

# Assessment of E-waste Management and Heavy Metal Analysis in Printed Circuit Boards of Computers from Woreda Offices of Addis Ketema Sub-city, Addis Ababa, Ethiopia

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## Abstract

**Background:** This study aimed to examine e-waste management in the woreda offices of Addis Ketema Sub-City, Addis Ababa City Administration, Ethiopia, and to determine the concentrations of heavy metals in computer printed circuit boards (PCBs).

**Methods:** This cross-sectional survey was conducted among 368 employees from 14 woredas using structured questionnaires. Three samples of discarded computer PCBs were analyzed for Mn, Ni, Pb, Cd, and Cu using Flame Atomic Absorption Spectroscopy.

**Results:** Most employees (74.2%) were not aware of e-waste management, 75% had not received training, and only 26.6% knew proper disposal methods. Although 81.5% recognized its environmental and health impacts, 70.4% did not believe e-waste harms human or environmental health. Logistic regression showed that training, educational status, access to collectors, and access to disposal sites were significantly associated with better awareness, attitudes, and practices ( $P < 0.05$ ). Analysis of PCBs revealed mean concentrations (mg/kg) of Cu:  $78,402.44 \pm 13.44$ , Pb:  $5,821.08 \pm 11.29$ , Ni:  $1,620.11 \pm 6.15$ , Mn:  $120.72 \pm 2.19$ , and Cd:  $0.1 \pm 0.09$ . The levels of Cu and Pb exceeded the Toxicity Threshold Limit Concentrations (2,500 and 1,000 mg/kg, respectively), indicating potential environmental and health risks. Administrative, economic, and socio-cultural challenges contributed to poor e-waste management in the sub-city's woreda offices.

**Conclusion:** E-waste management in the sub-city is inadequate. Enhancing training, access to formal collection systems, and enforcement of regulations is essential to reduce the adverse impacts of hazardous e-waste on human and environmental health.

**Keywords:** Copper, Educational status, Electronic waste, Heavy metal, Waste management

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## Introduction

The rapid expansion of the electronics sector has generated unprecedented volumes of electronic waste (e-waste) globally, with over 62 million tonnes produced in 2022, yet only about 22% formally collected and recycled (1-3). While this global trend highlights the magnitude of the problem, e-waste poses an even greater risk in low- and middle-income countries where management systems are underdeveloped (4-8).

In Ethiopia, and particularly in Addis Ababa, e-waste generation is accelerating due to increasing digitalization of public offices, the importation of second-hand electronics, and the absence of formal collection and recycling infrastructure (9-11). However, there is little empirical evidence on how government offices handle

e-waste, and no published studies have quantified heavy metal concentrations in discarded computer printed circuit boards (PCBs) in Addis Ketema sub-city. This gap limits the ability of policymakers to design safe and sustainable e-waste systems.

Heavy metals in e-waste, such as lead (Pb), cadmium (Cd), mercury (Hg), and copper (Cu), are highly toxic even at low concentrations. Children are especially vulnerable due to higher rates of exposure relative to body weight and developing neurological systems (12-14). Adults exposed to heavy metals can develop chronic liver, kidney, and nervous system disorders (15-17). Studies from India, Nigeria, and Kenya show elevated Pb and Cu in PCBs and significant health and environmental hazards from informal recycling (18-21).



Despite the rising risk, no prior study has simultaneously assessed e-waste management practices and measured heavy metal content of PCBs in government offices in Addis Ababa. This study addresses this critical knowledge gap. Specifically, it investigates the awareness, attitudes, and practices of woreda office employees regarding e-waste, and quantifies the concentrations of Mn, Ni, Pb, Cd, and Cu in discarded computer PCBs from these offices. By integrating behavioral and laboratory evidence, this study provides the first comprehensive baseline for designing targeted interventions and policy measures to manage hazardous e-waste in Addis Ababa.

## Materials and Methods

### Description of the Study Area

The study was conducted in the Addis Ketema sub-city of Addis Ababa, the capital of Ethiopia (FDRE). The city serves as a diplomatic hub, hosting various international organizations such as the African Union and the United Nations Economic Commission for Africa. Geographically, Addis Ababa is located between 9°1'48"N and 38°44'24"E, spanning an area of 540 km<sup>2</sup>. The city comprises 11 sub-cities and 116 woredas, with a population of approximately 5.1 million, an annual growth rate of 3.8%, and a population density of 5,936.2 people per km<sup>2</sup> (22). Addis Ketema is one of the 11 sub-cities and consists of 14 woredas. It is situated in the northern part of Addis Ababa, bordered by Gullele to the north, Arada to the east, Kolfe Keranio to the west, and Lideta to the south (Figure 1). The sub-city covers an area of 7.41 km<sup>2</sup>.

### Research Design and Approach

This study employed a mixed-methods design, integrating both descriptive and explanatory research approaches. Quantitative data were collected using structured questionnaires and laboratory analysis results, while qualitative insights were obtained from relevant documents, including published and unpublished literature, to provide a comprehensive understanding of e-waste management practices in government offices and heavy metals content in PCBs.

### Sampling Technique and Sample Size Determination

#### Sampling Technique

Addis Ketema sub-city, one of the 11 sub-cities in Addis Ababa, has a population of 312,414 (23). A purposive sampling method was initially used to select Addis Ketema due to its relatively higher number of woreda offices and the absence of prior studies on similar topics. Addis Ketema comprises 14 woredas and approximately 4,200 employees. From these employees, 368 respondents were selected using a simple random sampling technique to ensure representativeness.

#### Sample Size Determination

The sample size was determined using the finite population correction formula:

$$n = \frac{n_0}{1 + \frac{n_0}{N}}$$

Where  $n_0$  is the initial sample size, given by:

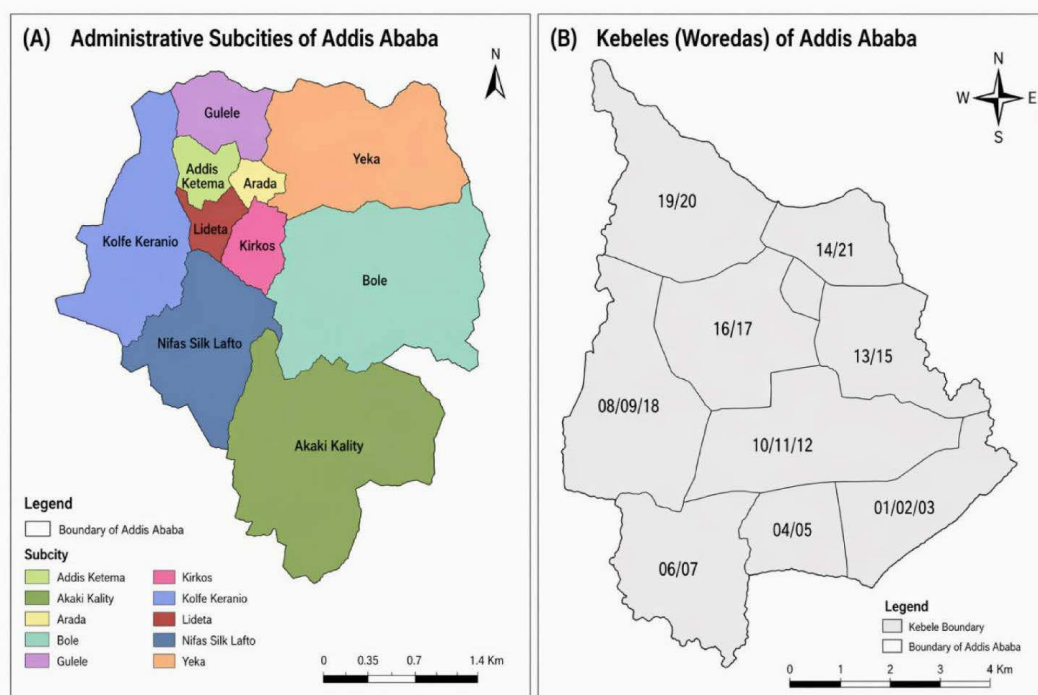


Figure 1. Map of the study area

$$n_0 = \frac{\left( Z_{\frac{\alpha}{2}} \right)^2 p \cdot (1-p)}{d^2}$$

Where  $n$  is the required sample size,  $N$  is the total population of the woreda office employees ( $N=4200$ ),  $Z_{\frac{\alpha}{2}}$  is the standard normal deviation at 95% confidence interval ( $Z_{\frac{\alpha}{2}}=1.96$ ),  $P$  is the estimated proportion of respondents with a favorable attitude, awareness, and practice (0.5),  $d$  is the margin of error (0.05), and  $1-p$  is the proportion of the population that does not possess the above character of interest.

$$n_0 = \frac{(1.96)^2 (0.5)(0.5)}{(0.05)^2} = 385 \text{ and } n = \frac{385}{1 + \frac{385}{4200}} \cong 353$$

By adding a 4% non-response rate:

$$n_{final} = 353 + (353 \times 0.04) = 368$$

### Methods of Data Collection

#### Structured Questionnaire

A structured questionnaire was developed, pre-tested, and tailored to the study context. The questionnaire comprised four sections: Demographic Information (gender, age, educational level, and work experience); Awareness (knowledge of electronic equipment (EEE) and e-waste, including protective measures and proper storage); Attitude (perceptions and feelings regarding e-waste management); and Practice (actual behavior concerning collection, storage, and disposal of e-waste). The questionnaire consisted of 20 closed-ended items and 5 open-ended questions, categorized under the sections above. Reliability testing was conducted using Cronbach's alpha, yielding a value of 0.82, indicating acceptable internal consistency. Validity was ensured through expert review and pre-testing with 10% of the sample before the main study. Additional data were obtained from secondary sources, including government reports, books, journal articles, and prior research.

#### Heavy Metal Analysis

Three samples of printed circuit boards (PCBs) from discarded computers were analyzed using Flame Atomic Absorption Spectroscopy (FAAS). Computers were selected because they are a major source of e-waste in government offices (18). Samples were disassembled, crushed, sieved, and analyzed for heavy metal content. Due to the small number of samples, the results cannot be generalized to all e-waste types or offices. This limitation is acknowledged in the discussion.

### Variables of the Study

#### Dependent Variables

The dependent variables in this study are the attitude,

awareness, and practice of woreda office employees toward e-waste management (Table 1).

- Awareness: Employees' knowledge about EEE and e-waste, including awareness of protective equipment use and appropriate storage to prevent environmental or health hazards.
- Attitude: Employees' feelings toward EEE and e-waste, including views on the importance of using protective equipment and storing waste appropriately.
- Practice: Actual behaviors related to e-waste handling, including proper storage, use of protective gear, and handing waste over to authorized collectors.

#### Independent Variables

The independent variables in this study included, educational level, work experience, adequate access to collectors, training on e-waste management, access to the disposal site, distance from the main road, and awareness of government regulations and their enforcement (Table 2).

- Gender: Dummy variable (0 = female, 1 = male).
- Educational Level: Number of years in formal education; expected to positively influence proper e-waste disposal.
- Work Experience: Continuous variable; expected to positively impact e-waste management.
- Access to Collectors: Dummy variable indicating availability of door-to-door collection services.
- Training: Dummy variable (1 if the respondent received training on e-waste management; 0 otherwise); expected to enhance awareness and practice.
- Access to disposal site: Dummy variable indicating whether a proper disposal site is accessible; expected to improve e-waste practices.
- Distance from main road: Measured in meters; hypothesized that institutions farther from the road are more likely to dispose of waste improperly.
- Government regulation awareness: Dummy variable (1 = aware of regulations and enforcement; 0 = not aware); expected to influence behavior positively

#### Data Analysis

Descriptive statistics (frequencies, percentages) and

**Table 1.** Classification of the dependent variables.

Response variables	Categories and labels
Attitude	Favorable = 1
	Unfavorable = 0
Awareness	Aware = 1
	Not aware = 0
Practice	Good practice = 1
	Poor practice = 0

**Table 2.** Descriptions and categories of study variables.

Variables	Categories and labels
Gender	Male=1
	Female=0
Educational level	Illiterate=0
	Certificate=1
	Diploma=2
	Degree=3
Work experience	Master and above=4
	(1-3) years=0
	(4-6) years=1
Enough access to collectors	> 7 years=2
	Yes=1
Training on EWM	No=0
	Trained=1
Access to the disposal site	Not trained=0
	Yes=1
Distance from the main road	No=0
	Continuous (meters)
Aware of the government's regulations and their enforcement	Yes=1
	No=0

inferential statistics were used. Cross-tabulations and Chi-square tests evaluated associations between variables. Binary logistic regression was applied to assess factors influencing awareness, attitude, and practice.

### Logistic Regression Model

Binary Logistic Regression is used when the dependent variable is dichotomous (i.e., when it has two categories), while the independent variables can be continuous, categorical, or binary. When the dependent variable has more than two categories, multinomial logistic regression is appropriate.

Following Gujarati (24) and Green (25), the logistic regression model for analyzing factors affecting employees' awareness, attitude, and practice of e-waste management can be expressed as a function of explanatory variables, including gender, educational level, work experience, training, access to disposal sites, and awareness of government regulations.

$$p(y_i = 1) = \frac{e^{z_i}}{1 + e^{z_i}}$$

Where:

$$Z_i = \beta_0 + \beta_1x_1 + \beta_2x_2 + \dots + \beta_px_p$$

The odds ratio is:

$$\frac{p(y_i = 1)}{1 - p(y_i = 1)} = e^{z_i}$$

The logit transformation:

$$\text{logit}(p(y_i = 1)) = \log\left(\frac{p(y_i = 1)}{1 - p(y_i = 1)}\right) = Z_i$$

Parameter estimation was based on the **likelihood function** of the Bernoulli distribution:

$$L = \prod_{i=1}^n \left( \frac{e^{x_i^T \beta}}{1 + e^{x_i^T \beta}} \right)^{y_i} \left( 1 - \frac{e^{x_i^T \beta}}{1 + e^{x_i^T \beta}} \right)^{(1-y_i)}$$

Where:

$$\pi = \frac{e^{x_i^T \beta}}{1 + e^{x_i^T \beta}}$$

Where  $\pi_i$  is the probability of proper e-waste disposal, and  $X_i$  represents explanatory variables. A positive regression coefficient ( $\beta$ ) indicates that an increase in the predictor variable increases the likelihood of a favorable outcome. All analyses were conducted using SPSS version 28.

## Results

### Awareness of Employees on E-Waste Management

The awareness of employees regarding e-waste management, training, environmental impacts, and associated hazards is summarized in Table 3. Out of 368 respondents, only 95 (25.8%) reported being aware of e-waste management, while the majority (74.2%) were not. Similarly, 98 respondents (26.6%) knew how to properly dispose of e-waste, and 92 (25%) had received lessons or guidance associated with e-waste management. Most employees (81.5%) acknowledged that e-waste disposal methods could impact the environment and human health, although 70.4% did not believe that e-waste negatively affects the environment or health.

Regarding the hazards of e-waste, 157 respondents (42.7%) reported awareness of dangers to humans and the environment. Among those aware (n=250), 240 (96%) indicated that toxic components require special treatment for environmentally sound disposal.

### Causes of Poor E-Waste Management

Employees identified the major causes of poor e-waste management as carelessness, weak law enforcement, lack of responsibility, and insufficient awareness. These causes were determined based on responses to structured survey questions and follow-up interviews with employees and are presented in Table S1. Additionally, 82.9% of respondents were unaware of environmental policies regarding e-waste management, and 92.7% were unaware of federal or state solid waste regulations. Among those aware of regulations (n=64), 92% rated law enforcement as weak. About 50.5% of respondents reported the absence of office-specific rules on e-waste management.

### E-Waste Management Practices of the Woreda Offices Disposal Practice

According to store managers, the most common e-waste

**Table 3.** Awareness of E-Waste Management and Associated Hazards (n = 368).

Question	Yes	No	Total
Awareness of E-Waste Management	95(25.8%)	273(74.2%)	368
Know the advantages of reducing e-waste	194(52.7%)	174(47.3%)	368
Know how to dispose of e-waste	98(26.6%)	270(73.4%)	368
Discuss with others how to reduce e-waste	56(15.2%)	312(84.8%)	368
Lesson received on e-waste management	92(25%)	276(75%)	368
Aware of dangers to human/environment	157(42.7%)	211(57.3%)	368
Components contain toxic materials	250(67.9%)	118(32.1%)	368
Toxic materials require special treatment*	240(96%)	10(4%)	250
Disposal impact on the environment	300(81.5%)	68(18.5%)	368

\*Only asked respondents who knew components contained toxic materials.

types were computer accessories, desktops, laptops, printers, photocopiers, fax machines, and TVs/radios. Most employees (73.4%) did not know how to dispose of e-waste. Disposal methods included storing e-waste, selling to recyclers, burning with general waste, or dumping in rivers (Figure 2).

### Challenges of E-Waste Management in Woreda Offices

Key challenges included the lack of targeted legislation, limited recycling capacity, and the importation of second-hand electronic equipment. Limited capacity for collection and recycling, combined with increasing e-waste generation, was reported to significantly hinder proper e-waste management in the sub-city.

### Factors Affecting Awareness, Attitude, and Practice

#### Awareness

Cross-tabulation analysis (Table 4) showed that awareness of e-waste management was significantly associated with educational level ( $P=0.001$ ), work experience ( $P=0.001$ ), training ( $P=0.033$ ), access to collectors ( $P=0.001$ ), and access to disposal sites ( $P=0.001$ ). Gender was not significantly associated ( $P=0.135$ ). Binary logistic regression (Table S2) indicated that employees without sufficient access to e-waste collectors had 85.5% lower odds of being aware of e-waste management ( $OR=0.145$ ,  $P=0.015$ ). Lack of access to disposal sites decreased the odds by 70.2% ( $OR=0.298$ ,  $P=0.039$ ). Employees without training had almost no likelihood of being aware ( $OR=0.001$ ,  $P<0.001$ ).

#### Attitude

Educational level, work experience, training status, distance from main road, and access to disposal sites were significantly associated with employees' attitudes (Table S3). Binary logistic regression (Table 5) indicated that employees with a certificate-level education had 79.2% lower odds of a positive attitude compared to those with a master's degree or higher ( $OR=0.208$ ,  $P=0.010$ ). Employees with 1–3 years of work experience were more likely to have a positive attitude ( $OR=3.002$ ,  $P=0.016$ ).

Lack of access to disposal sites decreased the likelihood of a positive attitude by 63.1% ( $OR=0.369$ ,  $P=0.003$ ). Lack of training strongly reduced positive attitudes ( $OR=0.048$ ,  $P<0.001$ ).

#### Practice

Practice was significantly associated with sex, educational level, training, and access to collectors and disposal sites (Table 6). Binary logistic regression (Table 7) indicated that employees indicated that female employees were 80.3% less likely to practice e-waste management than male employees ( $OR=0.197$ ,  $P=0.007$ ). Lack of access to collectors decreased practice likelihood by 88% ( $OR=0.120$ ,  $P<0.001$ ), while lack of access to disposal sites decreased it by 73.7% ( $OR=0.263$ ,  $P=0.007$ ). Employees without training rarely practiced proper e-waste management ( $OR=0.001$ ,  $P<0.001$ ).

### Heavy Metals Concentrations in Printed Circuit Boards (PCBs)

The concentrations of heavy metals in PCBs of discarded computers are presented in Table 8. Mean concentrations generally followed the order:  $Cu > Pb > Ni > Mn > Cd$ . Cu ( $78,402.44 \pm 13.44$  mg/kg) and Pb ( $5,821.08 \pm 11.29$  mg/kg) exceeded the Toxicity Threshold Limit Concentrations (TTLC), indicating potential environmental and health risks.

### Discussion

#### Awareness of Employees on E-Waste Management

This study revealed low levels of awareness regarding e-waste management among employees, with only about one-quarter reporting knowledge of appropriate practices. This finding aligns with reports from other low- and middle-income countries, where public understanding of e-waste hazards is generally poor (2,25–28). Limited awareness is often linked to the absence of structured training, weak dissemination of information, and minimal public engagement on e-waste issues (2). Although most respondents acknowledged that e-waste can affect the

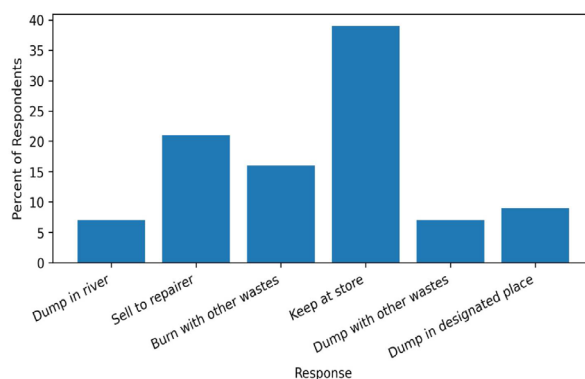


Figure 2. Methods of e-waste disposal practiced in Woreda offices

Table 4. Cross-tabulation of levels of awareness towards e-waste management with predictor variables

Variables	Category	Awareness towards E-waste management		Total	Chi-square	Df	P-value
		Aware	Not-aware				
Gender	Female	37(23.6%)	120(76.4%)	157	0.723	1	0.135
	Male	58(27.5%)	153(72.5%)	211			
Educational status	Illiterate	0(0%)	2(100%)	2	65.262	4	0.000
	Certificate	5(8.2%)	56(91.8%)	61			
	Diploma	19(22.7%)	65(77.3%)	84			
	Degree	28(18.4%)	125(81.6%)	153			
	Masters &above	43(63.3%)	25(36.7%)	68			
Work experience (Year)	1-3	43(37.1%)	73(62.9%)	116	17.364	2	0.000
	4-6	27(15.9%)	143(84.1%)	170			
	>7	25(30.5%)	57(69.5%)	82			
Training on EWM	Trained	84(90.5%)	8(9.5%)	92	274.71	1	0.000
	Not trained	11(4%)	265(96%)	276			
Enough access to collectors	Enough access	41(32.6%)	85(67.4%)	126	4.524	1	0.033
	Not enough access	54(22.4%)	188(77.6%)	242			
Aware of the government's regulations and enforcement	Yes	25(39.1%)	39(60.9%)	64	7.099	1	0.080
	No	70(23.1%)	234(76.9%)	304			
Access to the disposal site	There is access	54(38.3%)	87(61.7%)	141	18.598	1	0.000
	No access	41(18.1%)	186(81.9%)	227			

environment and human health, a substantial proportion did not perceive it as posing serious risks. This knowledge gap is concerning, as studies from Kenya (8), Uganda (19), and India (20) have shown that underestimating e-waste hazards contributes to unsafe disposal behaviors.

In contrast, evidence from India suggests that sustained public campaigns have improved awareness of e-waste hazards (20). The lower awareness observed in this study likely reflects the lack of targeted information campaigns and formal training in the Addis Ketema sub-city. Expanding structured training opportunities, such as mandatory workplace training on hazardous materials, could improve awareness and influence behavior. Integrating e-waste content into broader environmental education initiatives, as recommended by the WHO (14), may also be effective.

### Causes of Poor E-Waste Management

Carelessness, weak law enforcement, lack of responsibility, and poor awareness were identified as major contributors to poor e-waste management. These factors are consistent with the findings from other African contexts, such as Kenya (8), Zimbabwe (29), and Tanzania (30), where fragmented legislation and enforcement gaps hinder effective e-waste management. In contrast, Zangpo et al. (31) reported widespread access to e-waste information in Bhutan, highlighting how information availability can improve management outcomes.

The lack of public access to e-waste information in Addis Ketema reflects institutional gaps in environmental governance. Nuwematsiko et al. (19) similarly reported that low public awareness of legal obligations undermines environmental compliance in many developing countries.

**Table 5.** Parameter estimates of the binary logistic regression model for attitude towards e-waste management.

Attitude Categories	Categories	Estimate	S. E	Wald	Df	P-value	OR	95% C.I for OR	
								Lower	Upper
Educational level	Illiterate	-2.347	0.922	4.820	1	0.722	0.096	0.052	3.723
	Certificate	-1.573	0.607	6.717	1	0.010*	0.208	0.063	0.682
	Diploma	0.230	0.574	0.161	1	0.689	1.259	0.409	3.875
	Degree	0.540	0.564	0.919	1	0.338	1.717	0.569	5.181
	Masters and above	— — — — — 1.00 — —							
Work experience	1-3 years	1.099	0.456	5.807	1	0.016*	3.002	1.228	7.339
	4-6 years	0.301	0.386	0.611	1	0.435	1.352	0.635	2.878
	> 7 years	— — — — — 1.00 — —							
Distance from the road		-0.018	0.007	6.204	1	0.013*	0.982	0.969	0.996
Aware of government regulations and enforcement	Not aware	-0.443	0.456	0.945	1	0.331	0.642	0.263	1.569
	Aware	— — — — — 1.00 — —							
Access to the disposal site	No access	-0.998	0.340	8.614	1	0.003*	0.369	0.189	0.718
	Access	— — — — — 1.00 — —							
Training status	Not trained	-3.041	0.789	14.856	1	0.000*	0.048	0.010	0.224
	Trained	— — — — — 1.00 — —							
Constant		4.948	0.933	28.14	1	0.000	140.96		

\*Note: Bolded rows indicate reference category with OR= 1.00. Dashes (—) indicate not applicable for reference categories. OR=Odds Ratio; CI = Confidence Interval.\* Significant at  $P < 0.05$ .

**Table 6.** Cross-tabulation of levels of practice towards e-waste management with predictor variables.

Variables	Category	Practice towards E-waste management		Total	Chi-square	Df	P-value
		Good	Poor				
Gender	Female	4(2.6%)	153(97.4%)	157	17.891	1	0.000
	Male	34(16.2%)	177(83.8%)	211			
Educational level	Illiterate	0(0%)	2(100%)	2	34.989	4	0.000
	Certificate	0(0%)	61(100%)	61			
	Diploma	15(17.9%)	69(82.1%)	84			
	Degree	6(4%)	147(96%)	153			
	Masters and above	17(25%)	51(75%)	68			
Work experience (Year)	1-3	18(16.6%)	98(84.4%)	116	6.158	2	0.046
	4-6	16(9.5%)	154(90.5%)	170			
	> 7	4(4.9%)	78(95.1%)	82			
Training on EWM	Trained	21(22.9%)	71(77.1%)	92	20.699	1	0.000
	Not trained	17(6.2%)	259(93.8%)	276			
Enough access to collectors	Enough access	28(22.3%)	98(77.7%)	126	29.283	1	0.000
	Not enough access	10(4.2%)	232(95.8%)	242			
Aware of governments' regulation and enforcement	Yes	11(35.9%)	41(64%)	64	8.344	1	0.040
	No	25(8.3%)	279(91.7%)	304			
Access to the disposal site	There is access	11(7.9%)	130(92.1%)	141	1.573	1	0.210

These findings emphasize that improving enforcement alone is insufficient; comprehensive regulatory frameworks must be combined with public education, accessible collection systems, and clearly defined institutional responsibilities.

### *E-Waste Management Practices of the Woreda Offices*

Employees commonly reported storing obsolete

electronics or selling them informally, while some resorted to open burning or dumping them into rivers once storage space became unavailable. Similar practices have been documented in other low- and middle-income countries (8,32,33). By contrast, countries in Europe have developed advanced formal collection and recycling systems (34), which reduce reliance on unsafe informal practices. The absence of designated collection points

**Table 7.** Parameter estimates of the binary logistic regression model for the practice of e-waste management

Practice Categories	Categories	Estimate	S. E	Wald	Df	P-value	OR	95% C.I for OR	
								Lower	Upper
Gender	Female	-1.626	0.601	7.307	1	0.007*	0.197	0.061	0.640
	Male	1.00							
Educational level	Illiterate	-2.215	1.122	3.930	1	0.492	0.109	0.072	0.318
	Certificate	-3.443	6.515	12.35	1	0.296	0.032	0.009	0.250
	Diploma	-0.469	0.578	0.659	1	0.417	0.625	0.202	1.941
	Degree	-1.595	0.598	7.111	1	0.008*	0.203	0.063	0.655
	Masters and above	1.00							
Work experience	1-3 years	-0.394	0.741	0.283	1	0.594	0.674	0.158	2.879
	4-6 years	-0.251	0.749	0.112	1	0.738	0.778	0.179	3.377
	>7 years	1.00							
Distance from the main road		-0.002	0.015	0.014	1	0.905	0.998	0.970	1.027
Access to e-waste collectors	No access	-2.118	0.535	15.67	1	0.000*	0.120	0.042	0.343
	Access	1.00							
Aware of government regulations and enforcement	Not aware	-0.551	0.482	1.307	1	0.253	0.576	0.224	1.483
	Aware	1.00							
Access to the disposal site	No access	-1.335	0.498	7.184	1	0.007*	0.263	0.099	0.698
	Access	1.00							
Training status	Not trained	-6.907	0.843	67.084	1	0.000*	0.001	0.000	0.005
	Trained	1.00							
Constant		0.978	0.870	1.263	1	0.261	2.658		

\*Note: Bolded rows indicate reference category with OR = 1.00. Dashes (—) indicate not applicable for reference categories. OR = Odds Ratio; CI = Confidence Interval.\*  
Significant at  $P < 0.05$

**Table 8.** Heavy metal concentrations in PCBs (mg/kg)

Metals	Mean $\pm$ SD	TTLIC (mg/kg)
Mn	120.72 $\pm$ 2.19	N.M
Cd	0.1 $\pm$ 0.09	100
Pb	5821.08 $\pm$ 11.29	1000
Ni	1620.11 $\pm$ 6.15	2000
Cu	78402.44 $\pm$ 13.44	2500

\*N.M.: Not mentioned; TTLIC source: California Code of Regulations, Title 22, Chapter 11, Article 3.

in Addis Ketema, combined with minimal engagement from formal recyclers, contributes to uncontrolled disposal. Establishing localized collection centers and implementing take-back schemes, approaches shown to be effective in South Africa (35), could reduce unsafe disposal and encourage recycling.

### Challenges of E-Waste Management

Key challenges identified in this study include the absence of e-waste-specific legislation, limited recycling infrastructure, and the influx of second-hand electronic equipment. Baldé et al. (11) and Mishra et al. (9) noted that countries without national e-waste policies often treat e-waste as general waste, allowing hazardous components to enter municipal waste streams. Consistently, most

employees in this study were unaware of any legal framework and perceived enforcement as weak. As Forti et al. (2) and Baldé et al. (26) reported, the influx of second-hand electronics from high-income countries contributes to the rapid accumulation of obsolete devices in many African nations, overwhelming existing waste systems. Ethiopia faces similar pressures. Introducing national e-waste regulations, enforcing licensing requirements for second-hand electronics importers, and investing in local recycling infrastructure are essential to mitigate this growing burden.

### Heavy Metal Concentrations in Printed Circuit Boards

This study found that concentrations of Cu and Pb in discarded PCBs exceeded the Toxicity Threshold Limit Concentration (TTLIC), indicating significant environmental and health risks. Copper is present in large quantities due to its role in wiring and circuits (36,37), while Pb is commonly used in solder and glass components (33). Informal handling and open burning of PCBs can release toxic metal particles and fumes, which may contaminate nearby soil, air, and groundwater (3,14,38).

In Addis Ketema, such contamination poses particular risks as polluted soils can transfer heavy metals into crops grown on urban farmland, while leachate from open

dumpsites may infiltrate groundwater used for domestic purposes. Lead exposure is associated with neurotoxicity, kidney and liver damage, reproductive impairment, and developmental disorders in children (17,14). Copper, while essential in trace amounts, can cause mucosal irritation, liver and kidney dysfunction, and neurological symptoms when present in excessive concentrations (12,17). These findings highlight the urgent need to establish controlled collection systems, safe dismantling processes, and occupational safety measures for workers handling e-waste in Ethiopia.

### **Strengths and Limitations of This Study**

This study contributes to the limited empirical evidence on e-waste awareness, management practices, and heavy metal content in Ethiopia. It combined employee survey data with laboratory analysis of PCBs, providing a comprehensive overview. However, the study was confined to government offices within a single sub-city, which may limit generalizability. Self-reported data on disposal practices may also be affected by social desirability bias. Future research should include private sector institutions and directly observe disposal behaviors to complement self-reported information.

### **Conclusion**

This study identified low awareness, inadequate infrastructure, weak policy enforcement, and unsafe disposal practices as major challenges in managing e-waste in Addis Ketema sub-city. Employees lacked training and information on e-waste, while discarded PCBs contained hazardous concentrations of copper and lead, posing serious environmental and public health risks. To address these challenges, Ethiopia should adopt and enforce comprehensive e-waste legislation, strengthen institutional capacity for monitoring and enforcement, expand formal collection and recycling systems, and implement workplace training and public awareness programs. Without urgent action, the growing volume of e-waste will continue to contribute to environmental contamination and impose escalating health and economic burdens.

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### **Authors' contributions**

Data curation: Fate Kedir, Samuel Bekele  
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### **Competing interests**

There are no conflicts of interest associated with this publication.

### **Ethical issues**

The practical part of this work was carried out with the assistance of workers from the Addis Ketema Sub-city, after approval of the mission issued by the Sub-city's manager. No animals were used in this study.

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### **Supplementary files**

Supplementary file 1 contains Tables S1-S3.

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