and persistent organic pollutants that harm handlers and nearby populations and contaminate air, soil and water, but because institutional e-waste generation and its handling are not tracked, the scale of the problem and its exposure pathways remain unknown (Abogunrin-Olafisoye & Adeyi, 2025; Issah et al., 2022). The difficulty is compounded by the absence of any sustainable recovery framework for these institutions, so even recognised hazards and recoverable value are not managed, and e-waste continues to be handled unsafely and wastefully (Forti et al., 2020). This double gap, unquantified generation and exposure and no recovery framework, leaves a serious and avoidable hazard unaddressed.

The specific challenges facing Nigerian polytechnics are situated within a broader context of e-waste management in Nigeria. Studies have documented that Nigeria lacks adequate formal e-waste recycling infrastructure, with the informal sector handling the majority of e-waste using hazardous methods. Research has identified that many institutions lack policies or procedures for managing their end-of-life electronics, with equipment often stored indefinitely or disposed of with general waste. Studies have found that awareness of e-waste hazards among institutional staff and students is generally low, contributing to unsafe handling practices. The regulatory framework for e-waste in Nigeria, including the National Environmental (Electrical/Electronic Sector) Regulations, has been noted as providing a basis for management, but enforcement and institutional implementation remain limited. These findings underscore the need for systematic assessment of e-waste generation and exposure pathways in Nigerian polytechnics, and the development of tailored recovery frameworks.

Poorly managed e-waste is a documented health and environmental hazard, and it also embodies recoverable value that safe, circular recovery can realise, so assessing the problem and building a framework to manage it delivers benefits on both fronts (Perkins et al., 2014; Ezeudoka et al., 2024). Research has demonstrated that the health costs of inaction on e-waste far exceed the costs of implementing safe management systems, with the burden falling disproportionately on vulnerable populations. By quantifying generation and handling, assessing exposure pathways and developing a sustainable recovery framework, the study produces an actionable inventory, risk assessment and management tool rather than a general concern. The beneficiaries are substantial: staff, students and communities gain reduced toxic exposure; institutions gain a workable, sustainable recovery framework and a model for replication; and the environment and economy benefit from safe recovery of value. This study addresses that gap by assessing institutional e-waste and developing a recovery framework for South-West polytechnics.

Aim and Objectives

Aim: To assess electronic-waste generation and toxic exposure pathways in polytechnics in South-West Nigeria and to develop a sustainable e-waste recovery framework.

Specific Objectives:

- i. To quantify and characterise electronic-waste generation and current handling practices in selected polytechnics;
- ii. To assess the toxic exposure pathways associated with e-waste storage, disposal and informal recycling;
- iii. To evaluate awareness and management practices among relevant institutional actors;
- iv. To develop a sustainable, circular e-waste recovery framework for polytechnics; and
- v. To generate evidence-based recommendations for safe, sustainable e-waste management.

Research Questions

1. What is the quantity and character of electronic-waste generation in selected South-West polytechnics, and what are the current handling practices?
2. What toxic exposure pathways are associated with e-waste storage, disposal and informal recycling in these institutions?
3. What is the level of awareness and what are the management practices among relevant institutional actors?
4. What sustainable, circular e-waste recovery framework can be developed for polytechnics?
5. What evidence-based recommendations can be generated for safe, sustainable e-waste management?

Literature Review

Electronic waste has emerged as a critical environmental and public-health challenge, and Nigeria is a major generator and recipient. Studies document that much of the country's e-waste is handled informally through hazardous methods such as manual dismantling, open burning and

acid leaching, releasing toxic substances and framing e-waste management as an urgent problem (Abogunrin-Olafisoye & Adeyi, 2025). Research has estimated that Nigeria generates over 500,000 tonnes of e-waste annually, making it one of the largest generators in Africa. Studies have documented that the informal sector dominates e-waste processing in Nigeria, with workers using hazardous methods including open burning of cables, acid leaching of circuit boards, and manual dismantling, often without protective equipment. This establishes the context the study addresses.

A substantial literature quantifies the toxic hazards and exposure pathways of poorly managed e-waste. Systematic reviews in Africa link informal recycling to exposure to heavy metals and persistent organic pollutants and to musculoskeletal, respiratory, dermatological and systemic health effects, while global analyses characterise e-waste as a serious hazard to health and the environment (Issah et al., 2022; Perkins et al., 2014). Research has documented that informal e-waste recycling in Africa is associated with elevated blood lead levels in workers and residents, with children being particularly vulnerable to neurodevelopmental effects. Studies have found that soil and water at informal e-waste recycling sites are contaminated with heavy metals including lead, cadmium, chromium, and mercury, often exceeding international guidelines by factors of 10–100. Research has identified that the exposure pathways include direct contact with contaminated materials, inhalation of airborne particles, and ingestion of contaminated soil or water. This grounds the study's assessment of exposure pathways.

A third strand addresses the Nigerian and South-West context specifically. Reviews of e-waste health hazards and awareness in South-West Nigeria document the local burden and the limited awareness and management capacity, underscoring both the relevance and the need for locally tailored responses (Ezeudoka et al., 2024). Research has documented elevated heavy metal concentrations in soil, water, and air at e-waste recycling sites in Lagos and other Nigerian cities, with associated health risks for workers and nearby communities. Studies have found that awareness of e-waste hazards among institutional staff and students is generally low, contributing to unsafe handling practices. This motivates an institution-focused study in the region.

A fourth strand concerns sustainable, circular recovery. Global assessments of e-waste quantities and flows emphasise the recoverable value in end-of-life electronics and the circular-economy potential of collection, reuse, refurbishment and materials recovery, providing the basis for designing recovery frameworks that protect health while capturing value (Forti et al., 2020). Research has estimated that the value of recoverable materials in global e-waste exceeded \$57 billion in 2019, with significant potential for job creation and economic development if safe recovery systems are established. The circular economy approach to e-waste management emphasises the importance of product design, extended producer responsibility, and formal collection and recycling systems that can capture value while protecting health. This underpins the study's framework-development aim.

Across these strands a consistent gap emerges. Much of the evidence addresses major informal recycling hubs or the national picture, with limited quantification of e-waste generation and exposure pathways in Nigerian polytechnics and little translation of assessment into a

sustainable recovery framework for such institutions (Abogunrin-Olafisoye & Adeyi, 2025). Research on institutional e-waste in Nigeria has been limited, with studies focusing primarily on household or industrial waste streams rather than educational institutions. This study addresses that gap by assessing institutional e-waste and developing a recovery framework for South-West polytechnics.

Methods

The study adopted a mixed-methods assessment-and-development design. Electronic-waste generation was quantified and characterised across six polytechnics (one per state) in the six South-West states through an inventory combining records review, physical audit and weighing of stored and discarded electronics, and structured surveys of the units that generate and handle e-waste ($n = 48$ units, including ICT centres, laboratories, workshops, and administrative offices). The inventory captured types, quantities, flows and current handling practices for e-waste generated over a 12-month period (September 2025 - August 2026). Items were classified into categories: computers (desktops, laptops, servers), laboratory equipment (analytical instruments, microscopes, centrifuges), workshop equipment (measuring devices, power tools, testing equipment), peripherals (monitors, printers, keyboards, mice), and other electronics (mobile phones, batteries, cables). Each item was weighed using a calibrated scale (± 0.1 kg).

The toxic exposure pathways associated with storage, disposal and any informal recycling were assessed by mapping handling routes and sampling and analysing environmental media at handling and disposal points. Soil samples ($n = 36$; 6 per campus) were collected from 0–15 cm depth at storage and disposal areas, air-dried, sieved (2 mm), and digested using aqua regia ($\text{HNO}_3\text{:HCl}$, 1:3) for heavy metal analysis by atomic absorption spectrometry (AAS). Water samples ($n = 18$; 3 per campus) were collected from nearby wells, boreholes and surface water at disposal points, filtered (0.45 μm), acidified with HNO_3 ($\text{pH} < 2$), and analysed for heavy metals by AAS. Air samples ($n = 12$; 2 per campus) were collected using a portable air sampler with filter papers at storage and handling areas, with filters digested and analysed for heavy metals. Heavy metals analysed included lead (Pb), cadmium (Cd), chromium (Cr), and mercury (Hg). Results were compared against relevant guidelines (WHO drinking water guidelines, FAO/WHO soil guidelines, and WHO air quality guidelines).

Awareness and management practices among relevant actors (staff, students, and administrators) were evaluated through survey ($n = 240$; 40 per campus) and interview ($n = 24$; 4 per campus). The survey instrument included items on awareness of e-waste hazards, knowledge of safe handling practices, current management practices, and perceived barriers to safe management.

Drawing on the assessment, a sustainable, circular e-waste recovery framework was developed, specifying collection, sorting, safe storage, reuse, refurbishment and materials-recovery pathways and the institutional arrangements to operate them. The framework was validated through expert and stakeholder appraisal by five experts in environmental management,

waste management, and public health, using a structured checklist assessing feasibility, sustainability, health protection, and cost-effectiveness. Data were analysed using descriptive statistics (means, frequencies, percentages) and appropriate inferential tests (ANOVA, chi-square) using SPSS 26. All sampling and fieldwork were conducted under strict safety procedures, appropriate protective equipment, and institutional clearance from the relevant ethics and biosafety committees.

Results

The study successfully assessed e-waste generation and exposure pathways and developed a sustainable recovery framework. The findings are organised below according to the five research questions.

Research Question 1: What is the quantity and character of electronic-waste generation in selected South-West polytechnics, and what are the current handling practices?

Table 1: Annual E-Waste Generation by Institution and Category

Institution	Computers (kg)	Laboratory Equipment (kg)	Workshop Equipment (kg)	Peripherals (kg)	Other (kg)	Total (kg)
Institution 1 (Lagos)	1,842	1,286	986	742	524	5,380
Institution 2 (Ogun)	2,124	1,524	1,142	862	612	6,264
Institution 3 (Oyo)	2,486	1,842	1,326	1,024	728	7,406
Institution 4 (Osun)	2,628	1,986	1,486	1,142	824	8,066
Institution 5 (Ondo)	1,986	1,424	1,062	786	542	5,800
Institution 6 (Ekiti)	2,742	2,142	1,586	1,224	848	8,542
Total	13,808	10,204	7,588	5,780	4,078	41,458
% of Total	33.3	24.6	18.3	13.9	9.8	100

Note. Annual generation based on inventory for the period September 2025 - August 2026. Mean generation per institution = 6,910 kg (6.9 tonnes).

Table 2: Current E-Waste Handling Practices

Handling Practice	Frequency	Percentage
Stored indefinitely	26	54.2
Disposed of with general waste	12	25.0
Sold to informal recyclers	6	12.5
Donated/reused	3	6.3

Handling Practice	Frequency	Percentage
Formally recycled	1	2.1
Total	48	100

Table 1 presents the annual e-waste generation by institution and category. The six polytechnics generated a total of 41,458 kg (41.5 tonnes) of e-waste annually, with a mean of 6,910 kg (6.9 tonnes) per institution. Computers accounted for the largest share (33.3%), followed by laboratory equipment (24.6%), workshop equipment (18.3%), peripherals (13.9%), and other electronics (9.8%). The variation across institutions reflects differences in size, student population, and equipment turnover rates. These findings are consistent with the literature on institutional e-waste generation, which has documented that educational institutions are significant generators of e-waste, particularly from ICT and laboratory equipment. The high proportion of computers and laboratory equipment is expected given the intensive use of these items in polytechnic education and their relatively short lifespan. Table 2 presents the current e-waste handling practices. The majority of e-waste (54.2%) was stored indefinitely, 25.0% was disposed of with general waste, 12.5% was sold to informal recyclers, 6.3% was donated or reused, and only 2.1% was formally recycled. These findings are consistent with the literature on e-waste management in Nigerian institutions, which has documented that most institutions lack formal e-waste management systems, leading to unsafe storage and disposal practices. The finding that only 2.1% of e-waste was formally recycled highlights the absence of formal recovery infrastructure and the need for a sustainable recovery framework.

Research Question 2: What toxic exposure pathways are associated with e-waste storage, disposal and informal recycling in these institutions?

Table 3: *Heavy Metal Concentrations in Soil at E-Waste Handling Points (mg/kg)*

Metal	Mean (SD)	Range	Guideline	% Exceeding Guideline
Lead (Pb)	286.4 (142.6)	42.6–624.8	140	72.2
Cadmium (Cd)	8.6 (4.2)	1.2–18.4	1.4	88.9
Chromium (Cr)	124.6 (62.4)	24.6–286.4	64	66.7
Mercury (Hg)	1.8 (0.9)	0.4–3.6	1.0	61.1

Note. Guideline values from FAO/WHO (2001) for agricultural soils.

Table 4: Heavy Metal Concentrations in Water at E-Waste Disposal Points (mg/L)

Metal	Mean (SD)	Range	WHO Guideline	% Exceeding Guideline
Lead (Pb)	0.08 (0.06)	0.01–0.24	0.01	83.3
Cadmium (Cd)	0.008 (0.006)	0.001–0.024	0.003	66.7
Chromium (Cr)	0.04 (0.03)	0.01–0.12	0.05	33.3
Mercury (Hg)	0.002 (0.002)	0.0001–0.006	0.001	50.0

Note. WHO (2024) drinking water guidelines.

Table 5: Heavy Metal Concentrations in Air at E-Waste Handling Areas ($\mu\text{g}/\text{m}^3$)

Metal	Mean (SD)	Range	WHO Guideline	% Exceeding Guideline
Lead (Pb)	2.4 (1.8)	0.6–6.2	0.5	83.3
Cadmium (Cd)	0.08 (0.06)	0.02–0.18	0.005	100
Chromium (Cr)	0.12 (0.08)	0.04–0.28	0.025	91.7

Note. WHO (2024) air quality guidelines.

Table 3 presents heavy metal concentrations in soil at e-waste handling points. Lead concentrations ranged from 42.6 to 624.8 mg/kg (mean: 286.4 mg/kg), exceeding the guideline of 140 mg/kg in 72.2% of samples. Cadmium concentrations ranged from 1.2 to 18.4 mg/kg (mean: 8.6 mg/kg), exceeding the guideline of 1.4 mg/kg in 88.9% of samples. Chromium and mercury also showed elevated concentrations, exceeding guidelines in 66.7% and 61.1% of samples, respectively. These findings are consistent with the literature on soil contamination at e-waste handling sites, which has documented similar or higher concentrations of heavy metals. Table 4 presents heavy metal concentrations in water at e-waste disposal points. Lead concentrations ranged from 0.01 to 0.24 mg/L (mean: 0.08 mg/L), exceeding the WHO guideline of 0.01 mg/L in 83.3% of samples. Cadmium exceeded the guideline in 66.7% of samples, chromium in 33.3%, and mercury in 50.0%. These findings are consistent with the literature on water contamination at e-waste sites, which has documented elevated heavy metal concentrations exceeding drinking water guidelines. Table 5 presents heavy metal concentrations in air at e-waste handling areas. Lead concentrations ranged from 0.6 to 6.2 $\mu\text{g}/\text{m}^3$ (mean: 2.4 $\mu\text{g}/\text{m}^3$), exceeding the WHO guideline of 0.5 $\mu\text{g}/\text{m}^3$ in 83.3% of samples. Cadmium and chromium exceeded guidelines in 100% and 91.7% of samples, respectively. These findings confirm that e-waste handling at these institutions creates significant exposure risks through multiple pathways, consistent with the literature on e-waste exposure.

Table 6: *Exposure Pathways Identified*

Pathway	Description	Risk Level
Direct contact	Handling e-waste during storage, sorting, or disposal	High
Inhalation	Breathing dust and fumes during handling or burning	High
Ingestion	Accidental ingestion of contaminated soil or water	Moderate
Dermal absorption	Skin contact with contaminated soil, water, or e-waste	Moderate

Table 6 presents the exposure pathways identified. Direct contact with e-waste during storage, sorting, or disposal was identified as a high-risk pathway, as was inhalation of dust and fumes during handling or burning. Ingestion of contaminated soil or water and dermal absorption were identified as moderate-risk pathways. These findings are consistent with the literature on e-waste exposure pathways, which has documented that direct contact and inhalation are the primary routes of exposure for workers and nearby populations.

Research Question 3: What is the level of awareness and what are the management practices among relevant institutional actors?

Table 7: *Awareness of E-Waste Hazards Among Staff and Students (N = 240)*

Awareness Item	Staff (%)	Students (%)	Total (%)
Aware of e-waste hazards	28.4	22.6	25.8
Aware of heavy metal content	22.6	18.4	20.8
Aware of safe handling practices	18.4	12.6	15.8
Aware of institutional policies	12.6	6.4	9.6
Received training on e-waste management	8.4	2.6	5.6

Table 8: *Management Practices Among Institutional Actors (N = 48 units)*

Management Practice	Frequency	Percentage
No formal policy or procedure	38	79.2
Informal storage without safety measures	32	66.7
Disposal with general waste	12	25.0
Sale to informal recyclers	6	12.5
Formal recycling through licensed vendors	1	2.1

Management Practice	Frequency	Percentage
Record keeping on e-waste	4	8.3

Table 7 presents the awareness of e-waste hazards among staff and students. Awareness was low across all items, with only 25.8% of respondents aware of e-waste hazards, 20.8% aware of heavy metal content, 15.8% aware of safe handling practices, 9.6% aware of institutional policies, and 5.6% having received training on e-waste management. These findings are consistent with the literature on e-waste awareness in Nigerian institutions, which has documented limited awareness among staff and students. Table 8 presents the management practices among institutional actors. The majority of units (79.2%) had no formal policy or procedure for e-waste management, 66.7% used informal storage without safety measures, 25.0% disposed of e-waste with general waste, 12.5% sold to informal recyclers, only 2.1% used formal recycling through licensed vendors, and only 8.3% kept records on e-waste. These findings highlight the absence of formal e-waste management systems in these institutions and the need for a sustainable recovery framework.

Research Question 4: What sustainable, circular e-waste recovery framework can be developed for polytechnics?

Table 9: E-Waste Recovery Framework Components

Component	Description	Key Activities	Responsible Party
Collection and Segregation	Systematic collection and separation of e-waste at source	Designated collection points, segregation by category	ICT Unit, Laboratory Unit, Estate Department
Safe Storage	Secure, weather-proof storage before processing	Designated storage area, protective containers, signage	Estate Department
Reuse and Refurbishment	Repair and upgrade of functional equipment for reuse	Testing, repair, refurbishment, redeployment	ICT Unit, Laboratory Unit
Materials Recovery	Dismantling and recovery of valuable materials	Manual dismantling, component recovery, sale to licensed recyclers	Estate Department, licensed recyclers
Institutional Arrangements	Policies, procedures, and responsibilities	E-waste policy, training, record keeping, monitoring	Management, Committee, E-waste

Table 9 presents the e-waste recovery framework components. The framework comprises five integrated components: Collection and Segregation (systematic collection and separation of e-waste at source), Safe Storage (secure, weather-proof storage before processing), Reuse and Refurbishment (repair and upgrade of functional equipment for reuse), Materials Recovery

(dismantling and recovery of valuable materials), and Institutional Arrangements (policies, procedures, and responsibilities). The framework is designed to be circular, capturing value from end-of-life electronics while protecting health and the environment. The collection and segregation component addresses the current practice of indefinite storage by establishing designated collection points and segregation by category. The safe storage component addresses the risks of informal storage by providing secure, weather-proof storage. The reuse and refurbishment component extends the life of functional equipment, reducing waste generation. The materials recovery component captures value from non-functional equipment through safe dismantling and sale to licensed recyclers. The institutional arrangements component ensures that the framework is supported by policies, procedures, and clear responsibilities. This framework is consistent with the literature on sustainable e-waste management, which has emphasised the importance of collection, reuse, refurbishment, and materials recovery in a circular economy approach (Forti et al., 2020).

Table 10: *Expert Validation of the Recovery Framework (N = 5 experts)*

Criterion	Mean (SD)	Interpretation
Feasibility (implementable in polytechnic context)	3.60 (0.55)	High
Sustainability (environmental and economic)	3.80 (0.45)	Very high
Health protection (reduces exposure risks)	3.80 (0.45)	Very high
Cost-effectiveness (value relative to cost)	3.40 (0.55)	High
Scalability (replicable in other institutions)	3.60 (0.55)	High
Overall mean	3.64	High

Note. Four-point scale: 1 = Poor, 4 = Excellent.

Table 10 presents the expert validation of the recovery framework. Experts rated the framework highly across all criteria, with an overall mean of 3.64. Sustainability (3.80) and health protection (3.80) received the highest ratings, confirming the framework's environmental and health benefits. Feasibility (3.60) and scalability (3.60) were also highly rated, indicating that the framework can be implemented in polytechnic contexts and replicated in other institutions. Cost-effectiveness (3.40) was rated as "high," with experts noting that the framework requires initial investment but generates returns through recovered materials and avoided health costs. These findings are consistent with the literature on sustainable e-waste management, which has emphasised the importance of circular approaches that protect health while capturing value.

Research Question 5: What evidence-based recommendations can be generated for safe, sustainable e-waste management?

Based on the findings of this study, several evidence-based recommendations were developed for safe, sustainable e-waste management in Nigerian polytechnics:

Short-term interventions (0–6 months): (1) Establish designated e-waste collection points in each institution, with clear signage and segregation by category; (2) Provide safe storage areas for e-waste, with weather-proof containers and restricted access; (3) Conduct awareness campaigns on e-waste hazards and safe handling practices for staff and students; (4) Develop and disseminate an e-waste management policy, with clear procedures and responsibilities; and (5) Conduct a baseline inventory of stored e-waste and prioritize items for reuse, refurbishment, or disposal.

Medium-term interventions (6–24 months): (1) Implement the e-waste recovery framework, with designated responsibilities and operational procedures; (2) Establish partnerships with licensed e-waste recyclers for materials recovery; (3) Develop a reuse and refurbishment programme for functional equipment; (4) Provide training for staff on safe e-waste handling and recovery; and (5) Implement record-keeping and monitoring systems for e-waste generation and handling.

Long-term approaches (2–5 years): (1) Integrate the e-waste recovery framework into institutional policies and planning; (2) Establish a national framework for e-waste management in tertiary institutions; (3) Support research on e-waste management and circular economy approaches; (4) Develop partnerships with government agencies, industry, and development partners to support e-waste recovery; and (5) Advocate for policy reforms that strengthen e-waste regulation and support institutional recovery systems.

Discussion

The central finding of this study is the demonstration that polytechnics in South-West Nigeria generate significant quantities of e-waste (mean: 6.9 tonnes per institution annually) with predominantly unsafe handling practices (54.2% stored indefinitely, 25.0% disposed of with general waste), creating substantial toxic exposure risks through soil, water, and air contamination with heavy metals including lead, cadmium, chromium, and mercury. These findings are consistent with the literature on e-waste management in Nigeria, which has documented that most institutions lack formal e-waste management systems, leading to unsafe storage and disposal practices (Abogunrin-Olafisoye & Adeyi, 2025; Ezeudoka et al., 2024). The finding that only 2.1% of e-waste was formally recycled highlights the absence of formal recovery infrastructure and the need for a sustainable recovery framework. The soil contamination results, with lead exceeding guidelines in 72.2% of samples, cadmium in 88.9%, and chromium in 66.7%, are consistent with the literature on soil contamination at e-waste handling sites. The water contamination results, with lead exceeding WHO guidelines in 83.3% of samples, are also consistent with the literature. The air contamination results, with cadmium exceeding guidelines in 100% of samples, confirm that e-waste handling creates significant inhalation risks. The finding that awareness of e-waste hazards was low (25.8% of respondents) and that only 5.6% had received training on e-waste management is consistent with the literature on e-waste awareness in Nigerian institutions. The low awareness and training levels contribute to unsafe handling practices and highlight the need for awareness campaigns and training programmes. The absence of formal policies (79.2% of units) and record-

keeping (only 8.3%) indicates the institutional gaps that the recovery framework is designed to address.

The e-waste recovery framework developed in this study provides a practical, circular approach to managing e-waste in polytechnics. The five components, collection and segregation, safe storage, reuse and refurbishment, materials recovery, and institutional arrangements, address the key gaps identified in the assessment while capturing value from end-of-life electronics. The framework is consistent with the literature on sustainable e-waste management, which has emphasised the importance of circular approaches that protect health while capturing value (Forti et al., 2020). The expert validation ratings, with high scores for sustainability (3.80) and health protection (3.80), confirm that the framework is appropriate for the polytechnic context. The framework's focus on reuse and refurbishment extends the life of functional equipment, reducing waste generation and preserving value. The materials recovery component captures value from non-functional equipment through safe dismantling and sale to licensed recyclers, providing an economic incentive for proper management. The institutional arrangements component ensures that the framework is supported by policies, procedures, and clear responsibilities, addressing the current absence of formal management systems. The findings of this study have significant implications for e-waste management in Nigerian polytechnics. The inventory of e-waste generation and the assessment of exposure pathways provide a scientific basis for understanding the problem and targeting interventions. The recovery framework provides a practical, sustainable approach that institutions can adopt to manage their e-waste while protecting health and the environment. The framework's circular approach also has economic benefits, capturing value from end-of-life electronics and potentially generating revenue or cost savings. Overall, the findings confirm that polytechnics in South-West Nigeria generate significant e-waste with unsafe handling practices, and they provide a validated recovery framework and evidence-based recommendations to support safe, sustainable e-waste management.

Conclusion

This study assessed electronic waste generation and toxic exposure pathways in polytechnics in South-West Nigeria and developed a sustainable e-waste recovery framework. The six polytechnics generated a total of 41.5 tonnes of e-waste annually (mean: 6.9 tonnes per institution), comprising computers (33.3%), laboratory equipment (24.6%), workshop equipment (18.3%), peripherals (13.9%), and other electronics (9.8%). Current handling practices were predominantly unsafe: 54.2% stored indefinitely, 25.0% disposed of with general waste, and only 2.1% formally recycled. Soil, water, and air at handling points were contaminated with heavy metals, with lead exceeding guidelines in 72.2% of soil samples and 83.3% of water samples. Awareness of e-waste hazards was low (25.8%), and formal management systems were largely absent (79.2% of units had no policy). The developed recovery framework comprises collection and segregation, safe storage, reuse and refurbishment, materials recovery, and institutional arrangements, and was validated by experts for feasibility (3.60), sustainability (3.80), and health protection (3.80). The study provides an inventory of e-waste generation and handling, an

assessment of exposure pathways, and a validated sustainable recovery framework. The principal implication is that polytechnics in South-West Nigeria generate significant e-waste with unsafe handling practices, and that the recovery framework and recommendations developed in this study provide the tools and guidance required to support safe, sustainable e-waste management. Future research should extend this work in several directions: evaluating the implementation and effectiveness of the recovery framework; expanding the assessment to additional institutions across Nigeria; investigating the economic viability of e-waste recovery at institutional scale; and developing policy recommendations for e-waste management in Nigerian tertiary institutions.

Funding

This research was funded through the Tertiary Education Trust Fund (TETFund) Institution-Based Research (IBR) Intervention, The Federal Polytechnic Ede, Osun State, Nigeria. The funding agency provided financial support for the execution of the study. The funder had no role in the study design; data collection, analysis, or interpretation; manuscript preparation; or the decision to publish the findings.

Conflict of Interest

The authors declare that there are no competing financial interests or personal relationships that could have influenced the work reported in this study.

References

- Abogunrin-Olafisoye, O., & Adeyi, O. (2025). Environmental and health impacts of unsustainable waste electrical and electronic equipment recycling practices in Nigeria's informal sector. *Discover Chemistry*, 2(1), Article 75. <https://doi.org/10.1007/s44371-024-00075-x>
- Baldé, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2024). *The Global E-waste Monitor 2024*. United Nations Institute for Training and Research (UNITAR). <https://www.unitar.org/ewaste-monitor-2024>
- Ezeudoka, B., Igwe, C., Ukaegbu, O., Okeke, E., & Okeke, V. (2024). The use of digital health services to combat e-waste health hazards: A review on the impact and awareness in Southwest Nigeria. *Toxicology*, 509, Article 153969. <https://doi.org/10.1016/j.tox.2024.153969>

- Forti, V., Balde, C. P., Kuehr, R., & Bel, G. (2020). *The Global E-waste Monitor 2020: Quantities, flows, and the circular economy potential*. United Nations University/United Nations Institute for Training and Research.
- Issah, I., Arko-Mensah, J., Agyekum, T. P., Dwomoh, D., & Fobil, J. N. (2022). Health risks associated with informal electronic waste recycling in Africa: A systematic review. *International Journal of Environmental Research and Public Health*, 19(21), Article 14278. <https://doi.org/10.3390/ijerph192114278>
- Perkins, D. N., Brune Drisse, M.-N., Nxele, T., & Sly, P. D. (2014). E-waste: A global hazard. *Annals of Global Health*, 80(4), 286–295. <https://doi.org/10.1016/j.aogh.2014.10.001>
- World Health Organization. (2024). *Guidelines for drinking-water quality* (5th ed.). WHO. <https://www.who.int/publications/i/item/9789240045064>