MAKERERE UNIVERSITY

QUANTIFICATION OF ELECTRONIC/ELECTRIC WASTE AND THE ASSOCIATED ENVIRONMENTAL RISKS: A CASE OF KAMPALA CITY

BY

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DECLARATION

This dissertation is original and has not been submitted for any other degree award to any other University before.

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DEDICATION

This dissertation is dedicated to the Almighty God for his unwavering love for me. I also dedicate it to my dear wife Mrs. Grace Tukamwakira for standing with me through thick and thin.

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LIST OF ACRONYMS

AAS	Atomic Absorption Spectroscopy
ANOVA	Analysis of Variance
BFR	Brominated Flame Retardant
Cd	Cadmium
CD	Compact Disc
Cr	Chromium
CRT	Cathode Ray Tube
Cu	Copper
DVD	Digital Versatile Disc
EEE	Electrical and Electronic Equipment
EPR	Extended Producer Responsibility
ICT	Information Communication Technology
IT	Information Technology
MCDM	Multiple criteria decision making
MP3	MPEG-1 Audio Layer 3
NEC	National Enterprises Corporation
NEMA	National Environment Management Authority
Ni	Nickel
NITA-U	National Information Technology Authority - Uganda
PAHs	Polycyclic Aromatic Hydrocarbons
Pb	Lead
PBDEs	Polybrominated Diphenyl Ethers
PCA	Principal Component Analysis
PCBs	Polychlorinated biphenyls

PCs	Personal Computers
POPs	Persistent Organic Pollutants
PPP	Public Private Partnership
RAI	Risk Awareness Indicator
SIRA	Systematic Integrity Risk Assessment
TODIM	(Portuguese Acronym means) Interactive and multi-criteria decision making
TV	Television
UBOS	Uganda Bureau of Statistics
UCC	Uganda Communications Commission
UNBS	Uganda National Bureau of Standards
UNIDO	United Nations Industrial Development Organisation
VCR	Video Cassette Recorder
WEEE	Waste from Electrical and Electronic Equipment

ABSTRACT

The rapid increase in e-waste has become a critical environmental and public health concern in Uganda. According to NITA-U, 2020, e-waste management systems in Uganda remain inadequate, leading to improper disposal and recycling practices that worsen environmental pollution and health risks. This study investigated the quantification of e-waste and the associated environmental risks in Kampala City. Specifically, the study aimed at; characterizing the e-waste generated, determining its rate of generation, and assessing the environmental risks associated with e-waste management practices in Kampala. A mixed-methods research design was employed. Primary data was collected in two ways. The first part involved the survey method in the five divisions of Kampala: Central, Rubaga, Nakawa, Rubaga, Makindye, and Kawempe. The second part of the primary data involved collecting soil samples from areas deemed to be highly contaminated such as Kalerwe/Bwaise, Kisenyi, and Usafi market. Secondary data was obtained from the Uganda Bureau of Statistics (UBOS) between 1995 and 2020, a period of 25 years. This study used exploratory data analysis particularly, bar charts to visually analyze the classification of e-waste generated by households, businesses, and institutions. The study employed a multiple linear regression model to quantify the e-waste while the multinomial logistic regression was utilized to determine the environmental risks associated with e-waste management practices in Kampala. Results indicated that the e-waste generated in Kampala City predominantly consists of mobile phones (including smart and simple phones), followed by TV and media devices (such as DVD players, VCRs, MP3, and CD players), computers (including cameras, printers, and desktop computers), water heating equipment (such as kettles and percolators), cooking and lighting equipment (such as cookers, gas cylinders, and bulbs), refrigerators and washing machines (including microwaves and air conditioning units), and other miscellaneous items. Consumers were the primary generators followed by collectors, recyclers, manufacturers, and importers. Over the 25 years, the regression model revealed that 75 metric tons were generated in Kampala city, and other factors held constant. Among the classifications of e-waste, temperature exchange equipment, screens/monitors, large equipment (excluding photo equipment), and small equipment significantly predicted growth in the total quantities of e-waste generated. Soil samples from three Kampala areas show significant lead contamination, at Usafi Market, the lead concentration is 2.7 mg/kg, at Kisenyi it is 1.8 mg/kg, and at Kalerwe it is 7.4 mg/kg indicating that Kalerwe poses environmental risk 3 times that of Usafi market and 4 times that of Kisenyi market. This poses serious environmental and health risks, including neurological damage, developmental issues, and water contamination, indicating a potential threat to public health. Findings from this study revealed that Kalerwe is a critical hotspot for lead contamination, necessitating urgent interventions to mitigate environmental risks. Therefore, targeted restoration efforts, stricter environmental monitoring, and public awareness campaigns should be prioritized in Kalerwe to reduce lead exposure and safeguard public health.

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Globally, electronic waste (e-waste) is a major contributor to organic and heavy metal pollutants in municipal solid waste (Chi et al., 2011; Geeraerts et al., 2016). With an annual growth rate of 3–5%, e-waste is one of the fastest-growing waste streams worldwide (Cucchiella et al., 2015). In 2019, approximately 53.9 million metric tons of e-waste were generated globally, estimated at 82.6% likely to be discarded, traded, or unofficially recycled (Forti et al., 2020). According to the global e-waste monitor report of 2024, 62 million metric tons of e-waste were generated globally in the year 2022. This is a 15% increase in the e-waste generated between 2019 and 2022. According to the global e-waste monitor report of 2024, only 22.3% of this e-waste was formally documented as being collected and recycled in an environmentally sound manner (Baldé et al., 2024). Therefore, the continued consumer demand for electrical and electronic equipment (EEE) coupled with rapid technological advances has led to an increased generation of e-waste worldwide (Vishwakarma et al., 2023).

E-waste contains hazardous constituents that can negatively impact the environment and human health if not properly managed (Jain et al., 2023b). It is one of the most hazardous wastes on the globe, with chemicals such as lead, mercury, and cadmium that can harm living things and pollute air, water, and soil (Kalambe et al., 2023). E-waste also contains toxic materials, including heavy metals, which have adverse effects on plants, microbes, animals, and humans (Saha et al., 2021). E-waste contains hazardous pollutants like organic compounds and heavy metals that pose environmental and health risks. Persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and polycyclic aromatic hydrocarbons (PAHs) are common, along with heavy metals like cadmium (Cd), lead (Pb), chromium (Cr), and copper (Cu) frequently found in contaminated soils and dust from recycling areas He et al. (2017), Tang et al. (2010), Liu et al. (2013).

The above pollutants, often originating from crude e-waste recycling, highlight the urgent need for remediation efforts. Also, the COVID-19 pandemic further highlighted the need for proper management of e-waste, as the switch to remote work increased the purchase of electronic gadgets that may cause harm if not managed properly (Menon et al., 2023). In this regard, effective strategies and policies are necessary to regulate and manage e-waste generation and ensure sustainable recovery of valuable materials.

Despite the global scale of this issue, sub-Saharan African countries, experiencing rapid economic growth, witness a surge in electrical and electronic equipment (EEE) usage, resulting in a corresponding increase in local e-waste generation (Asante et al., 2019). Most of the previous studies indicate that the generation of e-waste in sub-Saharan Africa has severe environmental impacts.

According to Moyen Massa and Archodoulaki (2023), improper waste management in developing countries leads to environmental pollution and human illness (Moyen Massa and Archodoulaki, 2023). In light of this, Orisakwe et al. (2019) added that informal e-waste recycling exposes people to highly toxic heavy metals and chemicals, resulting in health risks. Tetteh and Lengel (2017) maintained that the lack of structures and regulations to manage e-waste in the sub-Saharan region exacerbates the crisis.

Asante et al. (2019) indicated that the inadequate infrastructure and non-enforcement of laws contribute to the release of hazardous substances during crude e-waste recycling. West African countries, in particular, face challenges in regulating and governing e-waste, which goes beyond environmental and health risks (Adejonwo-Osho, 2016). Despite these challenges, there are opportunities for precious metal recovery, employment, and economic benefits if e-waste is properly managed. It is therefore very crucial to raise awareness, implement proper strategies, and involve stakeholders to improve e-waste management in sub-Saharan Africa.

In countries like Uganda, the lack of appropriate treatment facilities and legislation has left the e-waste recycling sector largely unregulated (Tsydenova & Bengtsson, 2011). The Global E-waste Monitor Report 2020 estimated Uganda's e-waste at 17,000 tons in 2018, projecting an annual increase to 4,500 tons from end-user ICT devices (UCC, 2018). Formal collection and recycling efforts of e-waste in Africa are documented to be as low as 1% (Forti et al., 2020).

On 10th June, 2021, Uganda took a step towards addressing this challenge with the launch of its first E-waste Management center, a joint initiative by the National Environment Management Authority (NEMA) and the National Enterprise Corporation (NEC) (NEMA, 2021). However, the facility is still under construction. The e-waste generation in Uganda is a significant concern for sustainable waste management with various infrastructure taking place.

The role of various stakeholders in E-waste management sustainability has been evaluated, including E-waste handlers, financial institutions, local government, media, and producers (Juma et al., 2022). The study found that these stakeholders have a significant influence on E-waste management sustainability (Nuwematsiko et al., 2021, Shanti, 2018, Jain et al., 2023a, Juma et al., 2022). However, the role of consumers in E-waste management was found to be insignificant (Kilama et al., 2019). A previous study recommended strengthening Public-Private Partnerships (PPP), implementing the Extended Producer Responsibility (EPR) model, and initiating E-waste Web-based applications as policy recommendations for sound e-waste management practices (Nagawa, 2022). Furthermore, some studies highlight the importance of increasing awareness and knowledge among electronic consumers in Kampala, Uganda, regarding proper E-waste management to prevent its negative effects on health and the environment (Nuwematsiko et al., 2021). Informal sectors play a crucial role in managing e-waste in developing countries, where documented formal collection and recycling efforts are limited (Leigh et al., 2007; Mueller et al., 2008; Widmer et al., 2005).

The hazardous components of e-waste demand specialized techniques and improper disposal poses risks to both the environment and public health. The hazardous materials, including lead, zinc, nickel, barium, and chromium found in electronic products, have prompted regulatory measures, such as a ban on the importation of vehicles older than fifteen years in Uganda (NTV, 2018). However, the negative externalities persist. To address these challenges, this study utilized historical data on the e-waste generated from the Uganda Bureau of Statistics (UBOS) to perform a quantitative analysis of the rate of e-waste generation, common types of disposed e-waste, and associated environmental risks in Kampala.

E-waste in Uganda is a pressing issue due to its hazardous nature and increasing production, containing elements harmful to living organisms and ecosystems (Shanti, 2018). It is therefore believed that performing a study that quantifies the amount of e-waste generated and assessing the environmental risks associated with this generation would be a step in the formulation of stringent regulations and better management strategies to mitigate the environmental impacts of e-waste (Jain et al., 2023). The proper management of e-waste is crucial for human health and environmental sustainability, emphasizing the need for stringent regulations and international cooperation to address this complex issue (Akram et al., 2019).

1.2 Statement of the Problem

Electronic waste (e-waste) is a major source of heavy metal pollutants within municipal solid waste streams worldwide, contributing to significant environmental and health challenges (Chi et al., 2011; Geeraerts et al., 2016). With an annual growth rate of 3–5%, e-waste is one of the fastest-expanding waste categories globally, with 62 million metric tons generated as of 2022 which is up by 15% from 2019 (Cucchiella et al., 2015; Forti et al., 2020; Baldé et al., 2024).

Alarmingly, only 22.3% of this waste is formally documented as environmentally soundly recycled, leaving high-value materials like gold, silver, copper, and platinum, worth an estimated $57 billion, uncollected and mismanaged (Forti et al., 2020; Zhongming et al., 2020).

In Uganda, the Global E-waste Monitor (2020) estimated that 17,000 tons of e-waste were generated in 2019. Despite this figure, there is limited data on the specific quantities of e-waste generated by households/businesses, institutions, and government sectors, or the pathways through which this waste impacts the environment. Existing studies focus on global and regional trends, leaving gaps in local-level data and risk assessments, particularly in developing countries like Uganda (MoICT, 2012). Moreover, the rising sales of e-waste equipment in Uganda amplify the need for localized data to inform sustainable management policies.

This study addresses these gaps by quantifying the amounts of e-waste generated in Kampala and assessing its associated environmental risks. By providing a detailed analysis of e-waste streams and their environmental implications, the research contributes to the growing body of knowledge on sustainable waste management in Uganda, offering critical data for policymakers and stakeholders to mitigate risks and maximize resource recovery.

1.3 Objective of the Study

The main objective of the study was to quantify e-waste and the associated environmental risks in Kampala City.

1.4 Specific Objectives

The specific objectives of this study are:

- i). To categorize/classify the e-waste generated in Kampala city.
- ii). To determine the quantity of e-waste generated in Kampala city.
- iii). To determine the environmental risks associated with e-waste management practices in Kampala.

1.5 Research Questions

The following are the study research questions:

i). What are the categories/classes of e-waste materials generated in Kampala City?
ii). What is the quantity of e-waste generated in Kampala; and what are the trends and variations over time?
iii). What environmental risks are associated with current e-waste management practices and do these practices contribute to potential adverse impacts on the environment?

1.6 Scope of the Study

The study considered quantities of e-waste generated in Kampala City and how it impacts the environment. To investigate the impact of the quantities of e-waste on the environment, the quantities of e-waste accumulating in Kampala were determined. The study was supplemented by analyses of soil samples in areas deemed to have high e-waste activities such as Kalerwe/Bwaise, Kisenyi, and Usafi market/Katwe.

1.7 Significance of the Study

In Uganda, almost every household or business uses and owns products like basic kitchen appliances, toys, musical instruments, and ICT items, such as mobile phones, laptops, etc. As a result, e-waste from household items, accidents dumped cars, used-up electrical devices and electronic components have highly surged up creating risks to the environment as well as to humans. Therefore, the quantification of e-waste generated contributes to estimating the magnitude of challenges relating to e-waste, setting appropriate collection and recycling targets, establishing priorities for policymakers, influencing regulations on e-waste, setting policy targets, and allocating adequate financial resources.

The findings from this study provide much-needed information for Uganda's First National E-waste Management Facility, which was recently opened at Luwero Industries. This facility was officially opened on June 10, 2021, in the presence of representatives from UNBS, UCC, NITA-U, the Ministry of Information, Communications and Technology, and other stakeholders. It supports policymakers about the effect of the Ugandan government's recent ban on the importation of vehicles that are more than 15 years old effective July 1, 2018, in a bid to reduce pollution and lessen pressure on the ecosystem. Finally, the study was a springboard to enable the researcher to attain a degree of master of science in Civil Engineering at Makerere University.

1.8 Justification of the Study

Importing and using e-waste without oversight poses several environmental and health hazards. First, there are environmental difficulties such as groundwater contamination, air pollution, and even water pollution caused by immediate discharge or surface water runoff, which are typical in Kampala's mountainous terrain. Second, workers directly involved in waste processing face occupational health risks and catastrophic health consequences. Thousands of young men and women, as well as the elderly, in Uganda, are exposed to e-waste, which can cause lead and other harmful metals to be absorbed into their bodies/blood by inhalation.

1.9 Conceptual Framework

Based on the conceptual framework (Figure 1), this study examined the various components of electronic waste (e-waste), the primary sources and types of e-waste, and their environmental effects as independent variables. The management of e-waste, particularly in the context of Uganda where technology for such management is underdeveloped, acts represented the moderating variable.

The dependent variable in this model comprises the quantities of e-waste and its associated environmental risks. By analyzing the independent variables (sources, types, and the environmental effects of e-waste) and considering the moderating variables (e-waste management practices), the study led to a comprehensive understanding of the potential solutions relating to e-waste, quantities, and their associated environmental risks in Kampala City of Uganda.

In addition, using secondary data from UBOS, a linear function model helped to estimate the quantity of e-waste based on the various categories of e-waste generated in Uganda. This was meant to estimate and determine which of these e-wastes categorized as temperature exchange equipment, screens, monitors, lamps, large equipment, photovoltaic panels, small equipment, small IT and telecommunications equipment significantly predict total e-waste generated.

Furthermore, data from the soil sampling enabled to extraction of physical metal samples from the ground with the aid of the soil auger. This metals such as Lead, Mercury, and Nickel helped in estimating the Multinomial logistic regression which is accompanied by the relative risk ratios (RRR) for determining the levels of risks associated with each metal and what factors exacerbate it. Besides this, the study estimated the Kaplan Meier curve to show the likelihood of existence of the sampled soils given the levels of contamination.

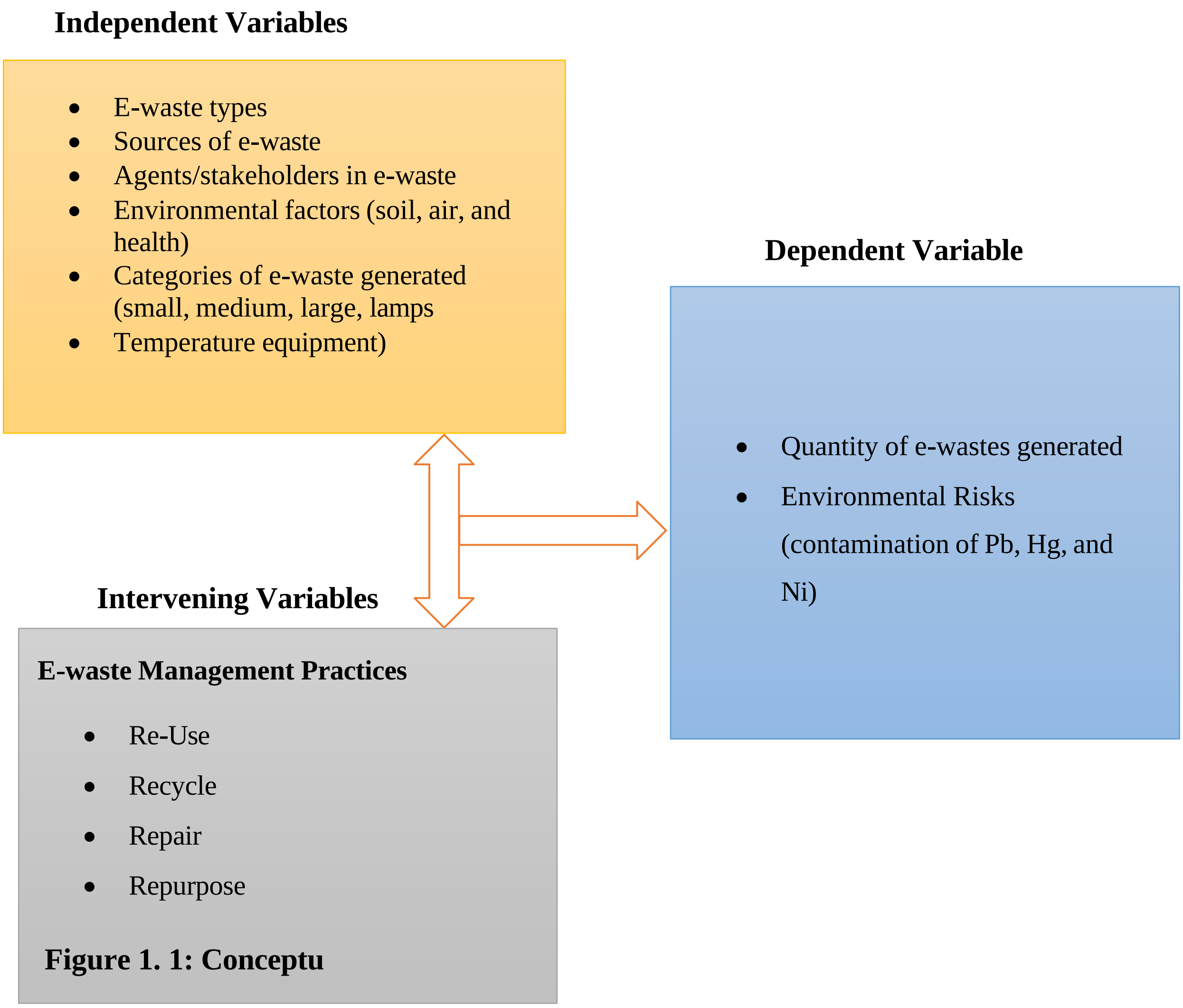

Figure 1: Conceptual framework of the study

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The main purpose of this study was to quantity electronic/electric waste and the associated environmental risks in Kampala City. This chapter presents the literature review starting with the theoretical literature which underpins the race-to-the-bottom theory, and the pollution haven theory. Secondly, the chapter provides the empirical/actual studies based on the study objectives starting with the categories and characteristics of e-waste as well as the studies on environmental risks from disposal of e-waste.

2.2 E-Waste and its Management

E-waste comprises discarded electronic appliances, of which computers and mobile telephones are disproportionately abundant because of their short lifespan. E-waste encompasses a wide range of electronic and electrical products, including obsolete or discarded computers, mobile phones, appliances, and various electronic gadgets. These items are classified into various categories, including but not limited to consumer electronics, office equipment, and industrial machinery. The improper disposal and management of e-waste can lead to several environmental effects, which include soil contamination, water pollution, air pollution, ecosystem disruption, resource depletion, and greenhouse gas emissions, among others.

In the context of this study, the management of e-waste plays a crucial moderating role. It involves various techniques and practices, from collection and segregation to recycling and disposal. Typically, when waste products are collected from residents in the city, they undergo a sorting process where e-waste is separated. Recyclable components are then extracted and sold in the market by the municipal authority. The remaining e-waste is further processed, including crushing it into small pieces, typically ranging from 2 cm to 6 cm in size.

2.3 Theories of E-waste

The underlying assumption of the current analysis of the e-waste problem is that the trade-in e-waste is primarily from developed to developing countries and that this causes the immensity of the problem. However, it has to be noted that, even without the trade, countries like China produce huge amounts of e-waste domestically. The theories outlined below provide the basis and underlying assumptions of this research work. They also facilitate a better understanding of the problem.

2.3.1 Race-to-the-Bottom Theory of E-waste

The race-to-the-bottom hypothesis is a common critique of globalization. It stipulates that increased competition for trade and foreign direct investment could lead to the lowering of environmental and labor standards and regulations, thus causing e-waste (Medalla and Lazaro, 2005). However, there are complexities and exceptions within this general theory, as some states decide to enforce stringent laws as they view them as improving quality of life and not necessarily being an obstacle to economic development. Also, companies moving production from developed to developing countries sometimes bring advanced environmental and labor practices with them (Konisky, 2007).

2.3.2 Pollution Haven Theory of E-waste

This is directly linked to the “race-to-the-bottom” theory but specifically regards environmental law and standards. It states that pollution-intensive economic activity will tend to migrate to those jurisdictions where costs related to environmental regulation are lowest (Lepawsky & McNabb, 2010). This theory overlaps with globalization and north-south issues, the debate over the disparate implications for the developed and developing countries, and whether globalization will lead to “industrial flight” from the north and the growth of “pollution havens” in the south (Medalla and Lazaro, 2005).

2.3.3 Distancing Theory of E-waste

Contemporary consumers are geographically more distant from their waste than in the past. This is exacerbated by consumer culture, waste habits, disposability of products, and denial (Hawkins, 2006). Most consumers, therefore, are no longer connected to the environmental meaning of their consumption (Bekin et al., 2007). About electronics, waste is often both produced and disposed of in developing countries, extending the distance from consumers in developed countries, and consumer information is lacking. It has been remarked that, as a result, the consumer will make decisions that will perpetuate the generation of waste (Vasudev and Parthasarathy, 2007).

2.4 E-waste Characteristics and Quantities

2.4.1 Categories and Characterization of E-waste

E-waste can be categorized based on its content and characteristics. Different studies have characterized e-waste to understand its composition and potential for recycling. One study analyzed printed circuit boards and screens from old mobile phones, smartphones, and laptops, and identified heavy metals such as Cu, Fe, Zn, Ni, Pb, and Al as the main components, along with precious metals like Nd, Ag, and Au, and rare earth elements like Pt, La, Dy, Pr, and Ce (Tunali et al., 2021). Another research focused on the most-cited articles on e-waste and found that the research content could be classified into four types: characteristic-and-property, environment-and-health, management-and-economic, and technique-and-processing (Chen et al., 2021).

A study conducted in Sao Paulo, Brazil, characterized the domestic flow of e-waste and described the stages of product acquisition, out-of-use storage, and end-of-life destination, providing insights for waste management policies (Rodrigues et al., 2020). Additionally, a paper analyzed e-waste using various analytical techniques and thermodynamic studies, highlighting the potential for recovering valuable metals like silver, gold, platinum, copper, zinc, nickel, tin, and others (López et al., 2016).

Akram et al. (2019b) showed that the common categories of e-waste materials, include ferrous/non-ferrous metals, plastics, glass, printed circuit boards, and valuable metals, as well as the release of toxic elements and the need for proper management and recycling strategies (Akram et al., 2019a). While more and more end-of-life electronics have been collected and treated by formal or licensed recyclers in China, many of them only have dismantling and separation activities. Hazardous e-wastes, including those from PCBs, CRT glass, and brominated flame retardant (BFR) plastics, have become problematic and probably flow to small or backyard recyclers without environmentally sound management (Duan et al., 2015).

With regard the e-waste categorization, Vaishnav and Diwan (2013) stated that personal computers (PCs) contain certain components, which are highly toxic, such as chlorinated and brominate substances, toxic gases, toxic metals, biologically active materials, acids, plastics, and plastic additives. The hazardous content of these materials poses an environmental and health threat.

2.4.2 E-waste Generation Rates

A range of studies have provided estimates of e-waste generation rates. Singh (2018) found that Chandigarh, India generated 3.1 kg of e-waste per capita annually, with a projected increase to 9565.1 tons per annum by 2020 (Singh et al., 2018). This is consistent with the global trend identified by Forti (2020), who reported a 53.6 Mt generation in 2019, projected to reach 74.7 Mt by 2030 (Forti et al., 2020). Islam (2019) estimated that Australia's e-waste generation would grow by 3% annually, with a focus on large and small household appliances and consumer equipment (Islam and Huda, 2019). Roychoudhuri (2018) proposed a lifecycle-based model for predicting e-waste generation, highlighting the need for more accurate methodologies.

The current global production of E-waste is estimated to be 20-25 million tons per year, with most E-waste being produced in Europe, the United States and Australasia. China, Eastern Europe and Latin America will become major E-waste producers in the next ten years (Robinson, 2009). Globally, approximately 53.6 million tons of e-waste was generated in 2019. Of this amount generated, less than 13% was recycled and the rest ended up in landfills or incinerators creating enormous environmental and health concerns due to the presence of hazardous materials (Andeobu et al., 2021).

The problem of e-waste disposal is a very well-known fact, and its generation is increasing exponentially every year. In 2015, 54 million tons of e-waste was generated, whereas it has been predicted that around 50 million tons of e-waste will be generated worldwide by 2018, by the UN report. Another source predicts that e-waste generation will be 72 million tons by 2017 (Roychoudhuri et al., 2018). These studies collectively underscore the urgent need for effective e-waste management strategies due to the large influx of e-waste generated globally, regionally and nationally.

2.4.3 Environmental Risks Associated with E- waste Management Practices

Ajeet (2012) highlights that “e-waste is going to become a great challenge for environmentalists and technologists as the rate of growth is much higher than the rate it is disposed of, reused or recycled”. He further emphasizes that there is an urgent need for improvement in e-waste management covering technological improvement, operation plan, implementing a protective protocol for the workers working in e-waste disposal, and educating the public about this emerging issue posing a threat to the environment as well as public health (Ajeet, 2012).

Shubham, Gaurav, Rahul, and Vijaya (2014) argued that “E-waste, if not managed properly, can have very fatal effects on the environment as well as the living beings in the vicinity.” They added that for profitable recovery of materials and a sustainable environment, the efficient recycling of electronic waste is very necessary and is still regarded as a major challenge for today’s society (Shubham et al., 2014). According to Samarakoon (2014), end-of-life management of e-waste activities, such as reuse, servicing, remanufacturing, recycling, and disposal, upstream reduction of e-waste generation through green design and cleaner production be introduced to enhance a sustainable e-waste management system for Sri Lanka (Samarakoon, 2014).

According to Arun and Gunasekaran (2018), electronic waste or e-waste is one of the rapidly growing problems of the world. It comprises a multitude of components, some containing toxic substances that can harm human health and the environment if not handled properly. In India, e-waste management assumes a greater significance not only due to the generation of its e-waste but also because of the dumping of e-waste from developed countries. By developing eco-design devices and collecting e-waste and safe handling, the disposal can bring about a clean environment (Arun and Gunasekaran, 2018).

Maheshwar and Mittal (2012), critically examined the environmental and social benefits of reuse that would result through systematic interventions in the existing Waste from Electrical and Electronic Equipment (WEEE) trade chain in India. The study used a Markov chain model to analyze the underlying relationship that exists within the reverse supply chain partners by quantitatively evaluating the performance measures of different policy scenarios. Results showed that prompt reselling of WEEE to other users can potentially go a long way in increasing their lifespan (Maheshwar and Mittal, 2012).

So far then, the research evidence indicates that there are substantial deficiencies in regulatory initiatives on worldwide trade, unlawful trafficking, and improper handling of e-waste. This has created attention of studies primarily focusing on linkages of improper handling and consequent health effects on workers in the developing countries. However, Ahsan, Mursheda, and Rafiq, (2015) suggested effective plans for collection, handling, disposal, and remedy of e-waste. An across-the-board review of available research and policy strategy is necessary to find a sustainable solution dealing with the global trafficking and trade of e-waste (Ahsan et al., 2015).

Insights from a decade of development cooperation in e-waste management revealed that, it is likely that the quantities of discarded electronics will increase substantially in the foreseeable future as a result of fast innovation cycles and increased market penetration of cheap electronics, the latter being the main driver of e-waste volumes in developing countries and countries in transition (Schluep et al., 2013). As illegal e-waste trade has been significantly growing throughout the last few years, the consequences on human health and the environment demand immediate action on the part of the global community (Efthymiou et al., 2016). Results from the study on quantifying the effect of macroeconomic and social factors on illegal e-waste trade showed that illegal e-waste trade occurs from economically and socially developed regions to countries with significantly lower levels of overall development, with few exceptions, which could be attributed to the fact that several countries have loose regulations on e-waste trade, thus deeming them attractive for potentially illegal activities (Efthymiou et al., 2016).

In India, the dumping of e-waste, particularly computer waste into India from developed countries has further aggravated the problem associated with waste management, and hence computer waste management is a major focus of this study. In regards to quantification, e-waste generation is estimated to be around 0.1–0.2%, of the municipal waste stream but the growing quantity of e-waste is beginning to reach disastrous proportions leading to the alarming situation from an environmental point of view (Mundada et al., 2004).

2.4.4 Determining Environmental Risks

Determining environmental risks involves a multifaceted approach that integrates various methodologies to assess and manage potential hazards. One significant aspect is the management of environmental risks in the financial sector, which encompasses evaluating the impacts of environmental concerns on financial risks, current practices, and measures to assess those risks within financial institutions. Studies have shown that financial institutions that commit to environmental responsibility can significantly reduce risks, driven by increased investor awareness and proactive environmental policies (Breitenstein et al., 2020).

Another critical area is the evaluation of methods for supporting failure risks analysis in eco-assessment, which involves identifying failures and analyzing their risks. This approach has highlighted the use of various methods such as simulations, failure mode and effect analysis (FMEA), and statistical methods to support risk analysis and life cycle assessment (LCA) for environmental impact calculations (Spreafico, 2021).

Furthermore, the assessment of environmental health risks involves systematic reviews and meta-analyses to summarize epidemiological evidence linking environmental factors to health outcomes. Major environmental risk factors identified include air pollution, environmental tobacco smoke, and exposure to chemicals, which are associated with various diseases and mortality (Rojas-Rueda et al., 2021).

Moreover, environmental risk assessment in urban environments emphasizes the importance of perceived risk, which often influences decision-making more than scientifically determined risk. This requires a multidisciplinary approach, incorporating social sciences and psychology, to address public perception and communication of risks (Fukushi, 2008). Table 1 presents a summary of previous studies documenting environmental risks and the methodologies used as well as key findings.

Table 1: Findings from Previous Studies on Environmental Risks

Author	**Title**	**Method Used in assessing risk**	**Findings**
Hameed et al. (2020)	Environmental risk assessment of E-waste in developing countries by using the modified SIRA method	Modified-Safety Improve Risk Assessment (Modified-SIRA) was used.	The study found that among various risks, air pollution from the e-waste recycling process is a severe hazard to the population of a developing country like Pakistan
Yigit et al. (2020)	Risk Assessment for sustainability in e-waste Recycling in circular Economy	Prospect theory-based TODIM method	There is a relationship between prospect theory and sustainability risk assessment
Pradhan and Sudhir (2014)	Informal e-waste recycling: environmental risk assessment of heavy metal contamination in Mandoli industrial area, Delhi, India	Environmental risk assessment was done by the multivariate statistical analysis such as the ANOVA, the principal component analysis (PCA), and the	Multivariate analysis and risk assessment studies based on total metal content reveal clear-cut differences among sampling sites and provide strong evidence of heavy metal pollution resulting from informal e-waste recycling.

Author	Title	Method Used in assessing risk	Findings
		multidimensional scaling	
Frazzoli et al. (2010)	Diagnostic health risk assessment of electronic waste on the general population in developing countries' scenarios	The diagnostic risk assessment matrix	The diagnostic risk assessment demonstrates how e-waste exposure poses an actual public health emergency
Duran and Bereketli Zafeirakopoulos (2019)	Environmental risk assessment of e-waste in reverse logistics systems using MCDM methods	The study employed the consistency ratio approach	Environmental risk assessment of e-waste in reverse logistics systems using MCDM methods
Appolloni et al. (2021)	Growing e-waste management risk awareness points towards new recycling scenarios: The view of the Big Four's youngest consultants	Risk Awareness Indicator	This work focuses on e-waste and the opinion of screenagers consultants, however, the methodology used to design the RAI index makes it easy to replicate the analysis in other social settings and other waste supply chains.

From the studies reviewed in Table 1, various techniques and methods have been employed to measure the environmental risks due to e-waste. These include the Modified-SIRA method and multivariate statistical analysis, which highlight severe hazards like air pollution and heavy metal contamination in developing countries, emphasizing critical public health threats. Techniques such as the prospect theory-based TODIM and the diagnostic risk assessment matrix show how decision-makers perceptions and structured assessments can enhance sustainability and emergency response strategies.

The consistency ratio approach in MCDM and the Risk Awareness Indicator (RAI) shows the complexity of managing e-waste in logistics systems and the importance of raising awareness among young consultants for improved recycling practices. Overall, the studies emphasize the necessity for comprehensive risk assessments from a more statistical point of view. This study employed the analysis of variance (ANOVA), the PCA, and the Kaplan-Meier estimate curve to show the probability of risk association with e-waste.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter of the study outlines the methodologies employed to quantify e-waste and its associated environmental risks in Kampala City. This chapter covers the description of the study area, the research methods and materials, the sampling procedures, the data collection methods, data collection tools, the process of soil sample extraction and procedure, the data analysis techniques, and the ethical consideration statement.

3.2 Research Design and Data Sources

This study employed a mixed research design. This design focused on incorporating both findings from the qualitative and quantitative data. Particularly, qualitative data was collected primarily from households/artisans, recyclers, and institutions. Additional primary data was collected using the Atomic Absorption Spectroscopy method by tilling highly contaminated areas of Kalerwe/Bwaise, Kisenyi, and Usafi markets with the aid of soil auger. On the other hand, secondary e-waste data was collected from the Uganda Bureau of Statistics from the years 1995 to 2020. This data was supplied in an Ms. Excel from the UBOS database, thus was presumed to be accurate.

3.3 Description of the Study Area

All the divisions that makeup Kampala were selected for primary data collection (Figure 2). Kalerwe Mambule through Bwaise was selected for soil extraction and collection due to car dismantling activities in the area. Kisenyi was also selected because it acts as a hub of plenty of old computer repair and dumping site. Lastly, the Usafi market along Katwe Road was also selected as a lucrative area for old printers and photocopiers around Kampala. Typically known for old car spares and wrecking activities. Human settlement in Kalerwe started in the 1970s around which time trade and other economic activities were thriving in the area. The name of the settlement, Kalerwe, came from the railway line that used to pass through a section of this settlement. Kalerwe is a densely populated suburb located in the northern part of Kampala. It is known for its bustling market and numerous informal e-waste recycling sites.

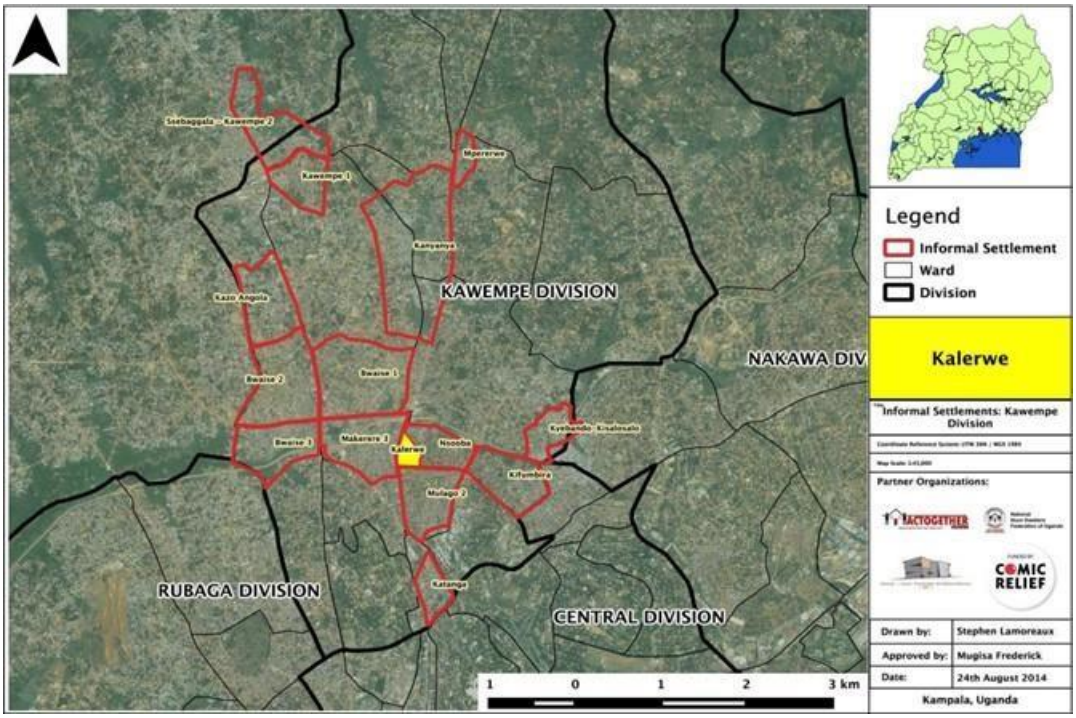

Figure 2: Map of the Study Area

Kalerwe is characterized by high traffic in both human and vehicle terms, making it a critical point for studying environmental hazards associated with improper e-waste disposal. It is also a designated area although not formal for wrecked and accident cars. These cars are taken there to be sold to old car dealers for spare, who in turn sell them to those interested in repairing them. These vehicles are transported there to be bought by vintage car dealers as spares and sold to individuals who want to fix them. The selection of this area was based on the abundance of scrap dealers and electronic parts as can be seen in Figure 3.

At Kalerwe, because the car dealers do not have a shredder and an automatic car wrecker, they use local hand axes to rip the damaged car apart and to separate spare parts for sale. For cars that cannot move completely, the car dealers use excavators or car cranes to move to destruction areas. To move out the heavy parts such as engines, gears, and other parts for a quick sale, they use ropes and timber logs which are lifted with the help of about four to five men. There are various kinds of electronic parts on every vehicle which are extracted and resold as scrap metal. Figure 4 shows a worker undertaking the process of car wrecking with the help of an axe.

Figure 3: Scrapyard of Old Vehicles in Kalerwe

Figure 4: Dismantling Process of Older and Accident Cars

3.4 Research Materials and Methods

The study utilizes both primary and secondary data sources. Primary data was collected through environmental sampling and questionnaires, while secondary data was gathered from existing records at the Uganda Bureau of Statistics and environmental reports from local agencies. The research materials included soil and water samples from selected sites, questionnaires for households and artisans, and various analytical instruments used for assessing contamination levels.

3.5 Sample Size Determination

Sampling was to ensure a representative sample for the collection of primary data, which was a crucial component of the mixed research design employed. While data from the Uganda Bureau of Statistics (UBOS) was utilized to complement the analysis, primary data collection provided insights directly from households and businesses generating e-waste. Sampling enabled the study to capture diverse perspectives, behaviors, and practices related to e-waste generation and management, ensuring that the findings were both reliable and representative of the population under study.

According to the 2024 National Population and Housing Census, the population of Kampala is 1,875,834 persons. According to UNIDO, about 4.2% of these individuals or households own electronic/electrical equipment contributing to e-waste. Therefore the estimated owners of e-waste in Kampala were 1,875,834×0.042 = 80000. Therefore, with the aid of the Taro Yamane sample size formula, using a 10% margin of error at a 90% confidence level, the sample size n was estimated as follows.

$$n = \frac{N}{1 + N * e^2} = \frac{80000}{1 + 80000 * (0.1)^2} = 99.87 \approx 100\ respondents \ldots\ldots\ldots\ldots \mathbf{3.1}$$

Based on this formula, 100 respondents represent the sample recognized as households.

In addition to households, artisans and institutions/recyclers were purposively selected as part of the sampling process. Purposive sampling was applied to target these groups because they play a significant role in e-waste management and recycling processes. This approach was justified as these specific groups were primarily required to provide qualitative data, such as insights into their practices, challenges, and experiences concerning e-waste handling.

Including purposively sampled artisans and recyclers ensured that the study captured expert perspectives, which are essential for a comprehensive understanding of the e-waste management landscape.

3.6 Data Collection Methods

The data collection methods were by survey and use of secondary data. Survey methods involved the use of a structured questionnaire administered to the households, the artisans or recyclers, and the institutions.

3.7 Data Collection Tools

3.7.1 Questionnaires for the Households

The first part was the informed consent (Appendix A) to be communicated prior to questionnaires were administered. Questionnaires (Appendix B) designed for households aimed to gather data on the types and volumes of e-waste generated per household, disposal practices, and awareness levels regarding the hazards associated with e-waste. The questionnaire included both open-ended and closed questions to capture a comprehensive view of household e-waste characteristics and practices. This tool was employed to address study objective one. For objective two, the study sought secondary data upon request from the statistician, Environment and Forestry Statistics, Uganda Bureau of Statistics (UBOS).

3.7.2 Questionnaires for the Artisans

The artisans' questionnaire focused on the collection, segregation, and recycling practices of e-waste. It also sought to identify the health and safety measures employed by workers in the e-waste recycling industry. This questionnaire helped to assess occupational risks and the effectiveness of existing regulations. A sample of the interview guide used for this category of respondents is shown in Appendix C.

3.8 Extraction of Soil Samples

Soil analysis was done by the method called Atomic Absorption Spectroscopy (AAS). This method is a widely used analytical technique for detecting and quantifying metals in soil by measuring the absorption of light by free atoms in a gaseous state (Idris et al., 2022, Abrham and Gholap, 2021). It is highly effective for analyzing metals like lead (Pb), cadmium (Cd), and zinc (Zn) at trace levels. Variants such as Flame AAS (for higher concentrations) and Graphite Furnace AAS (for ultra-trace detection) provide flexibility in sensitivity and application. As can be seen in Figure 5, two soil samples, one for the treatment and the other for the control were extracted from selected sites especially those that were deemed to be highly contaminated with e-wastes.

Figure 5: Utilizing a Hand-Operated Soil Auger to Extract Soil Samples

Therefore, there were six spots from which data was collected and no replications were made on the area. These areas were Bwaise, Kalerwe-Mambule Road a renowned area for dumping accident cars, and older cars for extraction of spare parts. Also, Kisenyi, a dumping area for older computer boards, laptop motherboards, printer boards, and photocopying machines was considered for soil sample collection for analysis. The soil data was extracted with the aid of a soil auger which enabled the collection of soil in two different spots, one which is contaminated (experiment) and the other in the neighborhood that appears less or not contaminated to act as the control group (Appendix D). This study investigated three e-waste elements, that is Cadmium, Nickel, and Lead (Pb). Cadmium (Ca) is common in car batteries, digital cameras, and emergency lighting systems. Nickel (Ni) is found on most metallic cars as a corrosion resistant while Lead (Pb) is commonly used in various computer hardware parts, primarily due to its effectiveness in solder and other components. This sample was meant to address objective number three.

3.9 Procedure for Soil Analysis

The procedure for analyzing soil samples to assess the risk of electronic waste on the environment began with air drying the samples at approximately 25°C for five days to eliminate moisture. After drying, the samples were ground with a porcelain pestle and mortar and sieved through a 2-millimeter sieve to remove debris, stones, and roots. The sieved soil was then repackaged, clearly labeled, and sent for analysis to the soil, plant, and water analytical laboratory at the Department of Agricultural and Environmental Sciences, School of Agricultural Sciences, College of Agricultural and Environmental Sciences at Makerere University.

The analysis process also included the digestion of plant samples, which involved weighing the samples and then digesting them using a mixture of concentrated sulfuric acid, hydrogen peroxide, selenium powder, and salicylic acid at 360°C until a colorless solution was obtained. The digestion mixture served multiple purposes: hydrogen peroxide prevented foam formation, selenium powder lowered boiling points, and sulfuric acid completed the oxidation process. After digestion, the samples were cooled, diluted with distilled water to a volume of 50 mL, and filtered through Whatman filter paper to achieve a clear solution. This prepared solution was then used to measure heavy metal concentrations using an atomic absorption spectrophotometer, by standard operating procedures.

The analytical process was stringent, incorporating reference samples and blanks for quality control and assurance as outlined in Appendix D. This ensured the reliability of the results. Additionally, the study utilized a Multinomial Logistic Regression within a survival analysis framework to explore the relative risks associated with each metal investigated. This method was aimed at estimating the risk ratios linked to different waste management practices and their impacts on the environment, adhering to the routine procedures recommended by Okalebo et al. (2002) and other internationally recognized standards.

3.10 Data Analysis Techniques

3.10.1 Analysis to Characterize the E-waste Generated in Kampala City

To analyze the characteristics of the e-waste produced, this study concentrated on the types of e-waste produced by different participants, including homes, businesses, and institutions. The majority of these were home appliances like refrigerators and stoves, but some were office-related e-waste like projectors, computers, and cameras, to name a few. Information about the type of electronic waste produced for this goal was gathered from homes, recycling facilities, and organizations that use and dispose of electronic waste. Frequency tables, bar charts, pie charts, and cross-tabulations were used in the analysis to look into relationships between other variables and the kinds and nature of e-waste produced.

3.10.2 Analysis to Estimate the E-waste Generated in Kampala City

The Uganda Bureau of Statistics provided data on the total amount of electronic waste generated in Uganda on a formal request basis. The data was gathered under the categories of temperature exchange equipment, screens, monitors, and equipment containing screens, lamps, large equipment (excluding photovoltaic panels), photovoltaic panels (including converters), and small equipment, including small IT and telecommunication equipment. This data was quantitative and numeric. This data indicated the nature of e-waste contained within Uganda in metric tons. This data allowed the determination of the rate of e-waste generation with the aid of trend analysis by examining historical data on e-waste generation over time. Specifically, regression analysis was used to establish a statistical relationship between various economic factors such as population growth and the level of urbanization.

$$Y_i = \alpha + \beta_i X_i + u_i \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.2$$

Where Y_i is the quantity of e-waste, α is the constant term, β_i is the parameter for each independent variable (Temperature exchange equipment, Screens/monitors/equipment, Lamps, Large equipment, and small equipment) while u_i is the error term that accounts for the unobserved factors of e-waste which are explicitly not included in the model.

ANOVA was used, with the assumptions, of the normality and independence considered.

3.10.3 Determining Environmental Risks Associated with E-waste

As put out by Bayaga (2010), Kwak and Clayton-Matthews (2002), Van Calster et al. (2017), the Multinomial Logistic Regression is a suitable model for estimating the probability of the different levels of environmental risk as a function of factors like pollutant levels, temperature variations, land use patterns, and other environmental indicators. Therefore, to determine the environmental risks associated with e-waste, this study considered three outcomes of e-waste contamination of lead, cadmium, and nickel and assessed their likelihood of existence in the environment through air quality measures, health, and soil quality with the aid of a multinomial logistic regression. Therefore, the following regression equations represent the relationship between the dependent variable (e-waste) and the independent variables (Lead (Pb), Mercury (Hg), Nickel (Ni), Environmental impact, Practices, and Sources of e-waste).

Based on this multinomial logistic regression model, the dependent variable is levels of environmental contamination due to lead, cadmium, and mercury. The independent variables include air quality measures, health statistics, and soil quality as follows.

$$log\,(\frac{P(Y=j)}{P(Y=0)}) = \beta_{oj} + \beta_{1j}X_1 + \beta_{2j}X_2 + \cdots + \beta_{pj}X_p \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

Where:

- Y is the categorical dependent variable representing the type of e-waste contamination (with j being each type of contamination, e.g., lead, cadmium, nickel, and 0 being the baseline category)
- X_1, X_2, and X_p are the predictor variables (such as pollutant levels, temperature variations, sources of waste, practices)
- β_{oj}, β_{1j}, and β_{pj} are the parameters to be estimated for each category j.

For Lead

$$log\,(\frac{P(Contamin = Pb)}{P(Contamin = None)}) = \beta_{o,lead} + \beta_{1,lead}AirQuali + \beta_{2,lead}Prac + \beta_{3,lead}Sou + \varepsilon_i \ldots 3.4$$

For mercury (Hg)

$$log\ (\frac{P(Contamin = Hg)}{P(Contamin = None)}) = \beta_{o,Hg} + \beta_{1,Hg}AirQual + \beta_{2,Hg}Prac + \beta_{3,Hg}Sou + \varepsilon_i \ldots 3.5$$

For Nickel (Ni)

$$log\ (\frac{P(Contamination = Ni)}{P(Contamination = None)}) = \beta_{o,Ni} + \beta_{1,Ni}AirQua + \beta_{2,Ni}Prac + \beta_{3,Ni}Sou + \varepsilon_i \ldots 3.6$$

These equations allowed the study to estimate the effect of various environmental factors on the likelihood of each type of metal contamination due to e-waste. Each parameter β provides insights into how significantly each predictor influences the risk of contamination for each type of metal.

3.11 Ethical Considerations

All participants were briefed about the purpose of the study and were politely asked to participate. They were further informed that the data collected from them was only to be used for purely academic purposes and that this would not be breached. For reliability of the study results, the data set of national e-waste generated was obtained with permission from the statistician, Environment and Forestry Statistics, Uganda Bureau of Statistics (UBOS).

3.12 Limitations of the Study

- The study faced limitations in collecting both primary and secondary data, as well as conducting soil analysis, which proved to be complex and challenging due to field sampling difficulties.
- The lack of documentation on e-waste by households and institutions is a problem, and therefore, only the information they can recollect was used.
- The cost of testing and analyzing soil for each element was quite expensive. This limited the number of elements/samples to be investigated in this study.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results from the study on the quantification of e-waste in Kampala and its associated environmental risks. The quantification study covered the whole of Kampala for the e-waste used by households, the recyclers/artisans as well as from the institutions. The data on soil quality for inferring environmental risks was collected from Bwaise and Kisenyi areas (for expected contaminated soil) and areas within the neighborhood not having e-wastes dumped in them to act as controls.

4.2 Stakeholders Involved in E-Waste

Figure 6 shows the key stakeholders or agents found to directly work hand in hand with e-waste. Findings revealed that that consumers majorly comprised the households, the collectors at the scrapyards, the recyclers, the manufacturers, and the importers are the agents involved in the generation and transfer of e-waste in Kampala city.

Figure 6: Agents involved in the transfer of e-waste in Kampala

Based on the results, about 20,000 tons of e-waste is held among the consumers or first-time buyers of electronic/electrical products; about 15,000 tons are within the township commercial collectors and local recyclers, these store it to sell in bulk; manufacturers and importers also hold relatively large amount of waste while the refurbishment centers have small quantities of e-waste. This highlights the role of the informal recycling sector, which, despite its significance, often operates without proper regulations, posing health and environmental risks (Manhart, 2011). Manufacturers and importers also hold significant amounts of e-waste, indicating challenges in implementing effective recycling or take-back schemes. Extended Producer Responsibility (EPR) is essential for managing this, but its implementation is still developing in many regions (Widmer et al., 2005). Refurbishment centers hold smaller quantities, showing their role in extending product life through repair and reuse, which helps reduce e-waste (Williams et al., 2008).

4.3 Users of E-waste

With regards to the stakeholders involved in e-waste management, Figure 7 shows that the recyclers or the artisans are the single largest users of e-waste followed by the companies making steel and other metallic components for industrialization and then the individuals. Here, the individual consumers expressed no interest in e-waste if it had reached its expected useful life while the recyclers and the recycling companies/steel-making companies still buy this steel from the consumers and collectors for further processing.

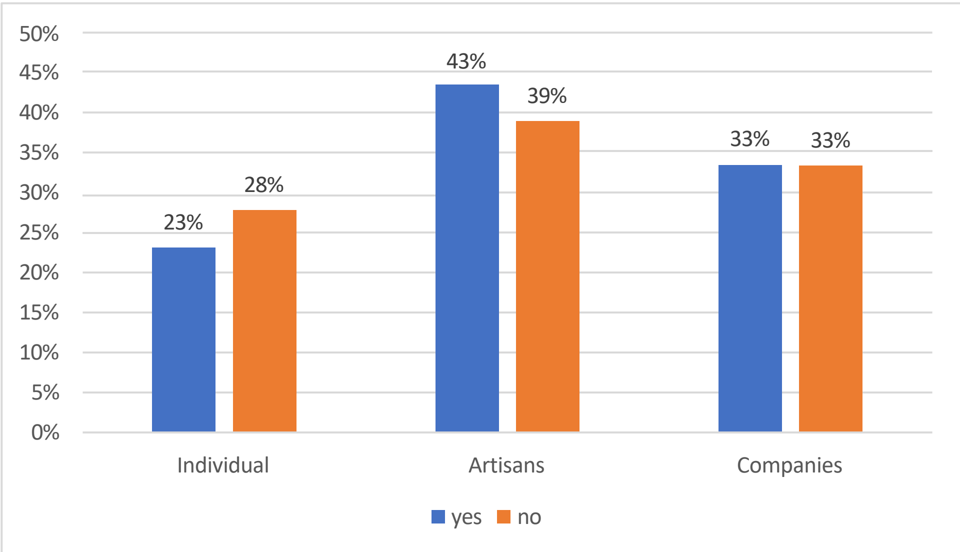

Figure 7: Stakeholders involved in e-waste management in Kampala

Recyclers or artisans, as the primary users of e-waste, are central to the initial stages of the recycling process. They collect, sort, and process e-waste to recover valuable materials. This sector, often informal, is essential for aggregating and preparing e-waste for further industrial processing. However, the lack of proper regulations and infrastructure can lead to environmental pollution and health risks for those involved, as noted by Manhart (2011).

Improving the conditions under which these recyclers operate can significantly enhance the efficiency and safety of e-waste management. Following the recyclers, companies involved in the production of steel and other metallic components are significant users of e-waste. These companies purchase processed e-waste from recyclers to extract metals such as steel, copper, and aluminum for use in industrial applications. This practice not only helps in reducing the demand for virgin raw materials but also supports the recycling industry by creating a market for recycled materials.

The involvement of these companies underscores the importance of integrating industrial stakeholders into e-waste management strategies to promote sustainable industrial practices (Widmer et al., 2005). Individual consumers, on the other hand, show little interest in e-waste once it has reached its expected useful life. This apathy can be attributed to a lack of awareness about e-waste management and the absence of convenient disposal options. Consumers often store old electronics at home, leading to an accumulation of e-waste that could otherwise be recycled. This behavior highlights the need for public education campaigns to raise awareness about the environmental impact of e-waste and the benefits of recycling. Additionally, establishing accessible and efficient e-waste collection systems can encourage consumers to dispose of their electronic waste responsibly (Baldé et al., 2017).

Recyclers and recycling companies continue to buy e-waste from consumers and collectors for further processing. In Uganda, the current ongoing demand for e-waste indicates a robust market for recycled materials, which is crucial for the sustainability of the recycling industry. Ensuring that these transactions are conducted within a regulated framework can enhance the efficiency of the recycling process and minimize environmental and health risks.

4.4 Distribution of E-Waste Categories in Kampala City

The bar chart (Figure 8) illustrates the proportion of e-waste types generated by households, recyclers, and artisans in Kampala City. The timeframe considered was the last twenty-five years.

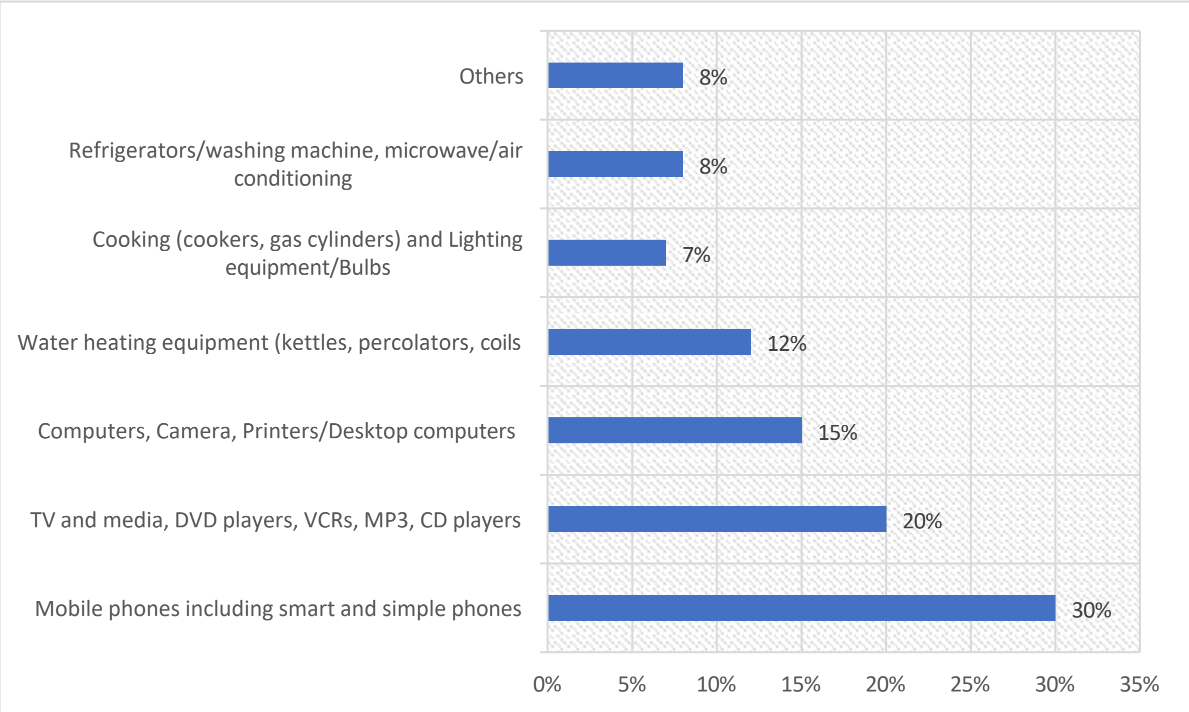

Figure 8: Distribution of E-Waste Categories in Kampala City

Based on Figure 7, mobile phones, including both smart and basic phones, represent the largest category of e-waste, contributing over 30%, followed by TV and media devices (approximately 20%). Computers, cameras, and printers account for around 15%, while water-heating equipment like kettles and coils contribute about 10%. Cooking and lighting equipment, as well as refrigerators and related appliances, each make up slightly less than 10%. This distribution reflects the widespread ownership and disposal patterns of consumer electronics in Kampala.

4.5 Classification of E-waste Generated in Kampala

The bar chart (Figure 9) illustrates the distribution of e-waste quantities across five divisions in Kampala: Makindye, Nakawa, Rubaga, Central Division, and Kawempe. The Central Division has the highest amount of e-waste at approximately 418,888.77 units, reflecting its status as a commercial and administrative hub with high electronic device turnover. Nakawa follows with 356,117.77 units, indicative of its mixed residential and industrial zones contributing to significant e-waste generation. Kawempe, with 340,447.30 units, also shows substantial e-waste accumulation, suggesting widespread electronic usage in its residential and semi-industrial areas. Rubaga, at 364,89.80 units, and Makindye, at 157,266.47 units, have lower e-waste quantities but still represent significant volumes requiring management.

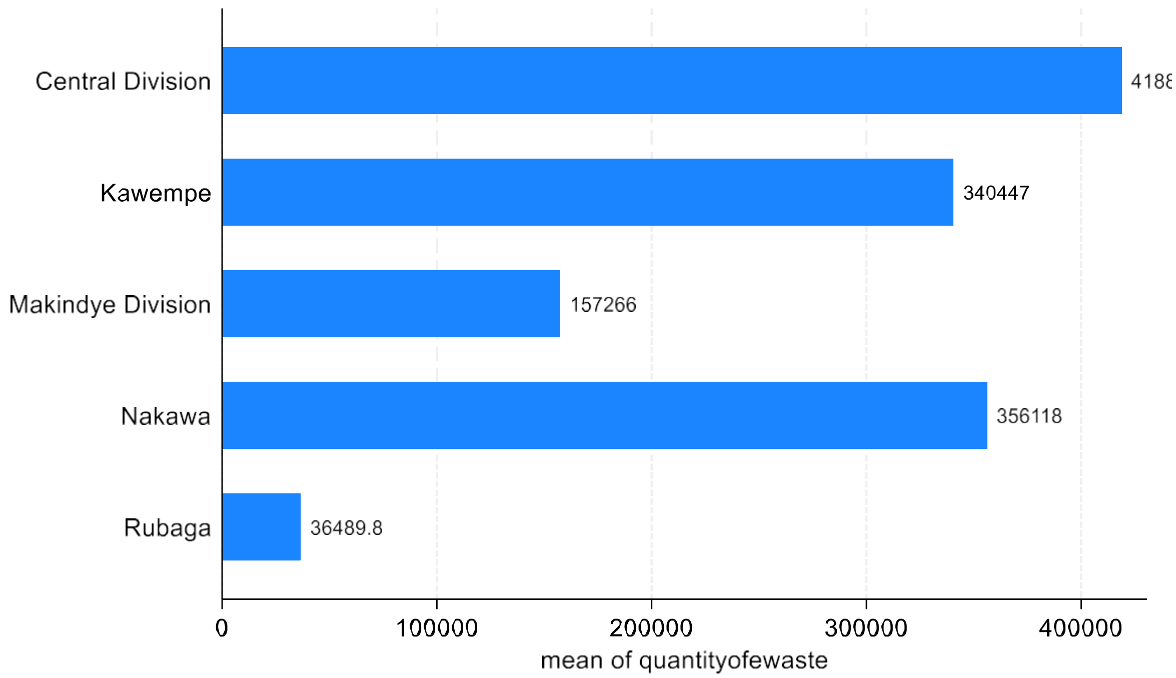

Figure 9: Classification of e-waste generated in Kampala

The figures of the different types of wastes highlight the urgent need for targeted e-waste management strategies, including public awareness campaigns, collection and recycling programs, enforcement of disposal regulations, and partnerships with the private sector to create an integrated system. The high e-waste quantities in the Central Division, Nakawa, and Kawempe reflect findings by Baldé et al. (2017), who noted that urban and industrial areas tend to generate more e-waste due to higher electronic device usage. Manhart (2011) emphasized the role of informal recycling in urban settings, which aligns with the substantial e-waste managed by local recyclers and artisans in these divisions. The need for effective e-waste management strategies, as highlighted by Widmer et al. (2005), is evident in these results, underscoring the importance of public awareness, regulatory enforcement, and formal recycling infrastructure to address the growing e-waste challenge.

4.5.1 Institutional Analysis

Many government institutions now have a variety of computer-related electronic materials, such as CRTs, mice, keyboards, and many unrepaired vehicles. One government agency had 77 unused computers and other electronic equipment. It was discovered that each of the 30 institutions surveyed had used computers and other related ICT materials at least once. Almost all institutions confessed to having e-waste on their premises, including CRTs, mice, keyboards, mobile phones, and air conditioners. The management asserted that they support e-waste disposal merely by identifying e-waste equipment and asking for permission to replace them with new ones from regional stock verifiers. All institutions asserted awareness of guidelines about e-waste management. However, none of the institutions visited confessed to properly handling and managing e-waste even with Uganda's First National E-waste Management Centre, launched on June 10, 2021, by representatives from UNBS, UCC, NITA-U, MoICT & NG, and other stakeholders. This scenario is consistent with findings by Baldé et al. (2017), who noted that despite existing regulations, effective e-waste management is often lacking due to poor implementation and awareness.

The Ugandan government recognized the challenges posed by e-waste and created an enabling environment to facilitate its adequate and sustainable management. The existence of the National Environment Act, 2019, the National Environment (Waste Management) Regulations 2020, the E-Waste Management Policy 2012, the E-Waste Management Strategic Plan, and the E-Waste Guidelines 2016 attest to this. However, stakeholders claimed that none of these regulations applied to the management of e-waste. This is echoed by Widmer et al. (2005), who emphasized that the existence of regulations does not guarantee their effective application without proper enforcement and stakeholder engagement.

Some institutions did not generate much waste, and the little that they did generate was stored on their premises. However, one institution's zonal management representative stated that they are aware of the profit made from e-waste recycling. He also stated that while he is aware that there are no specific guidelines for e-waste management, there are regulations and guidelines for disposing of hazardous waste. This reflects the findings of Manhart (2011), who highlighted the economic potential of e-waste recycling if properly regulated and integrated into the formal sector. Furthermore, Williams et al. (2008) discussed the importance of proper guidelines and infrastructure to manage e-waste effectively, stressing that awareness alone is insufficient without actionable frameworks.

4.5.2 Artisans/Recyclers Analysis

The data also shows that the electronic repair artisans rank first in terms of electronic equipment ownership, with up to 100 mobile phones each. According to these artisans, they repair a wide range of devices including laptop computers, photocopiers, electronic kettles, mobile phones, radios, TVs, DVDs, deck recorders, fridges, gas cookers, air conditioners, washing machines, microwaves, blenders, electronic jugs, irons, and other electronic materials. When asked what they believe should be done to ensure effective e-waste management, they advocated for e-waste management guidance and suggested the return of counterfeit electronic equipment likely to become e-waste to the manufacturers. Artisans, mostly found in Kisenyi, a Kampala suburb, reported having 20 to 100 pieces of electronic equipment to repair. However, the findings also show that electronic repair artisans had some ICT materials that were not in use. This situation is consistent with Manhart (2011), who noted the accumulation of e-waste due to inadequate regulation and infrastructure in the informal sector, and corroborated by Bakhiyi et al. (2018), who emphasized the health risks posed by improper e-waste handling in informal settings.

The data further indicates that the average age of the telephone artisans was 44 years, showing that people from various categories participate in the telephone artisan activity. Some artisans asserted that importers of counterfeit electronic materials should be held accountable for e-waste management and emphasized the need for education on how to dispose of waste without polluting the environment. This aligns with findings from Baldé et al. (2017), who stressed the importance of public awareness and accountability in effective e-waste management. Additionally, artisans advocated for the establishment of e-waste recycling factories, a sentiment echoed by Williams et al. (2008), who highlighted the role of proper infrastructure in managing e-waste efficiently. Furthermore, Streicher-Porte et al. (2005) discussed the potential benefits of establishing formal recycling systems to improve e-waste management and reduce environmental impact.

4.5.2.1 Valuable E-waste According to Recyclers/Artisans

Figure 10 illustrates the distribution of valuable e-waste, highlighting the proportions of lead/copper metals, aluminum metals, and heavy steel parts. This figure provides a visual representation of the most commonly sought-after materials by recyclers, with lead/copper metals accounting for the largest share, followed by aluminum metals and heavy steel parts.

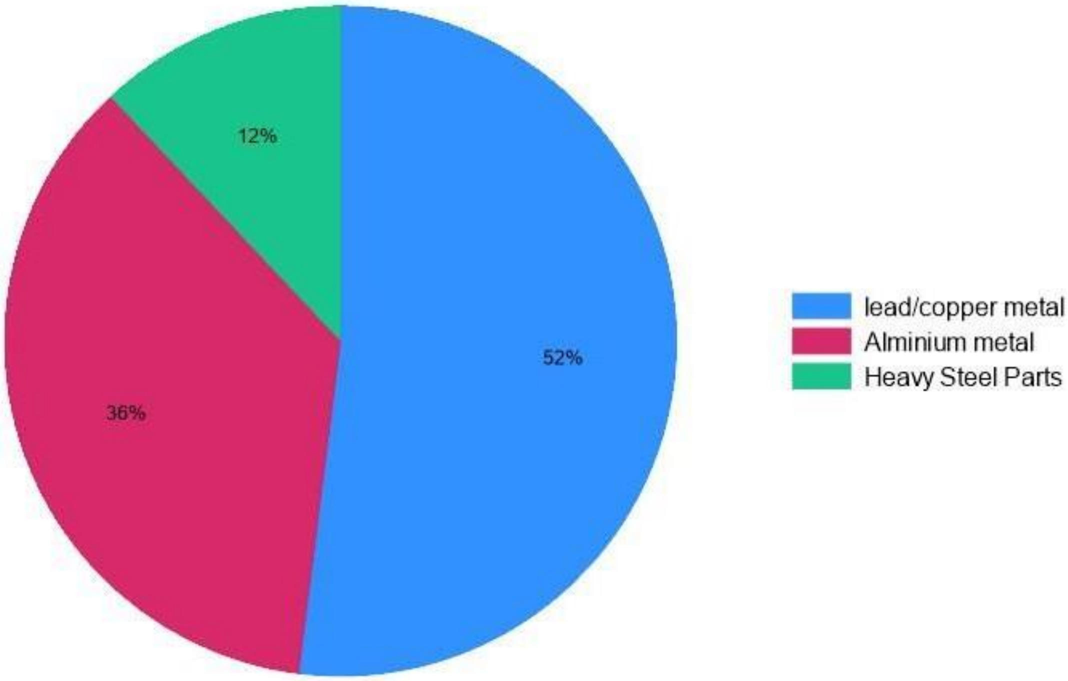

Figure 10: Valuable e-waste according to recyclers/artisans

The lead/copper metal parts were the most valuable e-waste contained and collected by recyclers and artisans, followed by the aluminum parts and then the heavy steel parts, despite the latter's enormous presence. This finding aligns with the observations of several scholars who have examined the value and challenges of e-waste recycling. For instance, Jang and Townsend (2003) found that the recovery of precious and base metals like copper and lead from e-waste is a significant economic driver for informal recyclers, given the high market value of these materials. Similarly, Chi et al. (2011) emphasized that copper and lead are among the most sought-after materials in e-waste due to their widespread use in electronic components and the profitability of their extraction and resale. Aluminum, while less valuable than copper and lead, is still highly recyclable and profitable. It is lightweight, non-corrosive, and used extensively in electronic casings and components, making it a valuable resource for recyclers

(Kiddee et al., 2013). However, the collection and recycling of heavy steel parts, despite their bulk, are often less prioritized due to their lower market value compared to other metals and the high costs associated with their extraction and processing (Bakhiyi et al., 2018). The prioritization of high-value metals like copper and lead over bulkier, less valuable metals like steel is a common trend observed globally. Research by Cui and Zhang (2008) further supports this, noting that the economic feasibility of recycling operations is significantly influenced by the market prices of recovered metals. Consequently, recyclers often focus on extracting metals that offer the highest financial return.

4.5.2.2 Methods Used by the Recyclers/artisans to Dismantle the E-waste

Figure 11 displays the distribution of the different dismantling techniques used, such as physical dismantling, selling components for further processing, and the use of metal crushers. The results show that physical dismantling is the most common method, followed by selling for further processing and using metal crushers.

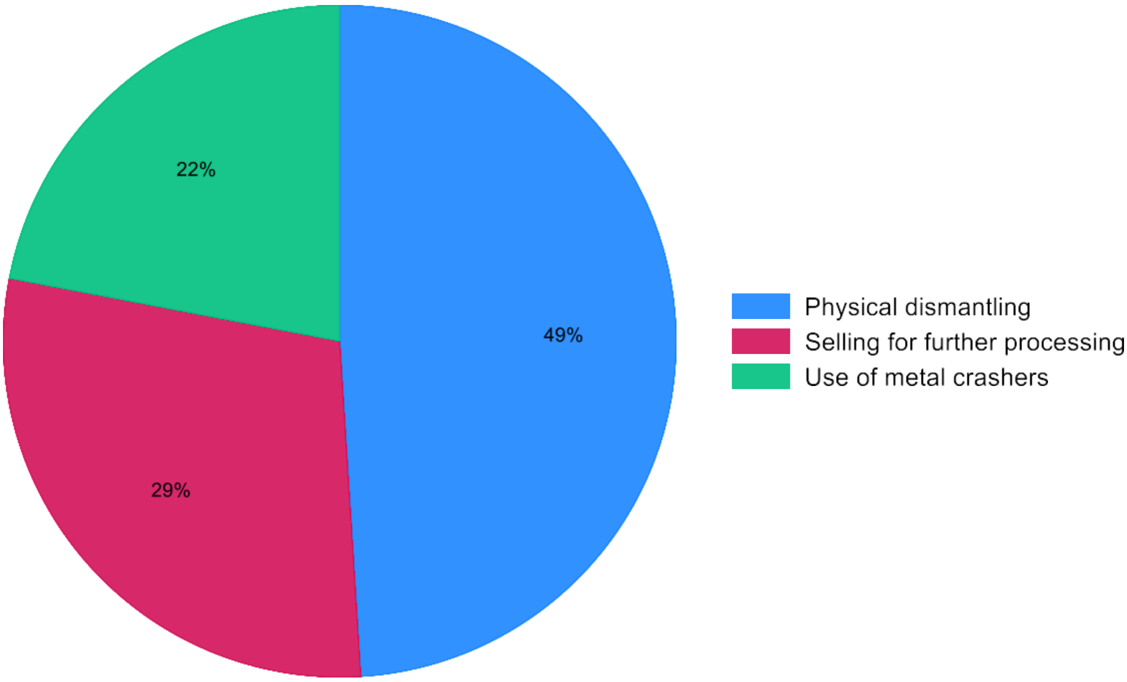

Figure 11: Methods recyclers use to dismantle e-waste parts

When it comes to dismantling e-waste, known to the artisans as scrap, most of them use physical dismantling equipment such as axes and other heavy metal vehicle parts. This method is prevalent due to its low cost and accessibility. Following this, some artisans prefer to sell the e-waste in its raw form directly to metal companies, avoiding the dismantling process entirely. Only a few artisans reported using metal crushers for dismantling e-waste, which indicates a lack of access to or awareness of more efficient and safer dismantling technologies. This finding is consistent with observations by Herat and Agamuthu (2012), who noted that informal e-waste recyclers in developing countries often rely on rudimentary tools and methods due to limited financial resources and technical expertise. These practices, while cost-effective, pose significant health and environmental risks due to the release of toxic substances during dismantling. Similarly, Li et al. (2011) highlighted that the informal recycling sector often lacks proper dismantling infrastructure, leading to inefficient recovery of valuable materials and increased environmental contamination. The use of basic tools like axes and heavy metal parts for dismantling is a common practice in many regions where formal recycling systems are underdeveloped. Conversely, the use of metal crushers, though reported by a few, aligns with findings by Chancerel et al. (2009), who emphasized the benefits of mechanical processing technologies in improving the efficiency and safety of e-waste recycling. Mechanical crushers can enhance material recovery rates and reduce health hazards by minimizing direct exposure to hazardous components. The nature of e-wastes encountered in the study is shown in Appendix E.

4.5.2.3 Pareto Curve for Quantity of e-waste by Type

The Pareto curve in Figure 12 illustrates the distribution of e-waste quantities by type and highlights the most significant contributors to the total e-waste generated. In a Pareto analysis, the principle often suggests that a small number of categories contribute disproportionately to the total impact—in this case, most of the e-waste. They included screens monitors, computer parts, motherboards, and so on. In addition, there was large equipment for industrial purposes, temperature equipment, small equipment for factories, car parts, small IT, and lamps as can be seen in Figure 12.

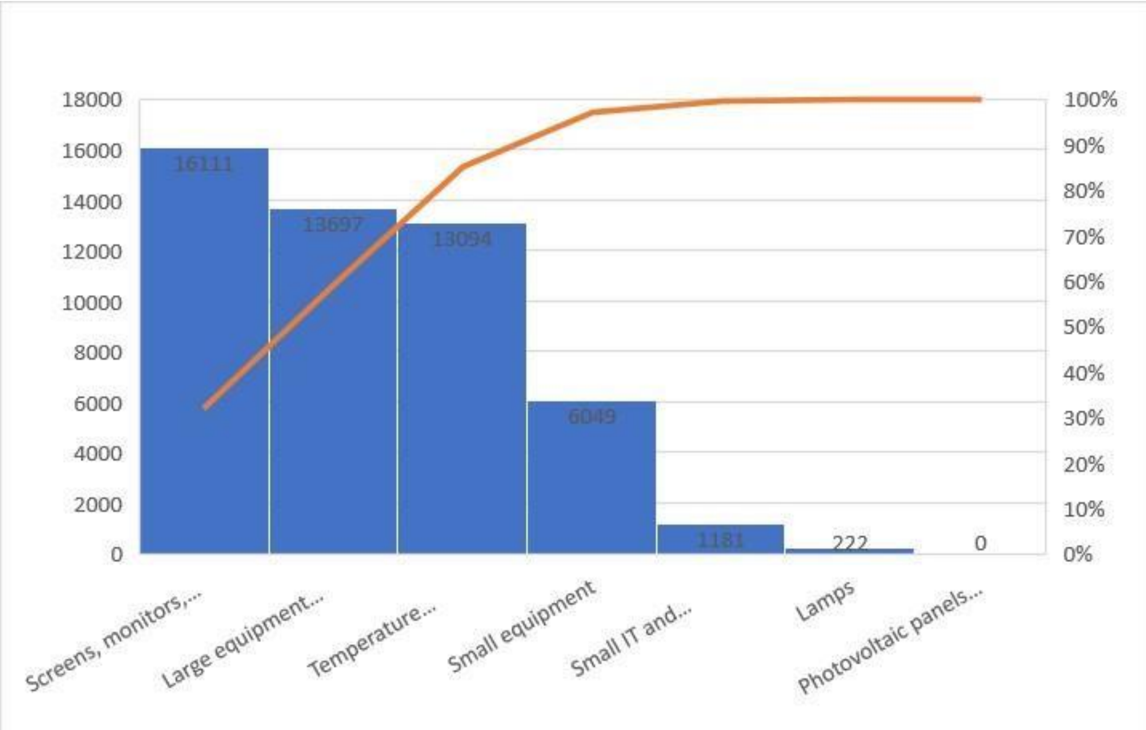

Figure 12: Pareto Curve for Quantity of e-waste by Type

As was previously reported, most of the e-waste discovered in Kampala was made up of computer-related items such as screens, monitors, large equipment like photocopying machines, large printers, scanners, cameras, and other related devices, as well as electrical parts like lamps, temperatures used in laboratories, photovoltaic equipment, and so on. The characteristics of the Pareto curve demonstrate that e-waste is continuously increasing. This trend is consistent with findings from other regions.

For instance, Baldé et al. (2017) observed that globally, the bulk of e-waste consists of large electronic equipment and ICT-related items, reflecting similar patterns in Kampala. These items often have shorter lifespans due to rapid technological advancements, leading to faster turnover and increased e-waste generation.

Similarly, Cucchiella et al. (2015) highlighted that the proliferation of large office equipment and consumer electronics significantly contributes to the overall e-waste stream. This includes items such as photocopiers, printers, and scanners, which are prevalent in both commercial and educational settings. Their disposal presents substantial challenges due to the complex materials and hazardous substances they contain.

In addition, Lepawsky (2015) pointed out that the increasing presence of photovoltaic equipment and other specialized electrical parts in e-waste is a result of the growing adoption of renewable energy technologies. As these technologies become more widespread, the associated e-waste will continue to rise, necessitating specialized recycling processes to handle these materials effectively.

The continuous increase in e-waste, as indicated by the Pareto curve, underscores the urgent need for comprehensive e-waste management strategies. This includes not only improving collection and recycling infrastructure but also implementing policies that promote the sustainable design and extended lifespan of electronic products (Widmer et al., 2005).

4.6 Quantification of E-waste

This study utilized the statistical properties of the Ordinary Least Squares to estimate the quantity of e-waste in Uganda using data from the Uganda Bureau of Statistics.

4.6.1 Visual plots for Quantity of E-waste Generated in Uganda since 1995

Figure 13 on the left is a time series plot that shows the trend of e-waste in Uganda for the period of 25 years (1995 to 2020) while the figure on the right is a bar chart showing the mean e-waste generated in each year. Both figures show that e-waste takes on an exponential upward trend of growth. This indicates that e-waste generation is ever-increasing in Uganda.

Over the study period, it was observed that Uganda generated an increasing amount of e-waste from 1995 to 2020. Each year that goes by, it is observed that the quantities of e-waste increase, with 2020 showing the highest amounts overall. Over the study period, it was observed that Uganda generated an increasing amount of e-waste from 1995 to 2020. Each year, the quantities of e-waste increased, with 2020 showing the highest amounts overall. This trend is consistent with global observations, where rapid technological advancement and increased consumer electronics usage have led to rising e-waste generation.

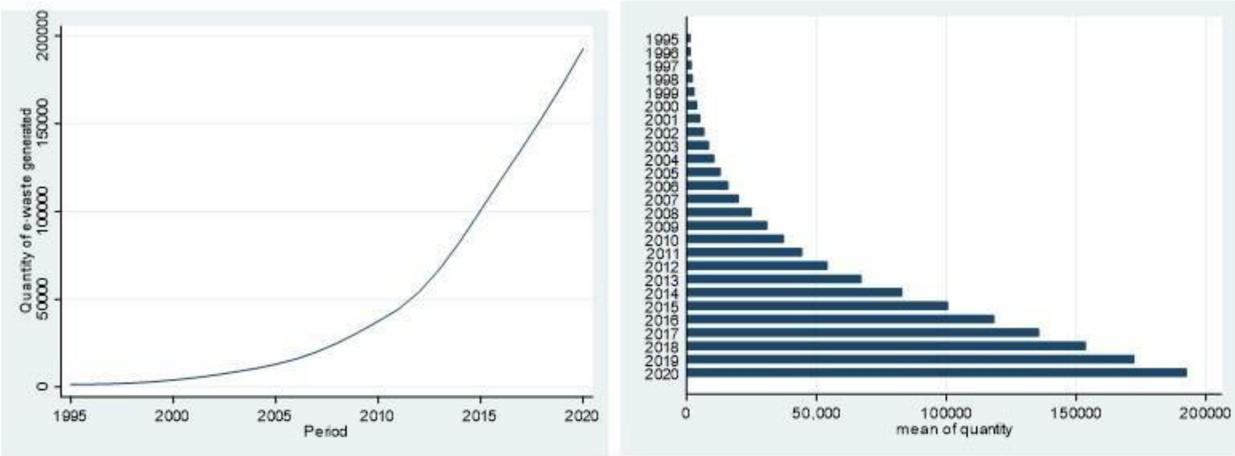

Figure 13: Visual plots for the Quantity of e-waste generated in Uganda since 1995

For instance, Forti et al. (2020) documented a similar global trend, noting a steady increase in e-waste production due to the short life cycles of modern electronics and the rapid pace of technological innovation. As consumers frequently upgrade their devices, older models are discarded, contributing to the growing e-waste stream. Kahhat and Williams (2009) also emphasized that developing countries are experiencing significant growth in e-waste generation as they adopt new technologies. In Uganda, this increase can be attributed to the expanding availability and use of electronic devices, which parallels the findings of other developing regions.

Additionally, Grant and Oteng-Ababio (2012) highlighted the challenges faced by African countries in managing the surge of e-waste. They pointed out that the lack of adequate infrastructure and regulatory frameworks exacerbates the issue, leading to increased environmental and health risks associated with improper e-waste disposal. The continuous rise in e-waste quantities in Uganda underscores the urgent need for robust e-waste management policies and infrastructure development. Implementing effective collection, recycling, and disposal systems is crucial to mitigating the environmental impact and ensuring sustainable e-waste management practices (Widmer et al., 2005). In summary, the observed increase in e-waste generation in Uganda from 1995 to 2020 mirrors global trends driven by technological advancements and consumer behavior. Addressing this challenge requires comprehensive strategies to enhance e-waste management and reduce its negative impacts on the environment and public health.

4.6.2 Shapiro–Wilk W Test for Normal Data

The study with the aid of the Shapiro–Wilk W tested the residuals for the quantity of e-waste positive for normality, thus no normality violation was encountered in this study. Table 2 therefore, presents the Shapiro-Wilks test for normality of the series. The null hypothesis for this test is that the series is normally distributed against the alternative of the violation of the normality assumption.

Table 2: Shapiro–Wilk W test for normal data

Variable	Obs	W	V	z	Prob>z
Residuals	26	0.96386	1.033	0.067	0.47322

The Shapiro–Wilk W test for normal data revealed that the residuals for the quantity of e-waste generated were normally distributed. This initiated the use of the multiple linear regression of the ordinary least squares method to assess the quantification of e-waste in Uganda.

4.6.3 Pnorm Plot for Testing Normality of the Quantity of E-waste

Figure 14 shows the probability of normal residuals plot of the scores of the fitted values against the normally distributed line. Figure 14 shows that the scores all lie along the straight line and thus implies no violation of the normality assumption.

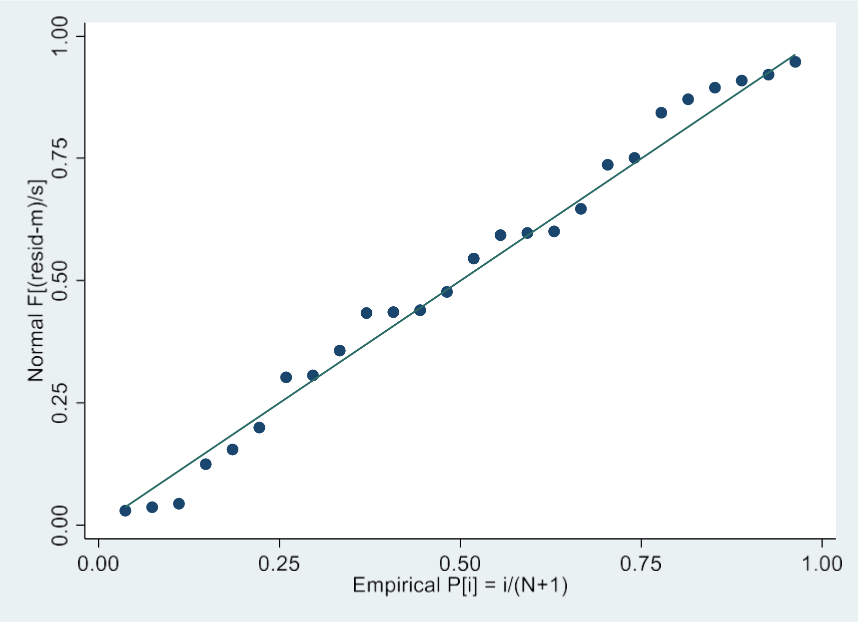

Figure 14: Pnorm plot for testing the normality of the Quantity of E-waste

Like the normality test above, the scores for the quantity of e-waste seem to be within the line of best fit. This suggested the residuals for the quantity of e-waste were normally distributed.

4.6.4 Model for Predicting Quantity of E-waste

Table 3 presents the multiple linear regression model. The regression model was meant to predict the total quantity of e-waste based on the categories of e-waste generated in Uganda for the past 25 years. The results are presented in Table 3.

Table 3: Model for predicting the Quantity of e-waste

Quantity of E-waste	Coef.	S. E	t	sig.	95% conf. interval	
Intercept	75.166	133.752	0.562	0.580	-203.835	354.167
Temp exchange equip	1.053	0.008	134.790	0.000	1.037	1.070
Screens/monitors/equipment	0.986	0.011	89.407	0.000	0.963	1.009
Lamps	0.227	0.827	0.274	0.787	-1.499	1.953
Large equipment	0.987	0.019	53.042	0.000	0.948	1.025
Small equipment	1.165	0.044	26.750	0.000	1.074	1.255
Number of obs = 26; F (4, 21) > 99999.00; Prob > F = 0.0000; R-squared = 0.9998						

First and foremost, the model was a good prediction model (good fit), due to p-value<0.05. Secondly, the model indicated that almost (99.98%) of all the types of waste generated in Uganda account for the accumulation of e-waste in the country. The intercept term had a coefficient of 75.1658, which represents the volume of e-waste if other considered e-waste types and sources were zero.

Temperature exchange equipment (b = 1.0532): This value indicated that as temperature exchange equipment such as refrigerators, hairdressers/warmers, boilers, etc., rise by one unit, the quantity of e-waste increases by 1.0532 units. Both variables were measured in thousands; therefore, for every USD 1000 spent on temperature exchange equipment(s), an extra 1.0532 thousand units of waste are created. The significant effect created by temperature exchange equipment is due to their complexity and difficulty in recycling, particularly refrigerators. This challenge is echoed by Cucchiella et al. (2015), who noted the recycling difficulties and environmental impact of temperature exchange equipment.

Screens, monitors, and computers (b = 0.9856): This value indicates that as the number of screens, monitors, and computers increases by one unit, the quantity of e-waste accumulated rises by 0.9856 units. Put differently, every USD 1000 spent on screens, monitors, and computers increases e-waste accumulation by USD 985.6. The rate of change of this equipment into e-waste is almost unitary. This finding aligns with Baldé et al. (2017), who observed that ICT-related items are major contributors to e-waste due to their high turnover rates.

Large equipment (b = 0.9866): Like screens, monitors, and computers, this value for large equipment such as cars, large generators, and sewers revealed that one unit rise in these items creates a significantly larger rise in e-waste. For every USD 1000 spent on large equipment, it translates into approximately the same value of waste. This observation is consistent with findings by Kiddee et al. (2013), who discussed the substantial e-waste generated from large electronic devices and the challenges in managing them.

Lastly, the small equipment (b = 1.1646): This value indicates that as the volume of small equipment rises by one unit, the quantity of waste accumulated rises by 1.1646 units. This suggests that small electronic devices, though individually smaller, collectively contribute significantly to e-waste volumes. Williams et al. (2008) similarly noted that small electronics, due to their high usage and short lifespan, substantially add to the overall e-waste burden.

4.6.5 Prediction of Quantity of E-waste in the Next Five Years

Figure 15 presents the value-added plots of the predictions of each category of e-waste on the total quantity. Most of them show linear steeper upward prediction of e-waste.

Based on the value-added plot, almost all the predictors of waste suggest a rise in the quantity of e-waste in the next five years. E-waste quantities for temperature exchange machines, screens, monitors, and computers, large equipment such as automobiles and vehicle parts, as well as small electric/electronic equipment, appear to be on a steeper rise shortly compared to lamps, which are locally manufactured in Uganda by firms such as Ledon lighting systems and total electrical cables.

This anticipated increase is consistent with global trends documented by Baldé et al. (2017), who noted that the rapid pace of technological advancement and consumer demand for newer electronic devices significantly contribute to the growing e-waste stream. The steep rise in e-waste from temperature exchange machines, screens, monitors, and computers is particularly concerning given their complex composition and the hazardous materials they contain, which complicates recycling efforts (Kiddee et al., 2013).

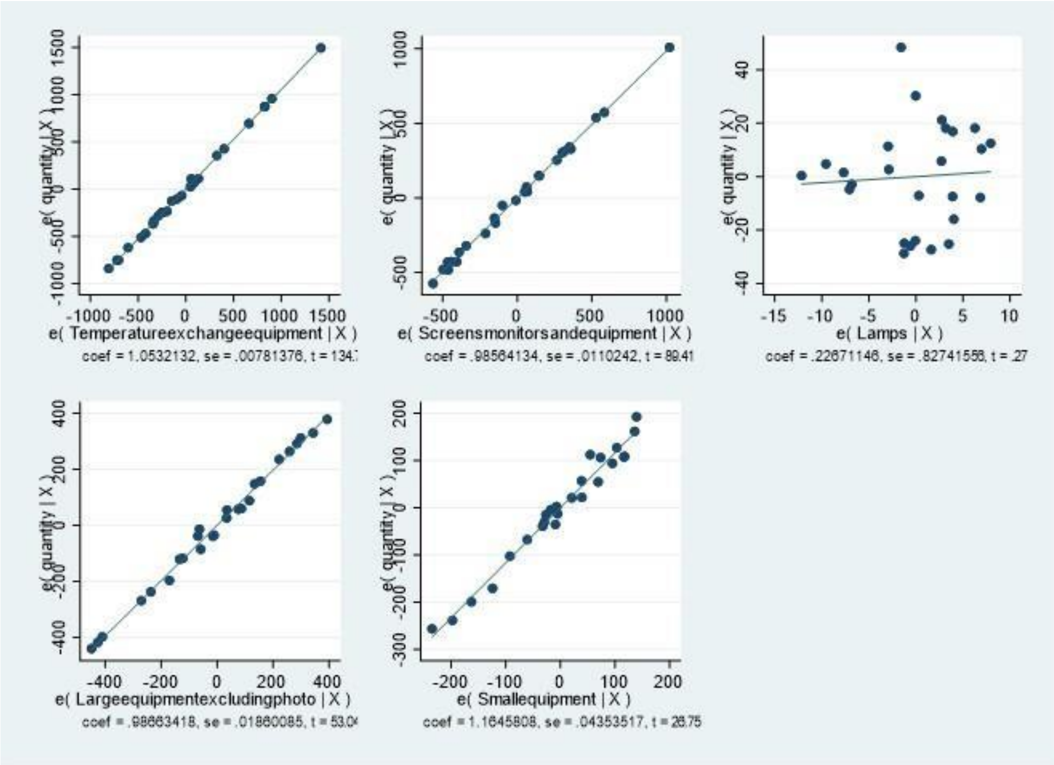

Figure 15: Value Added Plot for all the predictors of quantity of e-waste

Furthermore, the rise in e-waste from large equipment such as automobiles and vehicle parts align with findings by Li et al. (2011), who highlighted the challenges in managing e-waste from large and bulky electronic items due to their size and material diversity. Similarly, Williams et al. (2008) emphasized the significant contribution of small electronic devices to the overall e-waste volume due to their high turnover rates and shorter lifespans.

The relatively slower increase in e-waste from locally manufactured lamps may be attributed to the controlled production and possibly more sustainable practices employed by local manufacturers like General Salim Saleh's firms. This trend suggests a potential model for mitigating e-waste through local production and sustainable manufacturing practices, as discussed by Grant and Oteng-Ababio (2012), who advocated for localized solutions to e-waste management.

4.7 Environmental Risk Based on the Contamination Levels of the Metals

Table 4 presents soil analysis data from various spots in different markets. The values include pH levels and concentrations of Cadmium (Cd), Mercury (Hg), and Nickel (Ni) measured in milligrams per kilogram (mg/kg).

Table 4: Heavy Metals Present in the three study areas in Kampala

	Pb	Hg	Ni
A	2.7	30	28.5
B	1.8	190	56.6
C	7.4	130	98.6
y_{io}	11.9	350	183.7
$\bar{y}_{io}$	4.0	116.7	61.2

The pH values represent the acidity or alkalinity of the soil. The concentrations of Cadmium (Cd), Mercury (Hg), and Nickel (Ni) are given in milligrams per kilogram (mg/kg).

The presence of heavy metals like Cadmium, Mercury, and Nickel in soil poses significant environmental risks. At Usafi Market, the concentration of Cd is 2.7 mg/kg, which is considerably higher than typical background levels in uncontaminated soils (usually below 1 mg/kg). High cadmium levels can lead to soil contamination, affecting plant growth and entering the food chain, posing health risks to humans and animals. At Kisenyi Spot, the concentration of Cd is 1.8 mg/kg, also above safe background levels. This suggests moderate contamination, which can affect soil fertility and health. At Kalerwe Site, the concentration is 7.4 mg/kg, indicating severe contamination. This level can significantly impact plant and animal health and increase risks of kidney damage and skeletal disorders in humans through the food chain.

The concentration of Mercury (Hg) at Usafi Market is 30 mg/kg, significantly higher than the standard limit of 0.02 mg/kg. Mercury is highly toxic, and such elevated levels can lead to severe soil and water contamination, affecting microbial life, plants, and entering the human food chain, leading to neurological and developmental damage. At Kisenyi Spot, the concentration of Hg is 190 mg/kg, extremely high and dangerous. Such levels pose serious risks to the environment and human health, including damage to the nervous system and increased risk of cancer. At Kalerwe Site, the concentration is 130 mg/kg, also highly toxic. This level of mercury contamination can have devastating effects on ecosystems and human health, necessitating urgent remediation measures.

The concentration of Nickel (Ni) at Usafi Market is 28.5 mg/kg. While nickel is a common element in soils, elevated levels can be toxic to plants and pose health risks to humans through inhalation or ingestion, causing respiratory issues and skin conditions. At Kisenyi Spot, the concentration of Ni is 56.6 mg/kg, indicating significant contamination. Prolonged exposure to high nickel levels can lead to lung and nasal cancers. At Kalerwe Site, the concentration is 98.6 mg/kg, which is very high and poses severe risks to both environmental and human health, potentially leading to various forms of cancer and respiratory issues.

Based on the results from the Table 5, the Fc = 3.670273961> FT = 3.10. The findings resoundingly support the rejection of the null hypothesis that all metals in all three selected areas give the same level of contamination.

Table 5: ANOVA Table for Investigating Soil Contamination in Kampala

Source of variation	**Df**	**ss**	**Ms**	**F-ratio**
Between treatments	2	19054	MSB = 9527	$F_c = \frac{9527}{2596} =$ 3.670273961
Errors	6	15574	MSE = 2596	
Total	**23**	34628		

As a result, it can be concluded that heavy metals in Uganda are significantly different in terms of soil contamination. Table 6 provides the laboratory analysis of the soil samples collected in the 3 different spots and locations in Kampala. There were Usafi market, Kisenyi, and Kalerwe respectively.

Table 6: Soil Analysis Data From the Field

Lab No	**Particulars**	**mg/kg**			
		pH	**Pb**	**Hg**	**Ni**
A	Usafi Market spots 1 and 2	4.43	2.7	30	28.5
B	Kisenyi Spot 1 and 2	7.24	1.8	190	56.6
C	Kalerwe Site 0-30cm, 2/05/2022	7.05	7.4	130	98.6
1	Usafi Market spot 1 and 2 Control	6.99	BDR	BDR	BDR
2	Kisenyi 2 spots Control	7.5	BDR	BDR	BDR
3	Kalerwe 2 spots Control	8.78	BDR	BDR	BDR
	Standard/Limits		**Absent**	**Absent**	**0.02**

The quantities of heavy metals according to Table 6 are significantly above typical background levels and standard limits, indicating severe contamination. For example, the mercury levels at Kisenyi and Kalerwe far exceed the standard limit of 0.02 mg/kg. These elevated levels pose serious environmental and health risks due to their toxicity and potential for bioaccumulation, which can lead to neurological damage, developmental problems, respiratory issues, and contamination of water sources. Immediate remediation and monitoring measures are necessary to mitigate these risks and protect public health and the environment.

4.8 Environmental Risks Based on the Measured Values

The levels of lead (Pb) in the soil samples from the three areas in Kampala show significant contamination. At Usafi Market, the lead concentration is 2.7 mg/kg, at Kisenyi it is 1.8 mg/kg, and at Kalerwe it is 7.4 mg/kg. These concentrations are above typical background levels found in uncontaminated soils, which are usually below 1 mg/kg. Elevated lead levels pose serious environmental and health risks, including neurological damage, developmental problems in children, and potential contamination of water sources. The significant presence of lead in these areas indicates a risk to both the environment and public health.

The mercury (Hg) concentrations in the soil samples are alarmingly high, especially at Kisenyi and Kalerwe. At Usafi Market, the mercury level is 30 mg/kg, at Kisenyi it is 190 mg/kg, and at Kalerwe it is 130 mg/kg. These values are drastically above the standard limit of 0.02 mg/kg, indicating severe contamination. Mercury is highly toxic and can cause severe neurological and developmental effects. The high levels found in these areas pose a serious risk of contamination to the environment, including water sources, and can lead to bioaccumulation in the food chain, affecting wildlife and human populations.

Nickel (Ni) concentrations in the soil samples are also elevated. At Usafi Market, the nickel concentration is 28.5 mg/kg, at Kisenyi it is 56.6 mg/kg, and at Kalerwe it is 98.6 mg/kg. While nickel is naturally present in soils, these elevated levels can be toxic, affecting plant growth and posing health risks such as respiratory problems and skin allergies in humans. The significant nickel contamination in these areas suggests potential risks to agricultural soils, which can impact crop health and yield, and pose further risks to the food chain.

4.8.1 Lead (Pb) Negatively influences the Public Health

This metal was more prevalent in the cathode ray tubes, solder, batteries, printed wiring boards (circuit boards), solder-on components, and mobile phone coatings. Initial symptoms of exposure are anorexia, muscle pain, malaise, and headache. Long-term exposure to lead decreases the overall performance of the nervous system. High-level exposure causes brain damage and death. Lead (Pb) is a toxic metal that poses significant public health risks. It was more prevalent in components such as cathode ray tubes (CRTs), solder, batteries, printed wiring boards (circuit boards), solder-on components, and mobile phone coatings. Exposure to lead, even at low levels, can have serious health consequences, particularly for vulnerable populations such as children and pregnant women.

Initial symptoms of lead exposure include anorexia, muscle pain, malaise, and headache. These symptoms can be subtle and often go unrecognized, leading to prolonged exposure and accumulation of lead in the body. Over time, chronic exposure to lead can result in more severe health issues. According to the World Health Organization (WHO, 2010), long-term exposure to lead can significantly impair the nervous system, leading to decreased cognitive performance, behavioral issues, and developmental delays in children. High-level exposure to lead can cause severe health effects, including brain damage and death. The Centers for Disease Control and Prevention (CDC, 2012) notes that acute lead poisoning can result in encephalopathy, characterized by symptoms such as vomiting, staggering gait, muscle weakness, seizures, and coma. In extreme cases, lead poisoning can be fatal.

The prevalence of lead in electronic components such as CRTs, batteries, and printed wiring boards highlights the importance of proper e-waste management to mitigate these health risks. Inadequate recycling and disposal practices can lead to the release of lead into the environment, contaminating soil and water, and subsequently entering the food chain. As noted by Grant and Oteng-Ababio (2012), informal e-waste recycling practices, common in many developing countries, exacerbate these risks due to the lack of safety measures and proper facilities. Furthermore, occupational exposure to lead among workers involved in the recycling and disposal of e-waste is a significant concern. Workers in the informal sector often dismantle electronic components without adequate protective equipment, leading to direct exposure to toxic substances (Manhart, 2011). This underscores the need for stringent regulations and enforcement to protect both environmental and public health.

4.8.2 Mercury (Hg) Affects Both the Environment and Public Health

Mercury was found in the switches (mercury wetted) and housing, fluorescent lamps providing backlighting in liquid crystal displays (LCDs) for monitors and laptops, batteries, and printed circuit boards. When released into the environment, it builds up in sediments found in water, where it transforms into dangerous methylmercury and enters the food chain. Because methylmercury is easily absorbed into the bloodstream and has negative effects on the brain, mercury contamination is a serious public health and environmental issue. Mercury (Hg) is a hazardous metal that poses significant threats to both the environment and public health. It is commonly found in various electronic components, including mercury-wetted switches, fluorescent lamps used for backlighting in liquid crystal displays (LCDs) for monitors and laptops, batteries, and printed circuit boards. The improper disposal of these electronic devices leads to the release of mercury into the environment, which it can have far-reaching consequences.

When mercury is released into the environment, it often ends up in water bodies where it accumulates in sediments. Over time, microorganisms in the sediments convert mercury into methylmercury, a highly toxic form that readily enters the food chain. This transformation is particularly concerning because methylmercury is more easily absorbed by living organisms compared to inorganic mercury (Clarkson & Magos, 2006). As methylmercury accumulates in aquatic organisms, it biomagnifies up the food chain, leading to higher concentrations in predatory fish and marine mammals, which are often consumed by humans and wildlife.

The public health implications of mercury contamination are severe. Methylmercury is easily absorbed into the bloodstream through the consumption of contaminated fish and seafood. Once in the bloodstream, it can cross the blood-brain barrier and the placenta, posing significant risks to both the general population and particularly vulnerable groups such as pregnant women and developing fetuses (Rice et al., 2014). Methylmercury exposure can impair neurological development, leading to cognitive deficits, motor dysfunction, and developmental delays in children. In adults, high levels of exposure can result in neurotoxicity, manifesting as sensory impairment, tremors, and coordination issues.

The environmental impact of mercury is equally concerning. Mercury contamination in aquatic systems disrupts ecosystems and affects the health of various species. For example, mercury exposure can impair reproduction and development in fish and amphibians, leading to population declines and altered community dynamics (Scheuhammer et al., 2007). The persistence of mercury in the environment and its ability to bioaccumulate and bio magnify necessitate comprehensive strategies for its management and mitigation. Addressing mercury contamination requires concerted efforts at multiple levels. Proper e-waste management practices, including safe collection, recycling, and disposal of mercury-containing devices, are essential to prevent mercury release into the environment.

4.8.3 Nickel (Ni) Can Cause Pneumonia in Children

Common in car batteries, electron guns in CRT, and printed circuit boards. This metal produces Nickel fumes which are respiratory irritants and may cause pneumonitis. Contact with nickel can have several negative health effects on people, including allergies, kidney and heart disease, lung fibrosis, and lung and nasal cancer. Nickel (Ni) is prevalent in car batteries, electron guns in CRTs, and printed circuit boards. This metal produces nickel fumes, which are respiratory irritants and can cause pneumonitis, particularly in children. Exposure to nickel can have several adverse health effects, including allergies, kidney and heart disease, lung fibrosis, and lung and nasal cancer (Das et al., 2008). The presence of nickel in e-waste and its potential to release harmful fumes underscores the need for proper handling and recycling practices to protect public health and prevent respiratory conditions such as pneumonia in vulnerable populations.

4.9 Environmental Risks Associated with E-waste Management Practices

The Multinomial Logistic Regression model was employed to assess the e-waste risk based on the three metal elements. The dependent variable was environmental risks based on whether Lead, Mercury or Nickel was present in the soil sampled. The independent variables were environmental factors such as air, health and soil quality scores, the e-waste management practices, sources of e-waste such as households, industries/recyclers or institutions. Table 7 presents the multinomial logistic regression output predicting the likelihood of contamination of the three studied metal elements such as lead, nickel, and mercury.

Table 7: Multinomial Logistic Regression

e-waste	RRR	St. err.	*t*-value	*p*-value	[95% Conf Interval]		Sig
Lead (Pb)	(base outcome)						
Mercury (Hg)							
Environment Factors	1	.	.	.	.	.	
Air Quality	.783	1.09	0.95	.344	.538	5.907	
Health Quality	.943	.83	-0.07	.947	.168	5.29	
Soil Quality	1.483	.242	-1.46	.046	.181	1.787	***
Practices: Base Treatment	1	.	.	.	.	.	
Collection and Handling	14.289	17.651	2.15	.031	1.269	160.877	**
Sources of E-Waste	1	.	.	.	.	.	
Households	1.125	.107	-2.01	.09	0	1.29	*

e-waste	RRR	St. err.	*t*-value	*p*-value	[95% Conf Interval]		Sig
Industries/Institutions	1.164	.554	0.32	.749	.458	2.957	
Constant	2.001	1.324	1.05	.294	.547	7.318	
Nickel (Ni)							
Environmental Impact	1	.	.	.	.	.	
Air Quality	.481	.306	-1.15	.25	.138	1.674	
Health Quality	.76	.551	-0.38	.705	.184	3.149	
Soil Quality	.273	.119	-2.98	.003	.116	.64	***
Practices: Base Treatment	1	.	.	.	.	.	
Collection and Handling	0	.003	-0.01	.989	0	.	
Sources of E-Waste	1	.	.	.	.	.	
Households	7.491	9.997	1.51	.131	.548	102.449	**
Industries/Institutions	1.146	.508	0.31	.759	.481	2.732	
Constant	3.368	2.098	1.95	.051	.993	11.421	*

Mean dependent var	1.735	SD dependent var	0.842
Pseudo r-squared	0.591	Number of obs	200
Chi-square	37.205	Prob > chi2	0.002
Akaike crit. (AIC)	408.443	Bayesian crit. (BIC)	467.813
*** *p<.01*, ** *p<.05*, * *p<.1*			

Findings show a statistically significant increase in the risk of lead contamination with a Relative Risk Ratio (RRR) of 1.483 and a p-value of 0.046, suggesting that poor soil quality significantly elevates the risk of lead contamination compared to the baseline metal. This finding aligns with research by Alloway (2013), who noted that soil with poor quality, often due to industrial activities and inadequate waste management, can have elevated levels of lead. These soils can pose serious health risks due to the persistence and toxicity of lead, especially in urban areas.

Conversely, improvements in soil quality are associated with a highly significant decrease in nickel contamination risk, with a RRR of 0.273 and a p-value of 0.003. This suggests that enhancing soil quality can substantially mitigate nickel contamination risks relative to lead. Similar findings were reported by Chibuike and Obiora (2014), who emphasized that soil remediation and quality improvements, such as the addition of organic matter and proper waste disposal practices, can significantly reduce the bioavailability and mobility of nickel in soils.

Effective collection and handling practices for e-waste demonstrate a highly significant impact on reducing lead contamination risks, with an RRR of 14.289 and a p-value of 0.031. This emphasizes the critical role of efficient e-waste management in mitigating lead exposure. Manhart (2011) highlighted that organized e-waste collection and handling systems, coupled with proper recycling techniques, are essential for minimizing the release of hazardous substances such as lead into the environment. Implementing these practices can prevent lead from contaminating soil and water sources, thereby protecting public health.

Household sources of e-waste are associated with a significantly higher risk of nickel contamination, with an RRR of 7.491 and a p-value of 0.131, indicating that household e-waste is a considerable source of nickel contamination relative to lead. This finding is consistent with research by Cucchiella et al. (2015), who noted that household electronic waste often contains significant amounts of nickel due to the prevalence of nickel-containing components in consumer electronics. Effective management and recycling of household e-waste are crucial to reducing nickel contamination risks.

4.10 Risk Assessment of the Metal Elements by Location

Figure 16 shows the differences in the risk levels of various areas by the e-waste elements. From Figure 16, Kisenyi and Kalerwe are highly contaminated with mercury and Nickel while lead is found in other areas.

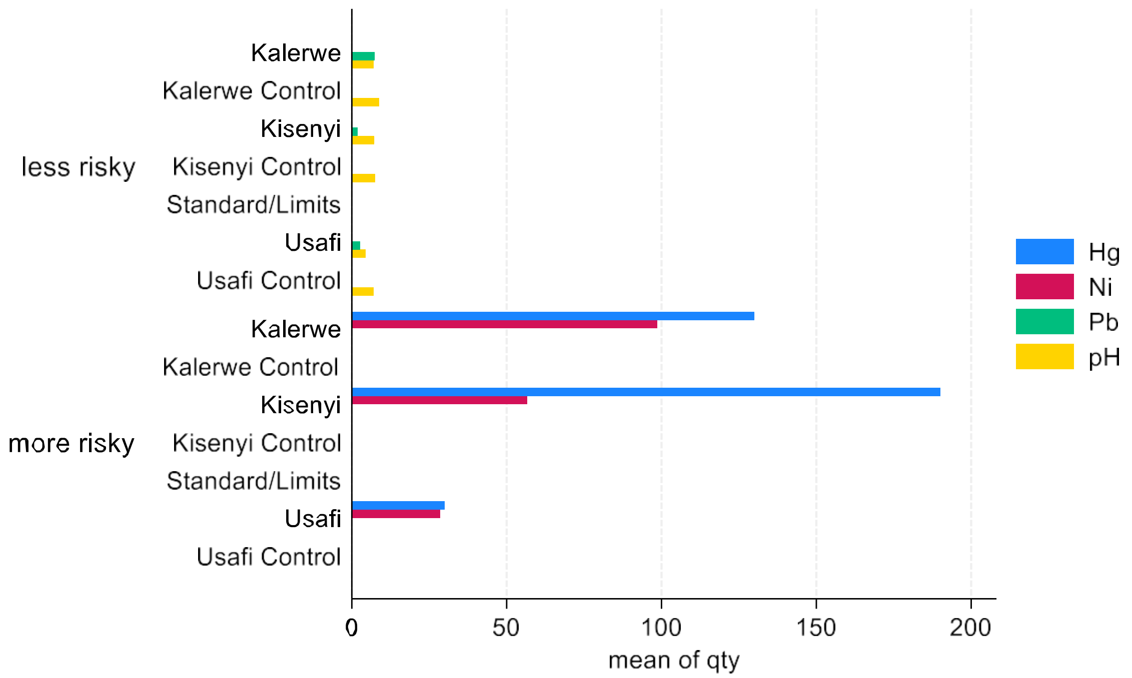

Figure 16: Risk Assessment of the Metal Elements by Location

From the chart above, the study reveals that treatment groups generally exhibit higher levels of hazardous materials like mercury, nickel, and lead compared to control groups, particularly in areas with more pronounced e-waste quantities such as Kisenyi and Usafi under riskier conditions. This effect is more evident in locations classified as riskier, where the differences between treatment and control groups are stark. These observations suggest that environmental risk factors amplify the impacts of treatments on e-waste accumulation, emphasizing the critical need to consider local environmental conditions when assessing the efficacy and environmental impact of e-waste management strategies.

The Kaplan-Meier failure estimates depicted in the accompanying graph illustrate the time-dependent probabilities of experiencing metal contamination events in environments categorized as less risky versus riskier.

4.11 Kaplan-Meier Estimates Curve for Assessing Survival Times

Figure 17 presents the Kaplan-Meier survival probabilities of risky and less risky metals. Risky metals appear to increase in probability while less risky metals decline in likelihood chances over time.

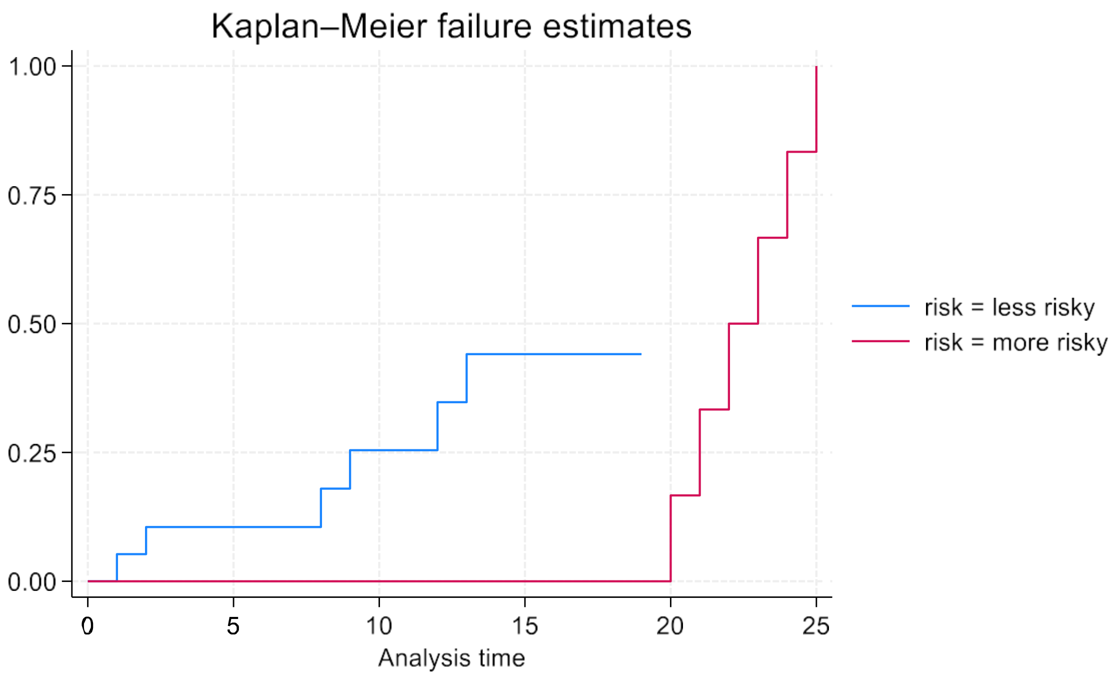

Figure 17: Kaplan-Meier Estimates Curve for Assessing Survival Times

The Kaplan-Meier curve reveals distinct patterns; the less risky environments (blue curve) exhibit a gradual increase in contamination probability over time, reaching about 25% by the

25-unit time mark. In stark contrast, riskier environments (red curve) maintain a low probability until around the 15-unit time mark, after which there is a sharp and rapid rise in contamination events, culminating in a 90% probability by the end of the analysis period. This sharp escalation in the red curve suggests that contamination events occur swiftly and extensively once a threshold is crossed in riskier environments.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Characteristics of E-waste Generated

- Mobile phones such as smartphones, simple phones, laptops, TV, DVD players, radio, MP3, CD players, media, and VCRs comprised the highest proportion of e-waste generated at the household level.
- Computers, cameras, and printers commonly used for commercial purposes by enterprises and small businesses commanded the second category.
- Water heating equipment such as water heaters, kettles, percolators, and rice cookers made it to the third position of the commonly used e-waste. These are common still at both household and institutional levels.

5.1.2 Quantities of E-waste Generated

- Over the period of 25 years, 75 metric tons of e-waste were generated in Kampala City. Temperature exchange equipment, such as air conditioners and refrigerators contributed 1.1 units of e-waste for each additional unit imported.
- Screens and monitors, integral to many household and commercial devices, contributed 0.9856 units of e-waste per additional unit, again showing a significant effect ($p < 0.0001$).
- Large equipment also showed a consistent effect on e-waste generation, with each additional unit contributing 0.9866 units ($p < 0.0001$).
- Small equipment had the highest average contribution at 1.1646 units per additional piece, reflecting its significant influence on e-waste levels ($p < 0.0001$).
- Lamps appeared to have a negligible impact on e-waste generation, with a coefficient of 0.2267 and a lack of statistical significance ($p = 0.7869$), suggesting variability in their contribution.

5.1.3 Environmental Risks Associated with E-waste

- The soil samples from Usafi Market, Kisenyi, and Kalerwe in Kampala exhibited significant contamination with heavy metals such as lead, mercury, and nickel. At Usafi

Market, the lead concentration is 2.7 mg/kg, the mercury level is 30 mg/kg, and the nickel concentration is 28.5 mg/kg. At Kisenyi, the lead concentration is 1.8 mg/kg, the mercury level is 190 mg/kg, and the nickel concentration is 56.6 mg/kg. At Kalerwe, the lead concentration is 7.4 mg/kg, the mercury level is 130 mg/kg, and the nickel concentration is 98.6 mg/kg.

- The risk of Pb contamination is highest in Kalerwe (62.2%), followed by Usafi Market (22.7%), and lowest in Kisenyi (15.1%). The risk of Hg contamination is significantly high in Kisenyi (54.3%), followed by Kalerwe (37.1%), and lowest in Usafi Market (8.6%). The risk of Ni contamination is highest in Kalerwe (53.7%), followed by Kisenyi (30.8%), and lowest in Usafi Market (15.5%). Kalerwe poses the highest overall e-waste risk due to elevated levels of Pb and Ni. Kisenyi stands out for its extreme Hg contamination risk. Usafi Market exhibits relatively lower risks but still shows notable contamination levels that require mitigation.
- The Kaplan-Meier curve revealed that the chances of environmental risks escalating into contamination events varied significantly between different risk levels. In less risky environments, the probability of contamination increased gradually, reaching about 25% by the 25-unit time mark. In contrast, riskier environments showed a minimal chance of contamination until approximately the 15-unit time mark. However, once this point was passed, the probability escalated sharply and rapidly, culminating in a 90% chance of contamination by the end of the analysis period. This demonstrated that once certain thresholds were crossed in high-risk environments, contamination events were much more likely to occur swiftly and extensively.

5.2 Recommendations

5.2.1 Characteristics of E-Waste Generated

Implement a robust classification system for e-waste streams based on their source and type. For household e-waste, prioritize collection systems that target commonly discarded items such as mobile phones, laptops, and TVs. For commercial and institutional e-waste, establish dedicated channels for collecting computers, printers, and water-heating equipment. This will enhance sorting efficiency and facilitate targeted recycling initiatives.

5.2.2 Quantities of E-Waste Generated

Develop and enforce policies to monitor and regulate the influx of electronic equipment, with a focus on temperature exchange equipment, screens, and small appliances. Establish e-waste tracking systems and collaborate with manufacturers to ensure that a percentage of newly sold units are collected for recycling or safe disposal. Quantitative measures such as levies on electronic imports could help control the escalating e-waste quantities.

5.2.3 Environmental Risks Associated with E-Waste

Initiate immediate remediation programs in high-risk areas such as Kalerwe, Kisenyi, and Usafi Market to reduce heavy metal contamination. Employ soil washing, chemical stabilization, or phytoremediation techniques to mitigate risks. Additionally, establish stringent monitoring systems to track heavy metal levels and introduce regulations mandating safe disposal practices for e-waste to minimize future environmental hazards.

5.3 Suggestion for Future Research

This study found that the e-waste problem is unceasingly increasing in Kampala and Uganda at large. It identified the common e-wastes in households, institutions, and that held by the recyclers. The e-waste was quantified, and its associated environmental risks were identified. Therefore, this study suggests that despite the plethora of suggestions and recommendations, there is need for a similar study that will conduct a more detailed investigation to cover the entire country and have more room for soil samples or elements for soil analysis.

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APPENDICES

Appendix A: Consent Form for Interviews

Post-graduate research project: QUANTIFICATION OF ELECTRONIC/ELECTRIC WASTE AND ITS ASSOCIATED ENVIRONMENTAL RISKS: A CASE STUDY OF KAMPALA CITY

Master of Degree of Science in Civil Engineering of Makerere University

Please initial box

I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. ☐

I understand that my participation is voluntary and that I am free to withdraw at any time ☐

I agree to take part in the above study ☐

I understand that the confidentiality of the information I provide can only be protected within the limits of the law ☐

Please tick relevant box

	Yes	**No**
I agree to the inclusion in the research assignment of direct quotations from our interview, using a 'pseudonym' to protect my identity. (*Or, if you don't want any quotations used, please tick 'no'*)	☐	☐
I agree (or not) to the interview being audio-recorded	☐	☐

………………………………………. ……………………. …………………………
Name of Participant Date Signature

TUKAMWAKIRA GODFREY ……………………. …………………………
Name of Researcher Date Signature

Appendix B: Households Questionnaire

My name is Tukamwakira Godfrey, a student from Makerere University pursuing a Master of Degree of Science in Civil Engineering at the College of Design, Art and Technology carrying out a study on; "*Quantification of e-waste and its associated environmental and public health risks*". The information from you is relevant to my study and is strictly for my academic purposes. You are kindly requested to participate in this study by providing appropriate responses to questions provided. I am looking forward to getting your cooperation in filling the questionnaire.

Thank you in advance

Section A: Background characteristics (Households)

1. What is your name: ____

2. Age of the respondent _______________________(In complete years)

3. Gender of respondent

1) Male
2) Female

4. About how many members do you have in your household? _______________________

5. Location of the respondent ____________________________

6. What electronic/electric devices are common in your household?

1) TV and media, DVD players, VCRs, MP3, CD players
2) Mobile Phones including smartphones, simple phones
3) Cars/Batteries
4) Computers, Camera, Printers/Desktop computers
5) Water heating equipment (kettles, percolators, coils)
6) Cooking (cookers, gas cylinders) and Lighting equipment/Bulbs
7) Refrigerators/washing machine, microwave/air conditioning
8) Others (specify) ______________________________

7. What do you do with working electronic devices that you do not currently use?

1) Put into storage
2) Give out to someone I know
3) Sell out as second-hand
4) Give away on freecycle
5) Take to local recycling center

6) Strip for spare parts/materials
7) Other (specify) ________________________

8. What do you do with broken electronic/electrical devices?

1) Put into storage
2) Give out to someone I know
3) Sell out as second-hand
4) Give away on freecycle
5) Take to local recycling center
6) Strip for spare parts/materials
7) Other (specify) ________________________

9. Do you know where all the electronic/electric waste generated ends up?

1) Yes
2) No

10. On a scale of 0-5, how much do you know?

1) 0-1—I know nothing
2) 1-1— I don't know much
3) 2-1—I know a bit
4) 3-1—I know more than average
5) 4-1— I know quite a lot
6) 5-1—I know about all stage

11. On the average, about how many electronic/electric products have you purchased since last year __________

12. And how many have you released out just about the same time ____________________

13. On the average, about how many electronic/electric products do you choose to repair in a year __________

14. Which factors would affect your choice whether to repair or dispose of?

1) Price of repair compared with replacing
2) Availability of spare parts
3) Need to disassemble product
4) Knowledge of skills needed to repair
5) Warranty of product
6) Other (specify)

15. How long do you expect the following electronic/electrical items to last?

Items	6 months	1 year	2 years	5 years	5+ years
TV, DVD, VCRs, MP3, CD players					
Computers, camera, printers					
Water heating equipment					
Cooking and Lighting equipment					
Refrigerators/washing machine, microwave/air conditioning					

16. To what extent do you think electronic/electric products are hazardous to the environment?

1) To a larger extent
2) To a smaller extent
3) Not sure

17. Electronic/electric waste products possess health implications to the public in form of pollution and cancer.

1) True
2) False

18. Depending on your response, elaborate.

____

____

____

____

Thank you for your insightful responses!!!

Appendix C: Institutions Interview Guide

Introduction:

My name is Tukamwakira Godfrey, a Makerere University student pursuing a Master of Science in Civil Engineering at the College of Design, Art and Technology. As part of the criteria for the award of the Master of Science in Civil Engineering, I am conducting a study on "*Quantification of e-waste and its associated environmental and public health issues*". You are kindly requested to take part in this study by responding appropriately to the questions. I eagerly anticipate your assistance in locating answers to the following inquiries.

Background:

According to the e-waste management policy report, Uganda, just like in many developing countries, workers in e-waste scrap yards are constantly exposed to toxic chemicals that are by-products of deconstructing components. These chemicals also pollute land, water and air.

E-waste encompasses all discarded and disposed of electrical and electronic assemblies, and scrap components. Some of these wastes contain hazardous materials such as cadmium, mercury, lead and polychlorinated biphenyl. Therefore, E-waste includes a broad range and growing number of electronic devices - from large household appliances such as refrigerators and air conditioners, to personal products such as handheld cellular phones, personal stereos, consumer electronics and computers.

A quantitative and qualitative assessment of e-waste in Uganda was carried out by United Nations Industrial Development Organization (UNIDO) in 2008. According to the data, government institutions own the most ICT equipment in the country, followed by non-governmental organizations (NGOs) with around 75 percent each, major corporations with about 20%, private households, Small and Medium Enterprises (SMEs), and others with approximately 5% each. In light of this, this study determined that it was necessary to look into the quantity of waste generated in households, recyclers and government institutions in order to determine its influence on the environment and human health. In a nutshell, there has been no policy or strategy to handle the E-waste threat ().

Legal and Policy Framework

The draft national IT policy for Uganda has an objective that addresses e-waste. Under Policy Priority area 2.7, it states that an e-waste policy should be developed and implemented. The National Environmental Act, Cap.153 that provides for sustainable environment, addresses solid waste management in general. However, it is silent on e-waste management. There is, therefore, no specific e-waste legislation in Uganda.

Questions

1. On a scale of 1 to 10, how much do you know about Uganda's e-waste legislation?
2. How many e-products are imported into the country on an annual basis on average? __________________
3. Do you have any idea how many are being destroyed at the same time? _________________
4. In this institution, which electronic devices do you use a lot? give specifics
5. How well do you understand the materials used in e-waste and their impact on human health?
6. In your institution, which of the following gadgets are regularly used?
    a) Entertainment gadgets (TV and media, DVD players, VCRs, MP3, CD players)
    b) Office e-products (desktop computers, laptop, tablets, mobile phones, monitor stands, Mouse, Keyboards)
    c) Cars/vehicles/motorcycles/ pickups, vans, and sport utility vehicles etc
    d) Industrial equipment (Tools and fabrication equipment, such as power saws, drills, hand tools, metal-working machines, polishing machines, presses, boilers, industrial ovens, and industrial scales, Tools and fabrication equipment, such as power saws, drills, hand tools, metal-working machines, polishing machines, presses, boilers, industrial ovens, and industrial scales)
    e) Cooking and Lighting equipment (Air conditioner, blender, cooker, blower, fryer, clothes iron, coffee maker, cables and bulbs)
    f) Domestic appliances (toaster, kettle, percolators, blenders, washing machines, stoves, refrigerators, microwave etc.)

g) Others (specify) ______________________________

7. Which e-products aren't widely utilized in your institution?
8. Estimate the expected useful life (in complete years) of the following electronic/electric products in your own opinion;

Electronic/electric products	1 year	2 years	3 years	4 years	5 years	5+ years
Entertainment gadgets						
Office e-products						
Automobiles, Cars/Vehicles						
Industrial equipment						
Cooking & Lighting equipment						
Domestic appliances						

9. What are the several methods your institution handles and manages e-waste?
10. When dealing with e-waste, which of the following phrases is frequently employed at this institution: reuse, recycle, or repair/repurpose? explain
11. Is there an organization/institution responsible for recycling or dismantling or reusing or refabricating your unused electronics?
12. Do you see any environment or health risks in e-waste management in your institution or in the country at large?
13. Do you ever interact with electronics producers? If so, please describe your interactions.
14. Do you think the government should do anything to assist you in your work?
15. Who do you think should have the responsibility of dealing with e-waste in Uganda?
16. Who is responsible for the growing amount of e-waste in Uganda?
17. What could be some of the benefits arising from the growing number of e-products?
18. What major challenges has this institution faced in managing and regulating the large influx of e-products?

Thank you for your insightful responses!!!

Appendix D: Soil Samples Analysis

Soil samples handling in the Laboratory

The samples were air dried at about 25ºC for 5 days to eliminate the moisture. They were then ground using a porcelain pestle and mortar and then sieved through a 2 millimetre sieve to remove debris and other non-soil materials including stones and roots. The sieved soil samples were repackaged, clearly labeled and analyzed from the **Soil, Plant and Water Analytical Laboratory** at the Department of Agricultural and Environmental sciences, School of Agricultural sciences, College of Agricultural and environmental Sciences - Makerere University.

On the sieved soils samples, 3 heavy metals including **(Lead (Pb), Mercury (Hg) and Nikel (Ni)** were analyzed.

Soil analytical methods employed

A known weight of the plant samples 0.50g were weighed and placed in a digestion tube and digested using 5 ml of digestion mixture (composed of concentrated sulphuric acid, Hydrogen peroxide, selenium powder and salicylic acid) at 360ºC and above until a colorless solution is obtained. The compounds in the plant samples are reduced to their corresponding forms after complete oxidation of organic matter. Hydrogen peroxide acts as an anti-foam by oxidizing the organic matter while Selenium powder lowers the boiling point and acts as a catalyst for the process and the concentrated sulphuric acid completes the digestion at elevated temperatures.

The digests were cooled, diluted to 50ml using distilled water and filtered through a Watman filter paper to obtain a clear solution. The concentrations of the heavy metals were determined from the diluent using an atomic absorption spectrophotometer (AAS). All analyses were performed using the routine procedures outlined by Okalebo *et al*., (2002) and other standard operating procedures (SOPs) that are internationally recommended. During the digestion and analysis, a reference sample and blanks were repeatedly included for quality control and assurance and hence authenticity of the results.

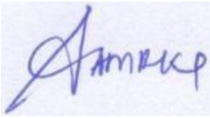
Soil analysis results

Lab No	**Particulars**	**pH**	**Cd**	**Hg**	**Ni**
			mg/kg	**mg/kg**	**mg/kg**
A	Usafi Market spot 1 and 2	4.43	2.7	30	28.5
B	Kisenyi Spot 1 and 2	7.24	1.8	190	56.6
C	Kalerwe Site 0-30cm, 2/05/2022	7.05	7.4	130	98.6
1	Usafi Market spot 1 and 2 Control	6.99	BDR	BDR	BDR
2	Kisenyi 2 spots Control	7.5	BDR	BDR	BDR
3	Kalerwe 2 spots Control	8.78	BDR	BDR	BDR
	Standard/Limits		**Absent**	**Absent**	**0.02**

References

1. **Okalebo, J.R., K.W. Gathua and P.L. Woomer, 2002**. Laboratory Methods of Soil and Plant Analysis: A working Manual. Second Edition. TSBF-CIAT and SACRED Africa, Nairobi, Kenya. p128.

Analyzed by,



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Appendix E: Nature of E-waste at Kisenyi