THE UNIVERSITY OF NAIROBI
DEPARTMENT OF COMPUTER SCIENCE
FACULTY OF SCIENCE AND TECHNOLOGY

INFORMATION EXCHANGE MODEL FOR SUSTAINABLE E-WASTE MANAGEMENT IN KENYA

BY

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P51/11198/2018

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A project proposal submitted in partial fulfillment of the requirements for the award of the degree of Masters of Science in Applied Computing of the University of Nairobi, School of Computing & Informatics

AUGUST, 2021

DECLARATION

Declaration by the Student

This Research Project is my original work and has not been presented for the award of a degree in any other University

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Date. 30th August 2021.

Declaration by Supervisor

I do hereby certify that this project proposal has been presented for examination with my approval as the Supervisor.

Supervisor

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Date. 1st Sept 2021

Signature......................................

DEDICATION

This project report is dedicated to my family and friends who continuously supported and encouraged me throughout the project.

ACKNOWLEDGEMENT

I, first of all, thank the creator, the Almighty God for seeing me throughout the study. My appreciation also goes to Dr. Lawrence Muchemi, my supervisor. I also appreciate the support of my friends and families that ensured that I have ample time to complete the project.

ABSTRACT

Globally, the quick adoption, use and disposal of ICTs wastes have resulted to the flourishing of the e-waste phenomenon that has increased the level of e-waste streams. The rate of growth of this stream of waste is between 3–5% per year. This is viewed as approximately three times faster than solid waste from ordinary municipalities. Davis and Heart (2015) argued that the e-waste stream increase has attracted attention from various bodies such as individuals, governments, and even researchers and academicians because of its impact on the human and environment and health. This research sought to examine the existing model and develop a new information exchange model for sustainable management of e-waste in Kenya. A pre-study was also carried out to investigate the process of e-waste management in Kenya. The study's targeted population is comprised of stakeholders of the e-waste management system in Kenya. In Kenya, the systems for management of e-waste comprises of stakeholders who range from importers, retailers, assemblers, downstream vendors, consumers, refurbishes, recyclers, and final waste disposers and chosen households located near dumpsites to policy-makers.

The study's sample size was determined using the Yamano Taros formula, Israel (2012). The study's sample size comprised 50 stakeholders of e-waste management in Nairobi. The participants were chosen using a simple purposive sampling technique. The 50 represents 50% of the total population. The participants were chosen using the purposive random sampling technique. The study employed questionnaires for data collection. This study employed both descriptive and exploratory survey designs. This is because the study involves a mix of quantitative and qualitative approaches. The responses from questionnaires were analyzed using SPSS. The study established that currently, there is no information exchange model in Nairobi and thus the whole practice of e-waste management was manual.

Rapid Application Development (RAD) was employed in system design to give high-quality results and for faster development compared to the traditional lifecycle of system development. The use of RAD entailed collecting requirements through use of workshops, prototyping, focus groups and early user texting of design, and also the re-use of software modules. The information model was developed and tested and found to be easier and to enhance the efficiency of e-waste management in Nairobi.

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LIST OF ABBREVIATIONS AND ACRONYMS

EoL	End-of-Life
EPR	Extended Producer Responsibility
ICT	Information Communication and Technology
NEMA	The National Environment Management Authority
SPSS	The Statistical Package for Social Sciences
UNEP	United Nations Environmental program
WEEE	Waste of Electrical and Electronic Equipment
GoK	Government of Kenya

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Information and Communications Technology (ICT) rapid growth has led to a demand for more electrical and electronic equipment marking a new age in human civilization. Chacko (2016) posit that the information and communication revolution has in the 20th century brought massive changes in the way economies, lives, institutions and industries are organized. With the current increased economic growth, technology has become an essential part of our life activities. Its use has generated vibrant opportunities as well as challenges such as the enormous volumes of electronic waste (e-waste) generated and inappropriate e-waste disposal methods. The digital revolution that started in the 1970s has resulted to the significant proliferation and digitalization of traditional electrical products and devices. The consumptive lifestyles coupled with fast technological development have hastened the speed with which electronic products are declared obsolete (GOK, 2018).

According to UNEP (2015), the world is currently undergoing first-rate industrialization with manufacturing and processing industries on the rise, technological change with a desire to improve efficiency in industries is also on the rise. The worldwide growth in electrical and electronic equipment manufacture and consumption in the last two decades has been exponential. E-waste is currently the fastest growing stream of waste, with about 4 percent growth annually. The global generation of e-waste is approximated at about 40 million tons annually which is attributed to an improvement of in the level of market penetration of products in emerging countries, the development of a replacement market in developed countries, and a generally high product obsolescence rate.

The waste state continues to prosper due to the rapid adoption and use of ICTs which contributes to the increase of the e-waste stream. Waste E is said to be one of the fastest growing streams at a rate of 3-5% per year, almost three times the amount of solid waste. Increase in e-waste stream has attracted the attention of many individuals, researchers and governments due to its effect on the human and environment health (Davis & Heart, 2015).

Electronic waste or e-waste embraces various forms of electrical and electronic equipment that have ceased to be of any use to their owners. Many day to day commodities for instance, refrigerators, household appliances, and toys that were formerly considered electrical equipment are becoming 'electronic' objects through the addition of programmable microprocessors. They also lead to the generation of a huge amount of waste which are hazardous and are a threat to the environment and human health (Agnthori, 2011).

In Europe, the EU enforced two directives which are Directive 2002/95/EC which restricts the use of different hazardous substances in WEEE and Directive 2002/96/EC on WEEE. The directives impose an extended responsibility to the producer and encourage, recycling, recovery, reuse and reducing the environmental effect of e-waste. The concept of QWERTY/EE "(Quotes for environmentally Weighted Recyclability and Eco-Efficiency)" is employed to enhance or enable the environmental performance of end-of-life products. According to Huisman and Stevels (2004), the QWERTY/EE strategies include ascertaining: hazardous substances restrictions, recycling that is weight-based and recovery targets, recyclers' treatment rules, minimum collection amounts, and recyclers outlet rules.

According to Ni and Zeng (2009), illegal exporters of e-waste from Asia to China evade detection by routing container ships through Hong Kong, Taipei, or the Philippines, and then trans-shipping them to smaller ports in mainland China, where customs officials are corrupting and willing to share the profits. Singapore and Dubai often serve as points for e-waste transit from industrialized countries. According to Green Peace International, hazardous wastes are also being shipped to China illegally from developed countries like the USA, Japan, and Canada, although Basal Convention prohibits transboundary movement of hazardous waste. The escalation of this problem in China is not due to the lack of laws and regulations, but rather due to ineffective enforcement.

In India, a study released by the ELCINA at the electronics industry expo Componex Nepcon 2009" in India estimated that more than 4,340,000 tonnes of e-waste generated from industrialized nations finds its way easily into emerging nations in the name of free trade. This further complicates the challenge related to management of e-waste. However, there are no specific regulations, guidelines or laws for e-waste management in spite of there being a wide range of environmental legislation in India (Devi et al., 2014).

Analyzing the e-waste scenario in Africa, the overview of existing literature shows that Tanzania has no specific policy or regulation related to e-waste management. However, there are numerous regulations and guidelines, which aim at protecting the surroundings and human settlements. The assessment of these distinctive policies reveals there being a need for e-waste specific guidelines to deal with the exclusive demanding issues and problems of e-waste management. In addition, some laws and regulations offer an institutional model for overall sustainable environmental management, among others is the EMA No. 20 of 2004. Tanzania has no specific e-waste management laws. However, e-waste management is carried out using solid waste and hazardous management practices under the e-waste environmental management law, and in particular. E-waste is thus addressed in section 4 of the environmental management act. Government through the Office of the Prime Minister, environmental division, has developed an action plan and strategy which among other things, attends to the issues of managing e-waste (UNEP, 2015).

E-waste poses one of the greatest environmental challenges to Kenya. This is linked to the country's need for industrial growth brought about by provisions in the vision 2030 and the Constitution that embraces county governments, and that the counties are all out to bring growth and development by embracing industrial growth. The processing and manufacturing industry in Kenya is among the key productive sectors recognized for growth and development of the country's economy because of their relative potential for employment and wealth creation, and poverty alleviation. The industrial sector in Kenya is considered one of the largest in Sub-Saharan Africa and is relatively fragmented with more than 2,000 manufacturing companies. This trend of development is expected to initiate industrial enterprises, which would in turn result in increased quantities and complexity of pollutants from e-waste (GoK, 2014).

1.2 Problem Statement

The industrial area of Nairobi County has the highest number of industries in one locality not only in the country but also in East Africa at large, majority of which are processing and manufacturing making it one of the largest sector currently in Sub-Saharan Africa. This level of industrialization is anticipated to increase to higher levels. This was further boosted by the provisions in the Constitution of Kenya 2010 and vision 2030 both of which embraces the establishment of county governments and the improvement of the country's economic growth generally. Given that, counties are all out to bring economic growth and development by embracing industrial growth.

Even though we have several regulatory and legislative frameworks governing general management waste in the country, there are no laws specifically on e-waste. The regulatory structure it is not efficient in handling the situation on the ground hence such waste is not properly managed. This is likely to affect the environment soon due to the poor handling of e-waste.

E-waste is the 21st century the main environmental problem. It poses a severely rising challenge to the suitability of the global environment. As such governments are forced to come up with and implement management practices that are environmentally sound to maximize recovery, recycling and re-using of important elements and minimize environmental impacts (Mmereki, Li, Baldwin & Hong, 2016). Effectively managing e-waste in emerging nations has not reached its full potential for reasons such as; absence of appropriate legislations; lack of technological, financial, technically skilled human resources, lack of awareness on e-waste impacts, lack of investment, little available information, lack of infrastructure and also inadequate description of the stakeholder individuals and institutions' roles and responsibilities (Ongondo, Williams & Cherrett, 2011). However, there has been quite little research on e-waste that focuses on emerging nations compared to developed countries (Sthiannopkao & Wong, 2013).

Studies have been conducted to try to explain the level of management of e-waste. For illustration; Cherutich (2013) examined the status of mobile phone E-waste management in Nairobi, Kenya. Using a descriptive research design and a sample of 80 stakeholders in the mobile phone sector in Kenya, the research found that in Kenya, the mobile phone comprises post-consumption activities that involve mobile phone E-waste being recycled and exported and that both economic and social upgrading is occurring in Kenya. Otieno and Omwenga (2015) reviewed the challenges and opportunities of E-Waste Management in Kenya. The study observed that the rapid growth and development in ICT in developed and developing countries is to blame for the ever-increasing level of e-waste. The study then concluded that E-waste management in Kenya faces challenges such as lack of proper policy and legislative framework, low citizen awareness, inadequate infrastructure for E-waste management; high cost of brand new electronic devices, and absence of frameworks for End-of-Life (EoL) product take-back.

This study will be relevant since there exists research gaps in this area of knowledge. This topic has not been researched extensively which is denoted by the limited literature on the topic. The literature reviewed on this area of knowledge is mostly based on other contexts for instance; a study by Heeks, Subramanian, and Jones (2015) focused on e-waste management in India. Kumar and Bhaskar (2016) focused on European countries together with Egypt. Anyango's (2011) review of sustainable e-waste managing framework in Kenya and came close to tackling this topic but did not narrow its scope to Nairobi City County. This research seeks to fill the gap by determining a communication model for sustainable e-waste management in Nairobi City.

1.3 Research Objectives

The objectives that will guide this study include:

i. To design an information exchange model
ii. To determine the information exchange models currently existing in e-waste management
iii. To process the mapping process of e-waste management in Kenya
iv. To validate information exchange model through prototype

1.4 Research Questions

The research questions that will guide this study include:

i. What are the responsibilities of different e-waste stakeholders in Nairobi City, Kenya?
ii. What e-waste disposal practices are employed by various stakeholders in Nairobi City, Kenya?
iii. What challenges face the e-waste stakeholders in Nairobi City, Kenya?
iv. How does the communication information exchange model influence the sustainability of e-waste management in Nairobi City?

1.5 Significance of the Study

The results of the study will be significant to both the national and local government and other regulators in the country such as NEMA (National Environment Management Authority) through enlightening them on making guidelines and policies that will enhance the sustainability of e-waste management in Nairobi City.

The findings of the study will also be significant to the investors in ICT through enlightening them on the best way to promote the sustainability of e-waste management in Nairobi County for sustainability.

The study findings will also benefit all types of organizations both private and public and others that are using ICT appliances in enhancing the sustainability of e-waste management in Kenya. This study will act as a reference point for e-waste management policy and practice implementation by the City-County.

The study will also add to the existing knowledge on e-waste management and sustainability. The study will also form a basis for future research on sustainable e-waste management in Nairobi City in Kenya.

1.6 Justification of the Study

The study will be carried out to examine the current status of the communication model for sustainable e-waste management in Nairobi city. The researcher will determine the responsibilities of different e-waste stakeholders in Nairobi City, Kenya, the e-waste disposal practices that are employed by various stakeholders in Nairobi City, Kenya, and the challenges that face e-waste stakeholders in Nairobi City, Kenya.

1.7 Assumptions and Limitations of the Study

1.7.1 Assumptions of the Study

The study will be focused on Nairobi City a major consumer of electronic and electrical products and is bound to observe the communication framework for sustainable e-waste management.

1.7.2 Limitation of the Study

The researcher is constrained by time and financial resources and as such, the study intends to focus on dealers in Nairobi City, as the representative of e-waste management in Kenya. However, different Cities in the country may be facing different e-waste related challenges.

1.8 Scope of the Study

The scope of this study revolves around an examination of the communication framework for sustainable e-waste management in Nairobi City which may not necessarily represent the communication framework for sustainable e-waste management in other cities in the country. The study's geographical scope focuses on Nairobi city since that's where most dealers in electronic handling and disposal operations. The study will be limited to descriptive and inferential statistics methods.

1.9 Definition of Key Terms

Environment:	The surrounding where the living and non-living things happen naturally.
Environment Impact Assessment (EIA):	Is an organized evaluation that is carried out to establish whether or not a project or activity will have a substantial impact on the environment to avail mitigation measures for the adverse impacts.
Electronic Equipment:	A component that has controlled electrons conduction especially in a vacuum or gas or semiconductor.
E-waste (Electronic waste):	Also Waste Electrical and Electronic Equipment (WEEE) entail discarded mobile phones, office electronic equipment such as entertainment device electronics, computers, refrigerators, and television sets.

Heavy Metal:	Denotes any metallic chemical element that is poisonous or toxic or at low concentrations and has relatively high density (76g/cm3) for instance; mercury (Hg), cadmium (Cd), chromium (Cr), lead (Pb), arsenic (As) and thallium (Tl) (Hati, 2009).
Information and Communication Technologies (ICT):	Is a general term that refers to any communication device or application that comprises television, radio, computer, cellular phones, and network software and hardware satellite systems as well as the various applications and services related to them, for instance, distance learning and videoconferencing.
Sustainability:	A combination of resources is used to preserve the environment as well as meet human needs not only in the present but also for future generations.
Re-use:	Involves continuing to use a component (the same way and for the same purpose) beyond the point it was developed for and the owner has stopped to use for at the point it fails to meet the requirements of the current owner.
Extended Producer Responsibility (EPR):	Is a strategy that entails making the manufacturer responsible for a product's entire life cycle, including, disposal, take back, and recycling.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This section presents literature on current policies and institutional mechanisms that are implemented to try to solve the e-waste challenge in Kenya, how e-waste is handled by manufacturing and processing industries especially from passive elements, validate information exchange framework through a prototype, existing information framework, conceptual framework, theatrical framework

2.2 Policies and Regulatory Framework that Govern E-Waste Management

E-waste is a worldwide challenge with environmental and health implications, several policies and regulatory frameworks governing the management of e-waste have been implemented to try to mitigate the problem. The Basel Convention was put in place and by September 2010, the Convention had been ratified by 178 members. The convention was developed to send a stronger message on hazardous waste management and trade in Africa. The 4^{th} Article in the Convention calls for companies to generally reduce the level of e-waste they generate by encouraging nations to keep the wastes they generate within their country's boundaries and if possible very close to where it was generated. The convention further puts pressure on the authorities to exert pressure on organizations so as the pressure works as an incentive for pollution prevention and waste reduction.

According to Liza (2015) as cited by Nuwematsiko, Oporia, Nabirye, Halage, Musoke, and Buregyeya (2021), only 20% of respondents had an e-waste policy. The Convention further considers trafficking of illegal hazardous waste as criminal but does not provide any enforcement grounds or provisions. Article 12 of the convention directs parties to implement a protocol that lays out liability procedures and rules that are suitable for damages that occur during the cross-border movement of hazardous waste. Most countries in Europe have also adopted several policies to help in the control and management of e-waste.

E-waste management calls upon nations to adopt their ways to formulate actions and define their responses regarding the challenges of managing e-waste. Most countries are reviewing their present legislation to improve the level of compliance with the legislation. This entails in some instances amending the existing legislation governing waste management to enable effective regulation of the management of e-waste. This has not been realized in Kenya as no legislation has been reviewed to allow for the regulation of e-waste (Durban Declaration, 2015)

More recently, Kenya has been hailed as an example of environmental progress in the region following the enactment of the constitution promulgated on August 27, 2010, and became Kenya's supreme law, containing specific environmental measures. Kenya's constitution The supreme law of the land contains certain provisions for the environment. Provisions are included in Chapter Four, under ‘Fundamental Rights and Freedoms’, Chapter Five, under ‘Environment and Natural Resources, and Chapter Ten, under the ‘Judicial Authority and Legal System’. Schedule Four also includes environmental provisions under the ‘Allocation of functions between National and Regional Governments’ and Schedule 5 entitled ‘Legislation by Parliament GoK (2016).

EMCA 1999 is an Act of Parliament to provide for the establishment of an appropriate legal and institutional framework for environmental management. It was set up to ensure that the appropriate legal and institutional framework was in place to effectively manage the environment and any other environmental issues. It seeks to integrate the functions of the various institutions assigned to the management of the various sectors. These institutions are called Lead Agencies in the EMCA. Lead Agencies are defined as including a government department, department, NGOs, and the state or local authority where any law provides for the control or management of any natural object or natural resource. The enactment of EMCA served as the first and main framework towards environmental sustainability. The right to a clean and healthy environment had been acknowledged in the EMCA 1999 (Kenya Gazette, 2000). The provision for a legal and institutional framework is one of the basic conceptual tools for environmental management NEMA waste management regulations (2016).

The Kenya Vision 2030 is the country’s development blueprint covering the period 2008-2030. It aims to transform Kenya into a newly industrialized middle-income country providing a high-quality life to all its citizens by the year 2030. The Vision is based on three key pillars of economic, social, and political as well enablers and foundations of micro vision. For each of the pillars and foundations, priority sectors have been identified to drive the aspirations of the vision. It is envisaged that the county government will identify vision 2030 flagship projects and programs that will be implemented at the county level to include environmental management and work with the national government to ensure there are realized GoK (2015).

Kenya has ratified several conventions internationally, regionally, and nationally. These include; the Montreal Protocol which focuses on the substances that deplete the Ozone Layer (1987); the Vienna Convention for the Protection of the Ozone Layer; the Basel Convention which focuses on the cross-boundary movement and disposal of hazardous waste (1992); the Ban Amendment (2004); the Stockholm Convention which focuses on the persistent organic pollutants (2004) and the Kyoto protocol. Regionally, Kenya has ratified conventions such as the Bamako Convention which focuses on the ban of imports into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa (1991); Africa agenda 2063, and the Maputo protocol.

Nationally, Kenya has implemented legislation to guide the management of electronic waste. These include; the Waste Management Regulations (2006) and the Environmental Management and Coordination Act 1999 (Revised 2015). The two legislations forbid handling, disposal, or transportation of waste without valid licenses allotted by NEMA. NEMA further in 2010 developed the National E-Waste Guidelines that would help stakeholders such as the private sector, the government, learning institutions, and others to effectively manage e-waste to improve environmental conservation.

Internationally there are three existing legislations and policies related to e-waste, namely: Silicon Valley Toxics Coalition, which was formed in 1982. It is a diverse grassroots coalition that engages and is organized around the environmental and human health problems caused by the rapid growth of the high-tech electronics industry. The other one is the Basel Action Network (BAN), which is a global 21 network of toxics and development activist organizations that share a vision of international environmental justice. The network seeks to prevent all forms of 'toxic trade' in toxic wastes, toxic products, and toxic technologies A major hurdle to the proper handling of E-waste on a global scale is, among others, a lack of policy frameworks on national, regional, and global levels. There are three major challenges to the definition and implementation of policies: Awadalla (2015) countries like the Japan, USA, and China have revised laws for the management of e-waste. Regulations in China that specifically deal with e-waste are in the implementation stage, for instance, the Management Measures for the Prevention of Pollution from Electronic Products regulation. This focuses on eliminating e-waste's environmentally adverse processing and reducing the utilization of toxic and hazardous substances in electronic appliances (Xianbing et al., 2016).

2.3 E-waste Handling in Manufacturing and Processing Industries

According to Sepulveda et al., (2010), E-waste is a global environmental and health emergency concern; which is due to the toxic substances it contains. E-waste, therefore, is a very critical and delicate process. A safe, cheap, and simple processing approach appropriate for introduction into the informal sector is lacking. The processes of handling e-waste are of concern, dismantling and disposing of e-waste in third world countries has led to several environmental impacts, toxic substances can be found within effluents from cyanide leaching and other leaching activities (Sepulveda et al., 2010).

Global emissions of mercury in the atmosphere are about 2000-3000 tons per year. It is estimated that 22% of the annual mercury use of EEE Mercury is used in thermostats, sensors, transmitters, and switches (printed circuit boards and measuring machines, and light bulbs). In addition, it is used for medical devices, data transfer, telecommunications, and cell phones. In the EU, 300 tons of mercury is used in AEA stand-alone position sensors (2014).

Cadmium metal or powder is still used as part of the negative electrode properties in nickel-cadmium (NiCad) batteries, such as electrodeposited, vacuum enclosed or mechanically coated in metal, metal, aluminum-base, alloys. Titanium-base alloys, or other non-ferrous alloys, and as part of combining low bean, soldering, and other special alloys (AEA, 2014).

Beryllium metal offers a unique and unique combination of properties. It is one of the simplest building materials available, but it is often stronger than steel. It has excellent thermal conductivity, high electrical conductivity, good corrosion resistance, good fatigue resistance, high strength, and good durability. Traditionally, copper-beryllium alloys were used on motherboards on your computers. Beryllium is no longer widely used in this form, but its use in combination with copper as an alloy is increasingly Five Winds International, (2015).

By the Danish standard, the WEEE represents about 78% of the total content of flame retardant pipes (European Commission, 2000). Tetrabromobisphenol-A (TBBPA) is the largest flame-producing volume in production today. It is used as a reactive (basic use) or additive flame retardant in polymers, such as epoxy and polycarbonate resins, high-density polystyrene, phenolic frames, adhesives, and others. Its main use in EEE is as an active flame retardant on printed circuit boards.

The Nairobi City Council is responsible for a comprehensive waste management and management function within its jurisdiction. In implementing the powers conferred on Local Government by section 201 of the Local Government Act (Section 265) of the laws of Kenya, the Nairobi City Council in 2007 came up with a strong by-law or by-laws to assist this law and the management of all solid waste generated in its area. Section 4 (7) of the by-laws stipulates that the occupier or owner of a dwelling or commercial premises within the area of jurisdiction of the City Council shall be liable for litter from such premises as directed by the Council specifically or under a planning scheme established by the Council under these by-laws; resides or conducts business or other activities (GoK, 2017).

Wang et al. (2014) noted that the constitution affirms that the right to a clean and healthy environment is a fundamental right and that any e-waste handling activity should pay attention to this close. Informal recycling enables dangerous job opportunities for thousands of people and therefore an important step should be to try to deal with occupational hazards in the sector. Employees need to be informed of the effects of e-waste waste disposal on health and the environment. As a result, the regulation should be incorporated into incentives for informal recipients not to engage in harmful practices, such as incentives to contribute parts to site collections rather than process them.

In Kenya, the management of electronic waste has not been prioritized as it deserved at the national level as shown by the inadequate regulatory framework in the country to effectively manage WEEE. The authorities in charge also face challenges of inadequate resources, limited capacity, effectively addresses the problems and challenges associated with E-waste. The Waste Management Strategy (2019) also suggests that the national government has no efficiently structured mechanisms for separation of WEEE from other solid wastes by the county government and collect, store, transport, and also process electronic waste.

2.4 E-Waste Practices in Kenya

Statistics show that in Kenya, about 150 tons of mobile phones, 500 tons of printers, 2,500 tons of personal computers, 2,800 tons of TVs, and 11,400 tons of refrigerators, are generated annually in the country (UNEP, 2010). Although reputable organizations in the country such as Nokia have come up with initiatives to manage electronic waste through their Computer refurbishment programmers and recycling schemes, the management practices of electronic waste are largely done by informal sectors known as “Juan Kali”. These informal sectors are mostly constrained by challenges such as they are neither registered nor authorized to operate thus they do their work in secrete and also have inadequate skills and resources. The work of the informal sector is well connected to the supply chain processes for sourcing raw material to finding marketplaces for the materials they have recovered at the post-recycling process. The processes involved in their operations are mostly toxic and have a huge impact on human health and the environment at large.

Most consumers around the country have ended up holding excessive stocks due to a lack of clear disposal mechanisms. UNEP (2010) observed that the unavailability of well-developed structures to manage electronic waste disposal results in a ‘drag’ on the volume of waste in the country. Lack of strategies and processes for the management of waste disposal has resulted in a lot of the old technology being kept in stores. Waste disposal approaches differ widely depending on the user. The approach used by the government in waste disposal includes bonding the computers and inviting the competitive tenders for disposing of as according to the procurement procedures is mostly slow which result in outdated computers being kept in stores by the government (Waste Management Strategy, 2019).

Other electronic waste management practices in Nairobi City include; extended the producer take-back scheme after the end-of-life of electronic equipment; reduce e-waste disposal to landfill;

regulate the design of electrical gadgets that are imported into the country to emphasize reducing e-waste and increasing its recyclability, recoverability, or reusability; clarification of the e-waste regulations, guidelines, and standards for all imports; establishment of financing mechanisms and systems for e-waste recovery and treatment; establishing collection facilities for e-waste from private households; set and attain targets for recovery, recycling and reuse of different types of electronic devices (Waste Management Strategy, 2019).

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2.5 Existing Information Exchange Models

There are various existing information exchange architectures. This study however reviews information exchange architectures from four countries that are deemed relevant to this study.

2.5.1 Information Exchange Architecture in Switzerland

In Switzerland, information exchange is given into three levels for collecting, treating, and disposing of e-waste with industry-established authorities including the Stiftung Entsorgung Schweiz (SENS), the Swiss Association for Information, Communications and Organisational Technology (SWICO), and Stiftung Licht Recycling Schweiz (SLRS) tasked with the responsibilities. Switzerland was the first country to implement a take-back system in 1998 to ensure Sthat WEEE is disposed of in a manner that is environmentally appropriate so that it does not mix with municipal waste. The system requires the end-users to dispose of WEEE with a manufacturer, importer, or to a disposal facility. The importers, manufacturers, and retailers were mandated to take back WEEE from consumers free of charge. The parties tasked with collecting WEEE in Switzerland are accountable for the disposal of the WEEE that they do not reuse and also disposal is required to be done in an environmentally sound manner. In Switzerland, most of the WEEE generated is collected. For instance, of the 184 kilo-tonnes generated in 2016, the take-back system collected 134 kilo-tonnes which is about 73% of that total WEEE generated.

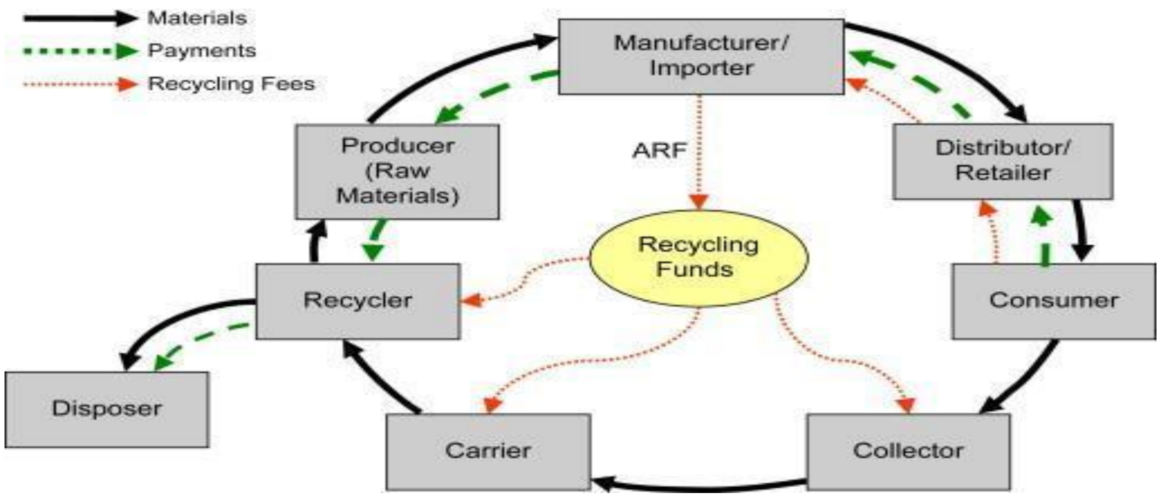


Fig 1: Information Exchange Architecture in Switzerland

2.5.2 Information Exchange Architecture in Malawi

In Malawi, it is estimated that between 8.69 and 11.66 million devices will be obsolete in the next five years between 2018 and 2022. 95 percent of the obsolete devices will be represented by mobile phones which are attributed to the high penetration and exponential growth as shown by an estimated 14.3 percent compound annual growth rate (CAGR) between 2018 and 2022. However, of all of the e-waste generated, only a small percentage is collected in Malawi. The country has developed a National Waste Management Strategy (2017-2022) which intends to work as shown by the information exchange architecture below n in figure 2 below.

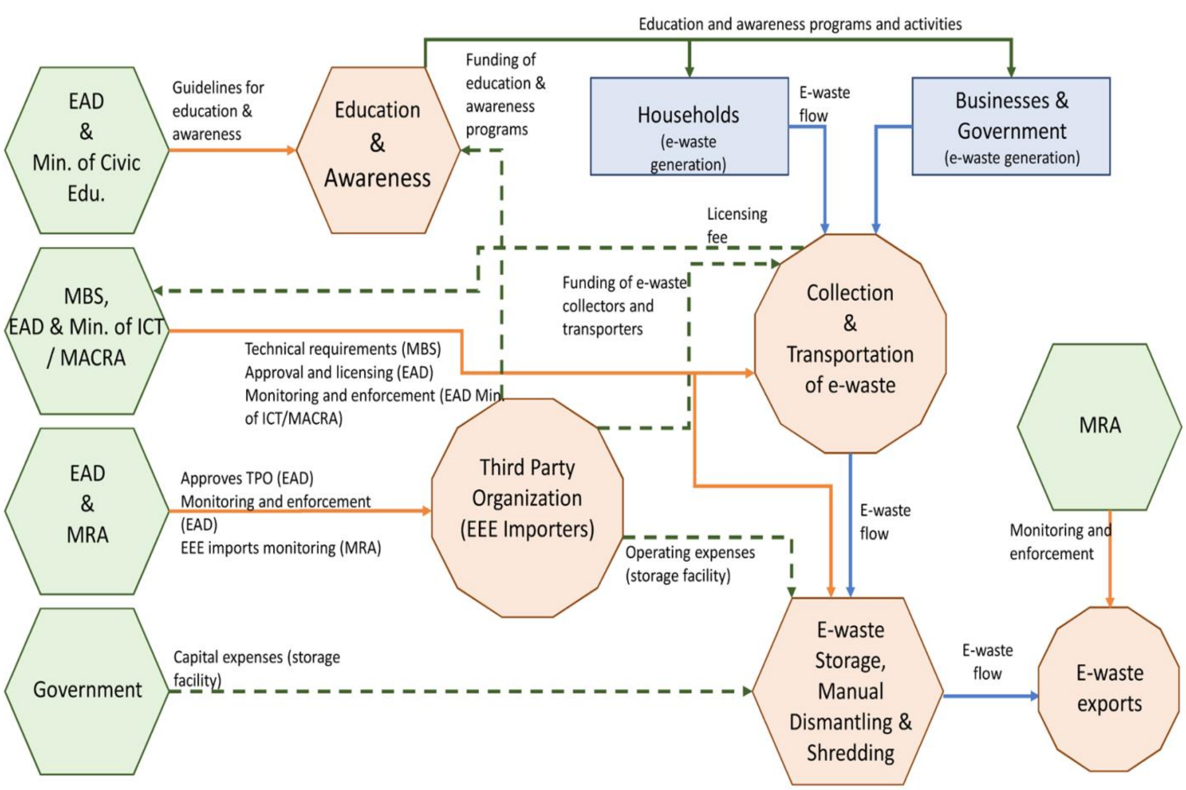


Fig 2: Information Exchange Architecture in Malawi

2.5.3 Information Exchange Architecture in the U.S

In the United States, California specifically, E-Waste Recycling Act.133 was enacted in 2004. The Act lays out a take-back system for electronic waste. The Act also lays out a financing mechanism for the take-back system. In the U.S, USD 5 to USD 7 is charged as a recycling fee by EEE retailers, including manufacturers who at the point of sale, sell directly to their consumers. The federal government then employs the funds to reimburse approved recyclers and collectors. The Act also stipulates that manufacturers in the U.S provide education and awareness outreach to consumers on how to return, recycle, and dispose of e-waste through a website, a toll-free number, the label on the device, information accompanying the sale, or information on the packaging of covered electronic devices. The information exchange architecture adopted in the US is as shown below in figure 2.

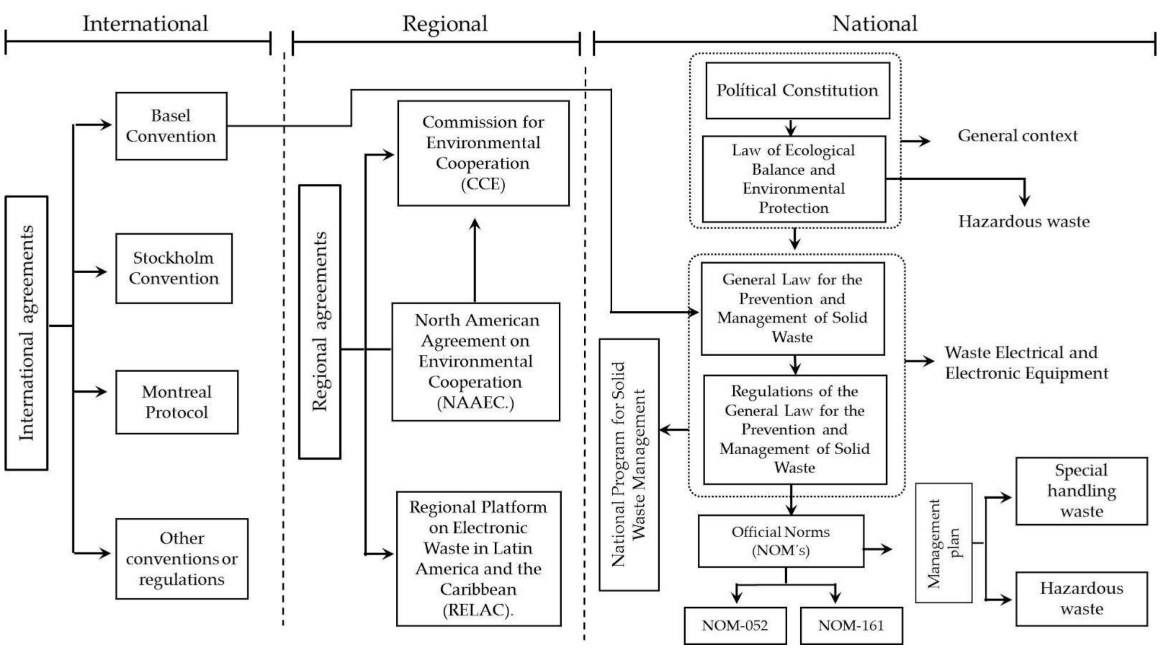
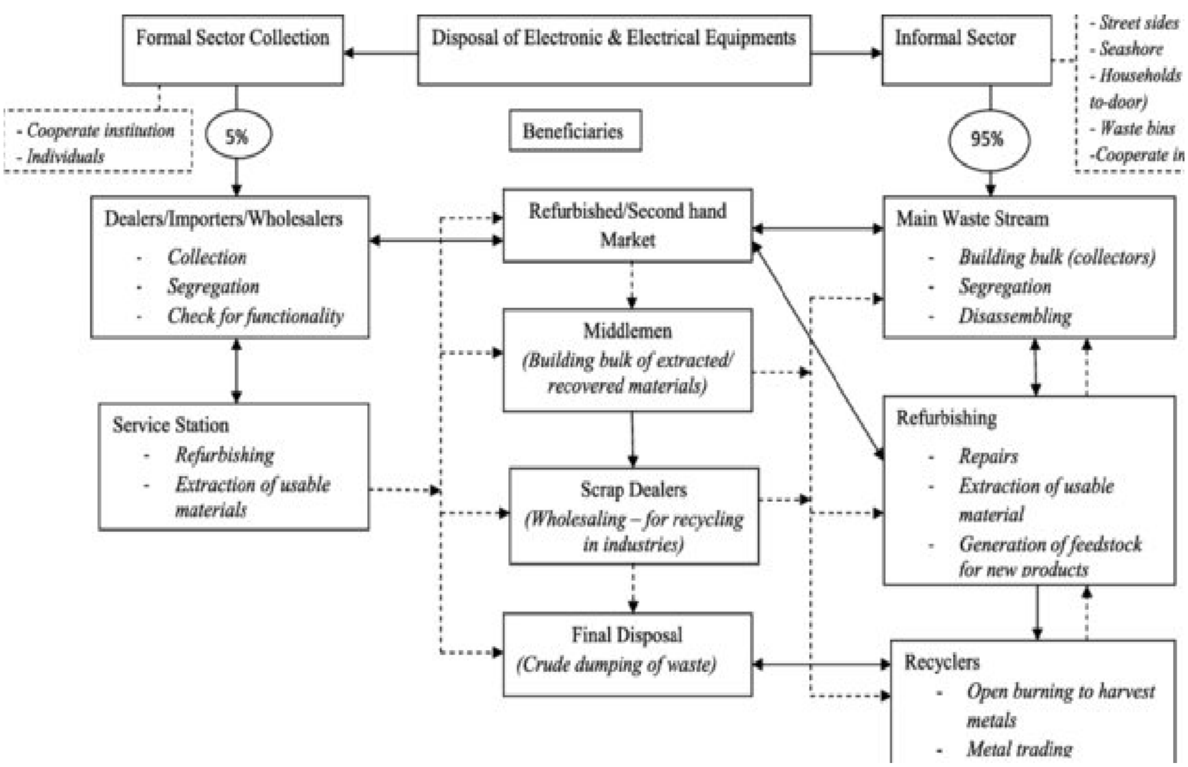


Fig 3: Information Exchange Architecture in the U.S

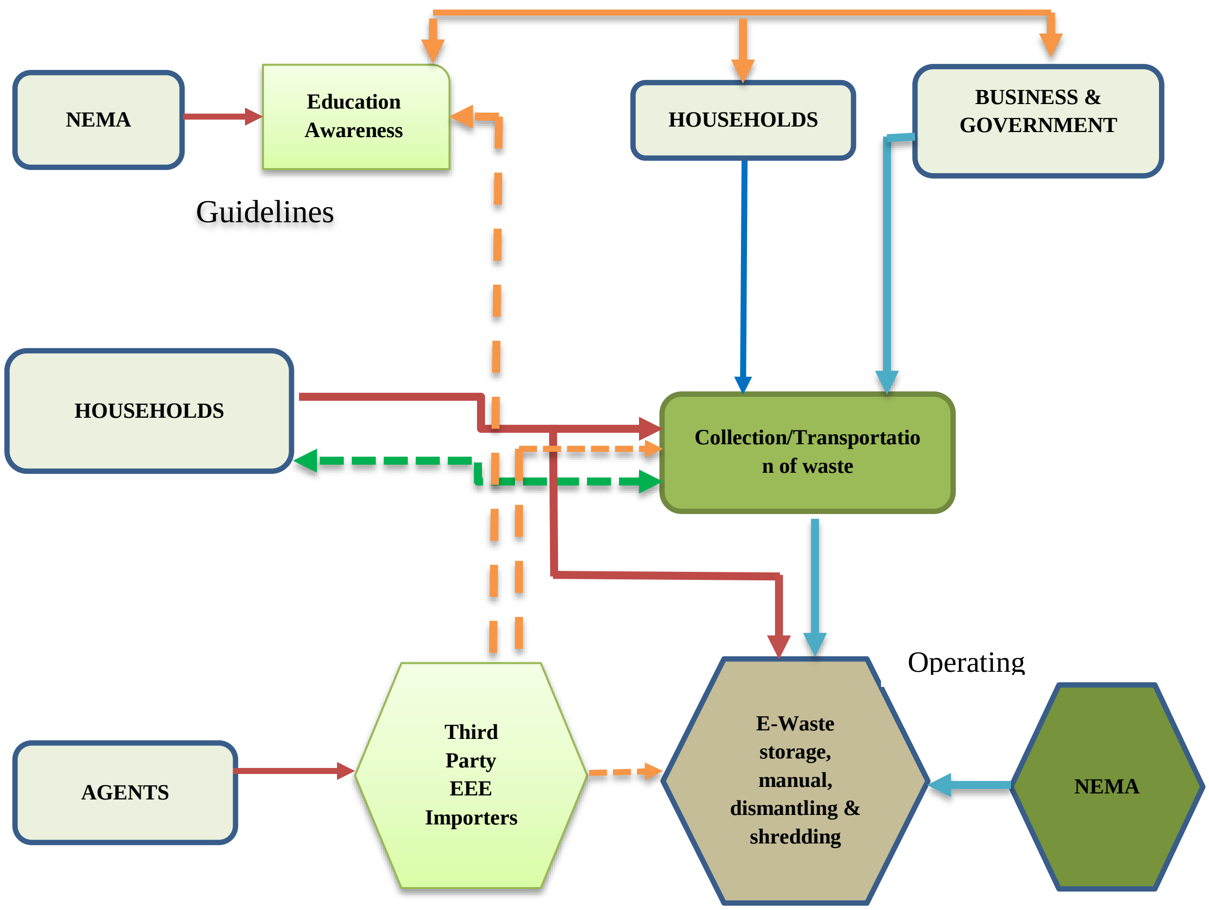
2.5.4 Information Exchange Architecture in Ghana

Ghana's high levels of e-waste are attributed to the improving standard of living and increasing prosperity together with an increase in the importation of used equipment and devices that have reduced lifespans with an estimated 15% of these non-functional (Owusu, 2017). However, the Hazardous and Electronic Waste Control and Management Act of 2016, ACT 917, ratified in 2016 as a measure to ensure that e-waste is properly managed together with other e-waste regulations provide key information exchange architecture to formalize and ensure e-waste proper management in Ghana. The information exchange architecture is as follows;



2.5.5 The Adopted Information Exchange Model

This model will be adopted by this study.



Reasons for adopting this model

a) The model provides education and awareness programs and activities to the household. This education and awareness are funded by the ministry of civil education in Malawi.

b) The model allows the collaboration of different stakeholders to participate in the process of management of E-waste. In Malawi this model allows the ministry of civil education, ministry of Information communication, the household, and the entire government to participate in this process

c) The Model includes a third-party organization that funds the awareness and education program. This third-party organization also participates in the collection and transportation of waste.

d) Malawi Revenue Authority (MRA) is a Malawian government agency and also participates in monitoring and enforcing the entire process of e-waste management in Malawi. This model will enable the researcher to incorporate the National Environment Management Authority (NEMA) to play a similar role in Kenya.

2.6 Theoretical framework

2.6.1 Sustainability Theory

It conceptualizes the management of e-waste in manufacturing and processing industries in a more holistic and integrative manner, the sustainability theory will be adopted. It integrates social, environmental, and Economic responses to achieve sustainable relations. At the 2005 World Summit on Social Development, it was a fund that sustainability requires the reconciliation of the three pillars; social equity, environmental and economic demands. According to McLennan (2005), a balance should be attained between the ecology, economy, and society, it is essential to have sensitive and strategic sustainable designs.

2.6.2 Economic Model

This theory seeks to sustain natural and financial capital. Natural and financial capital is a fundamental system in e-waste management. Sustainability is linked to the economy through the social and environmental effects of economic activity. Sustainable economies represent a broad interpretation of the environmental economy where flexibility and environmental and practical problems are fundamental but are part of a broader vision. Cultural, social, financial, and health-related aspects have to be factored into the analysis. Concerning this project, the economic model is important as its key support for technological innovations concerning the manufacture of industrial electrical and electronic equipment ensuring that manufactured equipment has minimal pollutants. Financial capital is also important to support proper activities of e-waste handling which have toxic substances and are normally released upon poor disposal leading to environmental degradations. Implementations of key environmental policies that are aimed at protecting the environment also require a lot of financial support

2.6.3 Social Model

The social model in sustainable development happens when both informal and formal processes; structures, systems, and relations actively support the power of the present and future generations to build healthy and vibrant communities. Socially sustainable communities are equal, connected, democratic, and diverse and provide a good and quality life. The model looks at human life, laws governing human and environmental relations, the link between human development, human rights, environmental justice, and corporate power. To attain sustainability in managing e-waste, all aspects of the social model must be observed and protected.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

This section focuses on the methodology that was used in the research to direct tasks such as the collection, processing, and analysis of data and presentation of the results. The section is divided into the following parts: research design, pre-study, the population of the study, sample, data collection and analysis procedures, analytical models and approaches, system design and test of reliability, prototype testing, and ethical issues.

3.2 Research Design

Research design entails the overall plan that is to be employed in acquiring answers to the questions that were posed by the study. It also involves the way the difficulties that may arise are to be dealt with (Polity & Beck, 2003). This study deploys both descriptive and exploratory survey designs. This is because the study involves a mix of quantitative and qualitative approaches. The descriptive research designs enabled the researcher to collect information, summarize it, present and interpret it (Orodho, 2002). The researcher considered descriptive survey design as appropriate because it enables the generalization of sample results to the entire population of the study. According to Kothari (2004), the design also maximizes the reliability of the data collected and makes enough provision for the protection against bias.

Descriptive and exploratory survey design assisted the researcher in analyzing both the quantitative and qualitative data because the researcher intends to use a semi-structured questionnaire for data collection to reporting the current status regarding the communication framework for sustainable e-waste management in Nairobi City. In addition to a questionnaire that will be administered, the researcher will use reports on the status of e-waste in Kenya and also make observations on the ground in the process of collecting data.

The table below shows how each objective was achieved

Table 3.1: Objectives Table

Objective	Methodology
To design an information exchange model	The researcher reviewed different information exchange models used in various countries. One model was adopted and modified/ Improved. Also, the researcher conducted a preliminary study that aided in designing the model
To determine the information exchange model currently existing in e-waste management	This was achieved by reviewing different information exchanges currently in use. The researcher was able to determine the existing model from the reviewed literature.
To process the mapping process of e-waste management in Kenya	A preliminary study was done by the researcher to map the process of e- waste management in Kenya
To validate information exchange model through prototype	The researcher used the prototyping model technique – In this validation technique, the prototype developed by the researcher was presented to the end users where they tested and experiment with the presented model to check if it meets their specified requirements.

3.3 Pre-Study

I conducted a pre-study, to inform about the process of management of e-waste in Kenya. We did a keen investigation in which we involved a significant number of participants involved in the entire process of e-waste management.

3.4 Population of the Study

A study target population involved the number of people that the researcher needed to simplify the finding of the research. The study's targeted population comprises stakeholders of the e-waste management system in Kenya. The system for management of E-waste in Kenya is comprised of stakeholders who range from importers, retailers, assemblers, consumers, downstream vendors, refurbishes, recyclers, and the disposers of final waste, the choses households residing near dumpsites and to policy-makers (Waema, Mureithi, Wanjira, Finlay & Schluep, 2008). The researcher also developed a working list since the licensing framework in Kenya doesn't differentiate general trade and ICTs thus there is no defined list of stakeholders that can be availed by the Ministry of Industrialization or Ministry of Trade.

3.5 Sample

A study sample involved a smaller group that is acquired from the target population and is selected to represent the whole population that is targeted by the study. Researchers such as Gay (1983) argue that in descriptive studies, 10% of the target population is adequate to represent the entire population. Best (1992) on the other hand suggests that a sample should be large enough to be ideal and adequate to represent the population of research.

In this study, a purposive sampling technique was used in recruiting participants from the population. This technique is crucial when the researcher intends to understand a certain cultural domain with experts within.

There being no definitive list of stakeholders that can be availed by the Ministry of Trade and the Ministry of Industrialization, this study opted to use ten questionnaires from each of the ten groups of stakeholders on a convenience basis including; importers, recyclers, retailers, downstream vendors, assemblers, refurbishes, consumers and lastly the disposers of waste to policy-makers and some households that live near the dumpsites. This results in 50 questionnaires as shown in table 3.1 below.

Table 3.2: Sample Size

Category		Target Sample
Stakeholders	Importers, assemblers, suppliers, and distributors	10
	E-waste refurbishes	5
	E-waste collectors	5
	Consumers	5
	E-waste recyclers	5
	Final disposers	5
	Downstream vendors	5
Households		5
Policymakers		3
Other bodies (international bodies).		2
Total		50

The approach is preferred since it eliminates any chances of bias in the selection of the sample in light of the absence of records on the exact number of stakeholders in the industry. This approach is also preferred since each aspect of the population will have an equal opportunity of being represented.

3.5.1 Sampling Technique and Procedures

The sample size for this research was 50 stakeholders of e-waste management in Nairobi. The study employed a simple random sampling technique to recruit the participants.

The sample size for this study was determined using the Yamano Taros formula, Israel (2012) as follows:

$$n = \frac{N}{1+N(e)^2}$$

Where: n = sample size

N = population size

e = is the level of precision ±10 (sampling error of 90 % confidence level)

Therefore: $n = \dfrac{100}{1+100(0.10)^2}$

$= 50$

$= 50$ respondents

The sample size for this study was 50 respondents. The 50 represents 50% of the total population. The respondents were chosen using a simple random sampling technique.

3.6 Data Collection Instruments

This study's scope is set to cover a sample size of 50 respondents who ought to provide primary data. The study employed questionnaires for data collection. The respondents were required to fill a predesigned semi-structured questionnaire. The researcher also employs observation techniques to collect additional data that is relevant. The researcher also gathered secondary data from reports on the condition of e-waste management in Kenya.

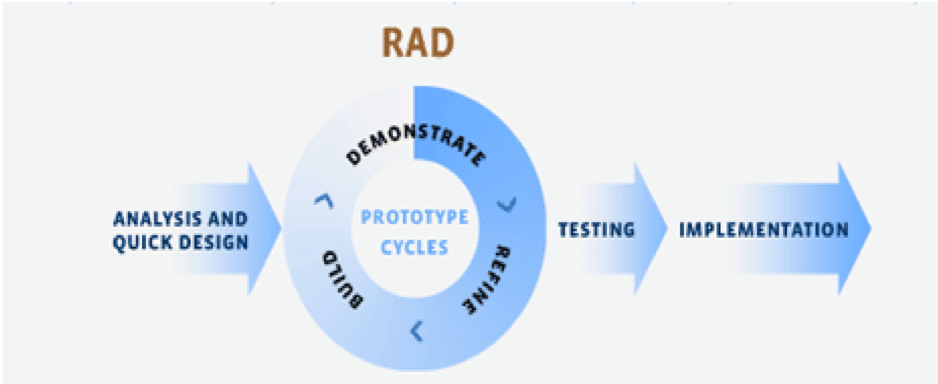
3.7 Data Collection Procedure

For the collection of data, permission was sought from the University of Nairobi which provided an introductory letter that enabled the researcher to get the data from targeted institutions. The study employed the "drop-and-pick-later" approach to distributing the research questionnaires. The respondents were allocated adequate time to satisfactorily respond to the questions.

3.8 System Design Methodology

Rapid Application Development (RAD) was used. RAD is a development lifecycle designed to give high-quality results and faster development compared to the traditional system development lifecycle. RAD entails acquiring requirements using workshops, focus groups prototyping and early user testing of design, and also the re-use of software components.

Figure 3.1: RAD



Rapid Application Development Model (Source: testing excellence .com)

Stages of RAD

Analysis and Quick design-This stage entail prototype designing and requirements planning.

Prototype cycles – This stage is mostly repetitive and entails the development of the actual system.

Deployment and Testing – this stage entails testing the completed prototype and determining whether it is ready to be implemented.

Advantages of RAD

i. RAD increases the reusability of components and reduces the development time all of which help speed up the prototype development process.
ii. It enables large projects to be broken down into smaller tasks that can be manageable and easy to develop.

3.9. Reliability Test

Reliability test measures the extent to which research tools produce consistent results (Mugenda & Mugenda, 1999). To test for the reliability of data, the researcher employed a Likert scale. The study also deployed Cronbach's Alpha to ascertain the reliability of the data. The researcher will consider the reliability coefficient of $\alpha \geq 0.7$ as adequate. This helped indicate a high level of internal consistency for the Likert scale used. This also enabled the researcher to address the weaknesses in the questionnaire and the research tools. Editing and improvements were also done on both the content and the structure of the research to help reduce the errors.

3.10 Data Analysis and Presentation

Analysis of data entails systematically applying logical or statistical tools to demonstrate, describe and evaluate data (Shamoo & Resnik, 2003). The questionnaires obtained from the field were inspected for completeness and sorted in preparation for coding after which they were keyed into the Statistical Package for Social Sciences (SPSS version 21). The data on sustainable management of e-waste in Nairobi city will be examined using descriptive statistics such as frequencies, means, and percentages. For open-ended questions was analyzed using the content analysis approach. Tables and charts were used to present the findings of the research.

3.11 Prototype Testing

The purpose of prototype testing is to identify and correct errors in the candidate system. Testing is an important for specification and quality assurance of software that reflects the latest updates on specifications, configurations and coding. Increasing visibility of software such as system cleanup and costs associated with software failures are the ability to promote well-planned, experimental.

System tests are performed to detect errors and compare the final system with demand specification reports, for instance whether the system meets the requirements. During testing, the software was developed with a set of test cases and the release of test cases programs were tested to see if the system was working as expected.

Testing brings an exciting challenge to software developers who are trying to build software from an incomprehensible concept to an acceptable performance. In testing an engineer creates a series of test cases that occur when errors are detected. Exploring the process of making an error detection system. A good test has a higher chance of finding the error revealed. Successful error exposes undisclosed errors.

Time error is used to determine the difference between the actual software release and the current release. An error is an old condition that the software failed to perform its required function. Software reliability is defined as a required function. Software reliability is defined as the possibility that the software will fail for a period of time under certain circumstances. Failure of a system failure or part of performing a task required in terms of its details. Different levels of software have been used to make it fault-free, error-free, and reliable.

Unit Testing

Unit testing is performed first. Different software modules were tested in comparison with the data generated during the construction of the modules. Verification of code generated during the writing phase is performed. Each module was tested separately.

Unit testing focuses on verification efforts in the smallest unit of software development module. This exposes errors within the module limit. Unit test to check the white box for both external objects and internal arc codes tested. In testing, the audible connectors are tested to ensure proper data flow within and outside the module.

To make sure that the module keeps its limit, boundary testing is done. All of the independent paths are tested to make sure that all statements are tested at least once. The error path is then also tested at the end.

3.12 Ethical Issues

The participants have informed of the purpose and nature of the study, the procedure to be used, and the expected benefits to the participants. Also, the participants were assured of the confidentiality of the information given or anonymity of the same. The participants were allowed to ask any questions and have they responded to them before answering the questionnaires

3.13 Chapter Summary

The chapter reviewed the research design that guided the study, target population, sample size data collection instruments, and how the data was analyzed and presented.

CHAPTER 4: SYSTEM ANALYSIS, DESIGN AND IMPLEMENTATION

4.1 Preliminary Study Results

The study considered a sample of 50 participants of which 30 respondents filled the questionnaires. Of the 30 responses, 24 were from households, 4 from recyclers/ handlers, and 2 from NEMA. The study sample comprised of individuals from both genders and of different ages. The respondents also came from different scrapyards around Nairobi.

Table 4.1: Response from the Households

Variable	Attribute	No. of respondents	Percentage of respondents
Gender	Male	16	67
	Female	8	33
Age of respondents	18-28	3	12.5
	29-39	9	37.5
	40-50	8	33
	51-60	4	17
	61 and above	0	0
Marital status	Single	9	37.5
	Married	12	50
	Separated	1	4.5
	Divorced	0	0
	Widowed	2	8
Education level	No education	0	0
	Primary level	0	0
	Secondary level	2	8
	Tertiary education	22	92

From the finding shown in table 4.1 majority, 16 (67%) of the participants were male while 8(33%) were female. The table also illustrates that majority of the participants 9(37.5%) were of age bracket 29 – 39, followed by 40 – 50(33%), 51-60 (17%), then 18 – 28(12.5%). None of the participants fell in the 61 and above group.

The researcher sought to establish the average family size of the participants. The results are as shown below;

Figure 4.1: The family size of the Households

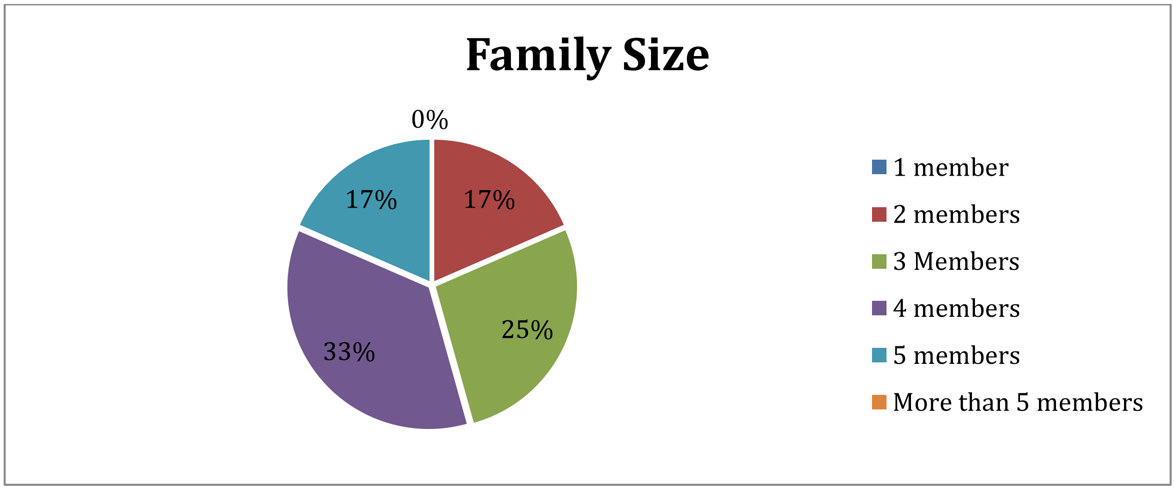
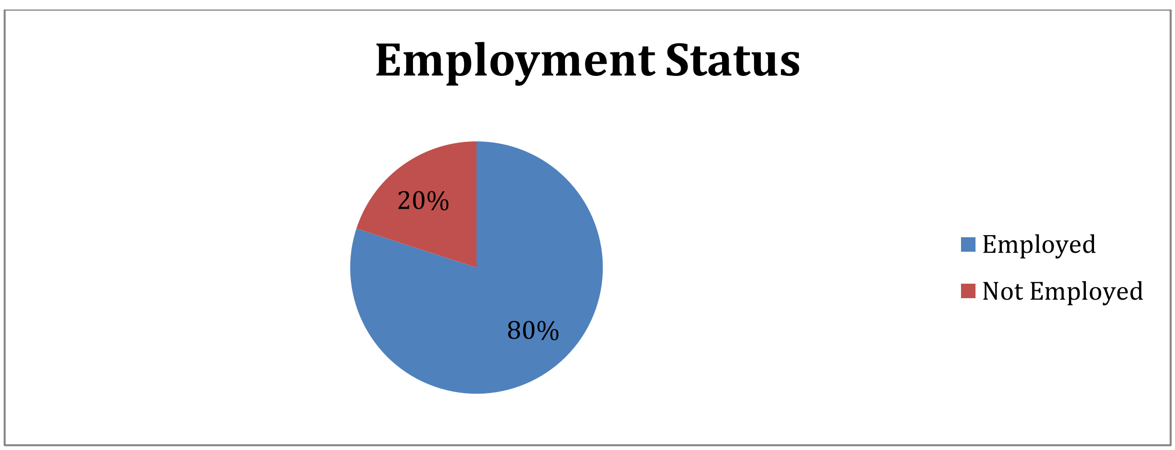


Figure 4.1 reveals that the majority 8(33%) of the households that participated in the study belonged to families of 4 members, followed by those of 3 members (25%), then a tie between the families with 2 and 3 members. There were no participants with a family size of 1. This implies that most participants had more than one person depending on them.

The researcher sought to find out the employment status of the respondents. The findings are as shown in figure 4.2 below;

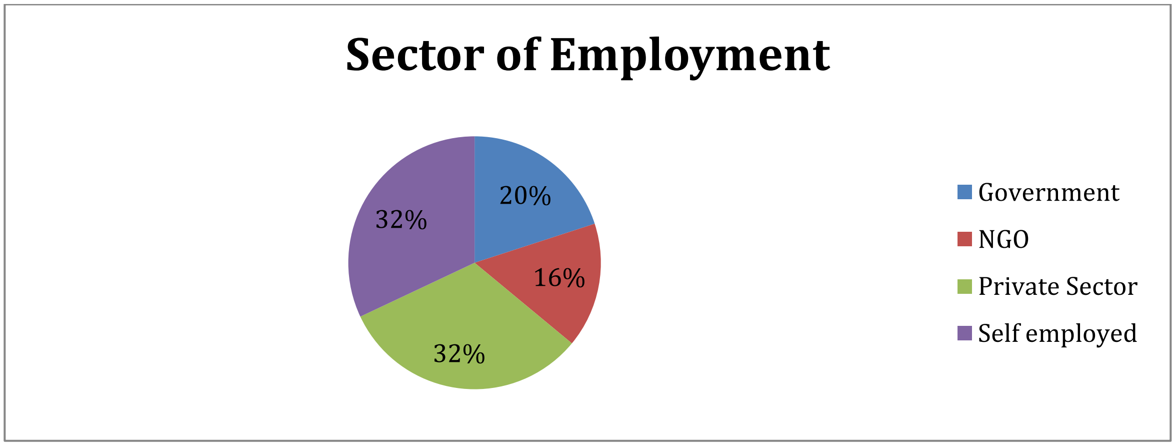
Figure 4.2: Employment status of households



Majority (80) of the participants were employed as shown in figure 4.2.

The researcher sought to understand the employment status of the participants. The results are shown in figure 4.3 below.

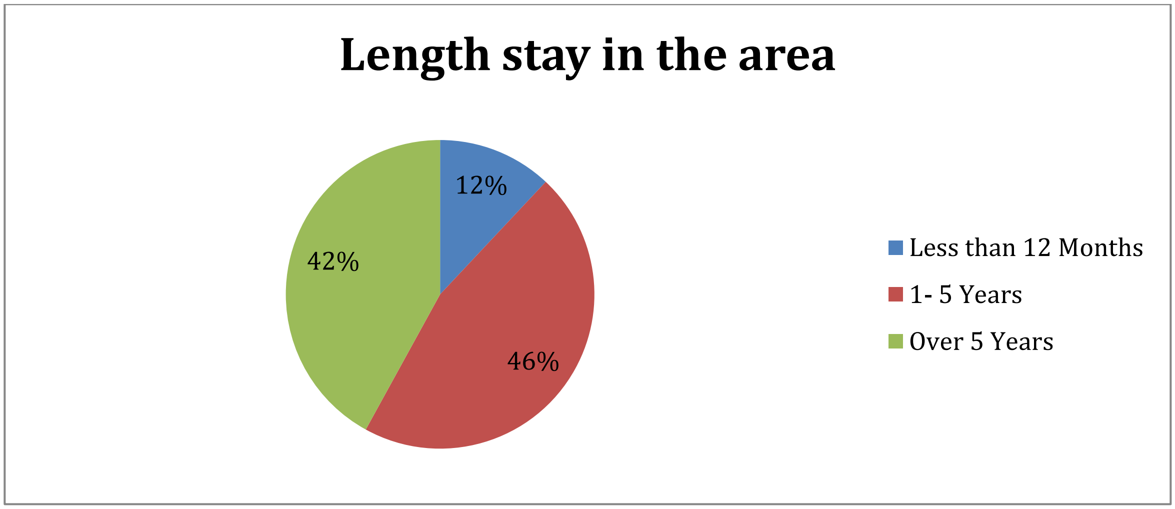
Figure 4.3: Sector of employment



Majority (32%) of the participants either worked in the private sector or were self-employed as shown in the table. Others either worked in the government (20%) or NGOs.

The researcher sought to determine the length of time that the participants had stayed in the area of residence. The results are as shown in Figure 4.4 below:

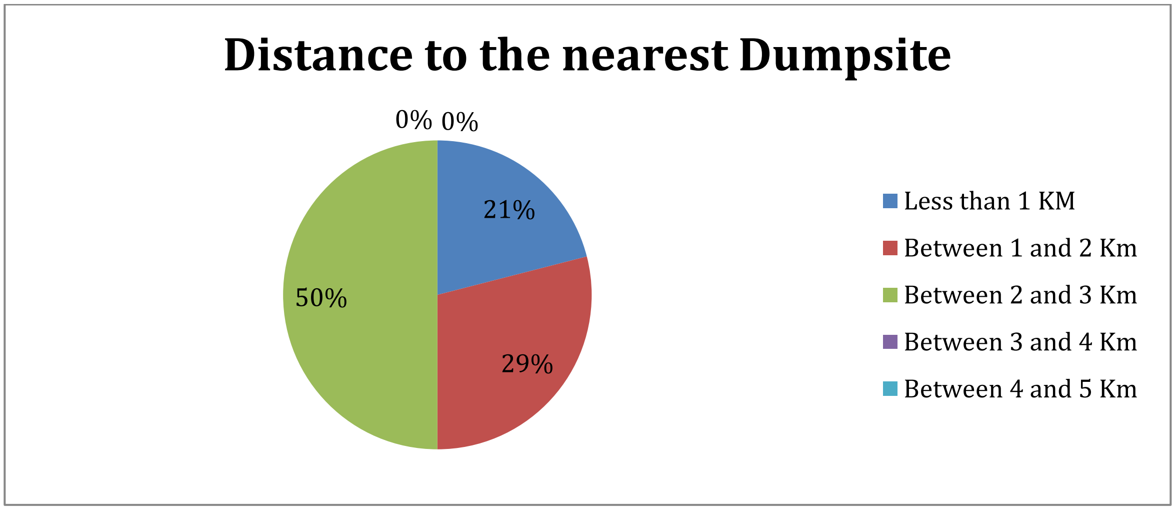
Figure 4.4: Length of time in the household residing in the area



Majority of the participants (46%) in the study had stayed in their area of residence for between 1 to 5 years. This is then followed by (42%) those that had stayed for over 5 years and then (12%) those that had stayed for less than a year.

The researcher sought to understand how far from the nearest solid waste dumpsite does the participants reside. The results are as follows:

Figure 4.5: Distance to the Nearest Dumpsite

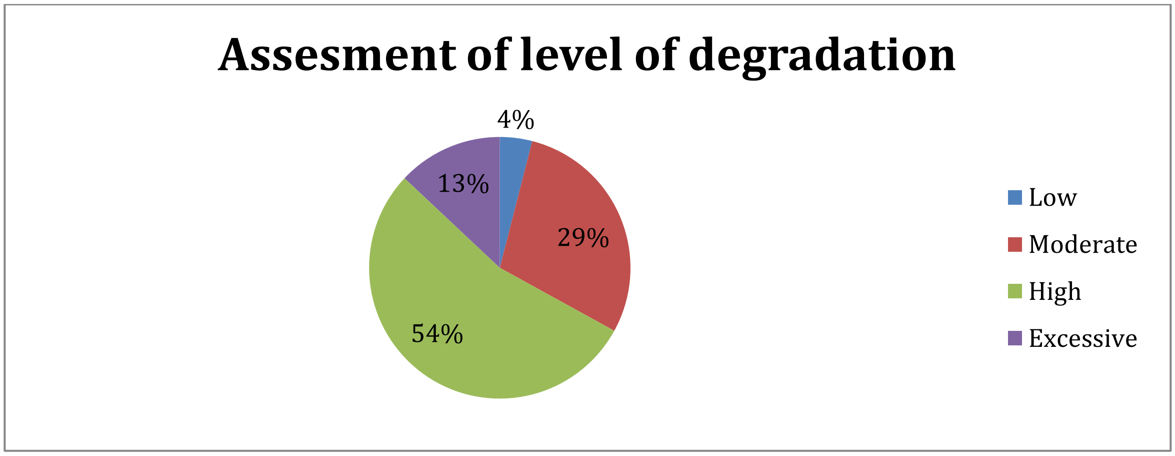


On whether the respondents know of any case of poor e-waste disposal in their neighborhood, Majority of the respondents (87.5%) said yes while others did not know of any cases of poor e-waste disposal in their neighborhood.

Concerning the disadvantages of poor e-waste disposal, the respondents listed disadvantages including; the air is polluted with toxins during melting and dismantling of the e-wastes; the soil is polluted also since inappropriate disposal of the e-waste leads to the heavy metals seeping into the soil; water is also polluted when the heavy metal seeps into the soil; human health is also affected by the toxins released when the e-waste is dismantled.

The researcher sought to understand the level of degradation from the participant's point of view. The findings are as follow;

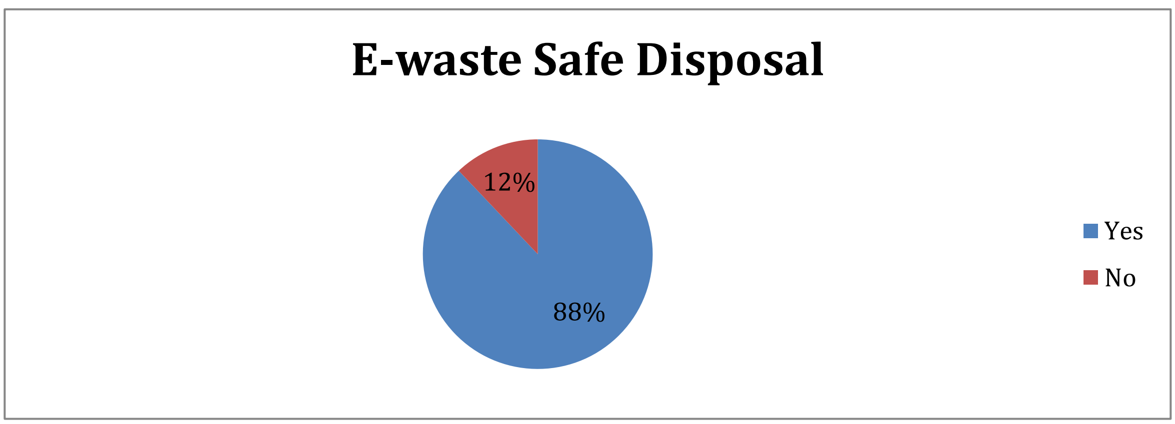
Figure 4.6: the Assessment of the Level of Degradation



Majority of the participants (54%) said the level of degradation dues to e-waste disposal was High, followed by Moderate (29%), then Excessive (13%), and finally Low (4%).

The researcher sought to find out whether the participants are aware that some hazardous portions of e-waste from passive elements need special treatment so as to safely dispose them off. The pie chart below reveals the results.

Figure 4.7: E-Waste Safe Disposal



From figure 4.7 above reveal that the majority of the respondents know what safe e-waste disposal is.

The researcher sought to determine the problems encountered in the management of e-waste service. The participants were to rate the factors as very serious, serious, not so serious, or no problem.

The participants posit that the problem of inadequate service coverage is very serious as shown by a mean of 1. The participants also posit that the problem of poor service qualities (not frequent enough) is serious as shown by a mean of 1.5. The problem of lack of authority to make administrative and financial decisions was said to be not so serious, as shown by a mean of 3. Lack of financial resources is found to be a serious problem as shown by a mean of 1.75. The researcher posits that lack of trained personnel is a serious problem in Nairobi as shown by a mean score of 2. Other factors, lack of equipment, lack of vehicles, lack of capacity to maintain equipment and vehicle, old equipment/ vehicles which frequent breaks down, no proper institutional set-up for management of e-waste service were classified by the participants as serious problems.

The participants also proposed that lack of legislation is a serious problem as shown by a mean of 1. Lack of enforcement capability and measures is also deemed by participants as a serious problem. The challenge of lack of planning (either long, medium or short term) in Nairobi was found to be serious as shown by a mean of 2. The participants posit that rapid urbanization outstripping service capacity is not a problem in Nairobi as shown by a mean of 4. Difficulty in locating or acquiring landfill sites was found to be a very serious problem in Nairobi. The participants posit that poor cooperation by Government agencies was found to be serious as shown by a mean of 2. Poor response to waste minimization was found to be a serious problem in Nairobi as shown by a mean of 2. The participants also proposed that the problem of lack of control on hazardous waste was serious in Nairobi as shown by a mean of 2.

The researcher sought to understand the recommendations of the participant concerning what can be done to make to achieve full support from all the relevant stakeholders on matters regarding e-waste management from passive elements?

Concerning the central government, it was recommended that the government strengthen the laws pertaining to collection and disposal of e-waste to enhance the management of sustainable e-waste in Nairobi. Pertaining industries, it was recommended that the industries comply with the laws to limit the level of e-waste dangerous disposal into the environment.

4.2 Discussion

From the findings of the survey, it was noted that the current e-waste disposal information exchange approach was inefficient which resulted in delays, inconsistencies, and inconveniences. From the survey, the majority of the households know what e-waste is but they do not know its negative impacts on the environment neither do they know the processes for its disposal. Some of the households don't know that e-waste from passive elements require special treatment so as to be safely disposed of.

The household however proposes that what has contributed to fast growth in e-waste in manufacturing and processing industries is the lack of an effective information exchange model and also the lack of laid out processes and procedures for e-waste disposal and dismantling. The other challenge was the lack of established regulations that follow up on the sustainability of the processes and procedures for e-waste management. Majority of the households also live close (between 1 to 3 Kms) to dumpsites and know of cases concerning e-waste in their neighborhood. Most respondents also rate the level of environmental degradation due to e-waste disposal as high. On whether Kenya's regulatory framework sufficiently addresses the e-waste issues in manufacturing and processing industries, the respondents felt it doesn't.

The table below highlights the existing gaps and how a new automated information exchange model can bridge these gaps.

Table 4.2: The Existing Gaps in the Current E-Waste Disposal System

Aspect	**Gap**	**Design Implementation**
Communication break down	Streamlined communication	Opportunity to use online communication platforms
Unsustainable e-waste management	Streamlined e-waste process and communication channels	Opportunity for more sustainable e-waste management system

Significant loss of follow up	Follow - up	Opportunity for the authorities to follow up effectively through online systems.
Lack of awareness	Ease information access	Opportunity to access to communication on different topics
Delayed pick-ups	Real-time pick-ups	Opportunity to increase efficiency in pickups and disposal
Expensive to dispose of e-waste	Affordability	Opportunity to dispose of e-waste at an affordable price

4.3 System Design

The objective of the study was to design and build a prototype that will enable improved information flow for sustainable e-waste management in Nairobi by eliminating communication breakdowns, delayed pick-ups, expensive disposal procedures, and lack of information and awareness concerning e-waste management. Rapid Application Development (RAD) is the preferred methodology for the development of the prototype.

RAD concerns with gathering client requirements, early testing of the prototypes by the user using the iterative concept, reuse of the existing prototypes components, continuous integration, and rapid delivery.

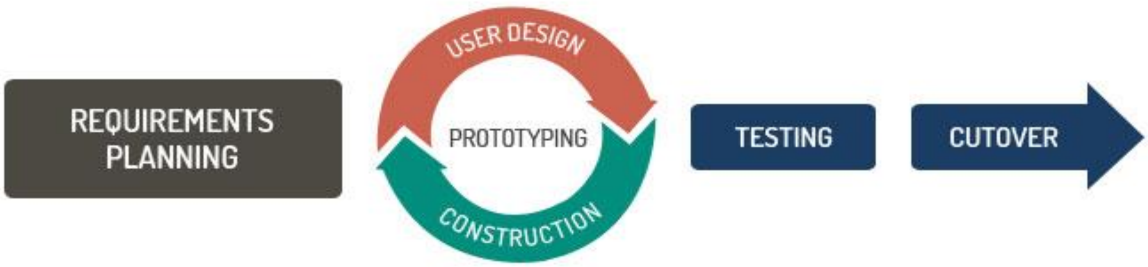


Fig 4.1 RAD

The proposed solution from this study would aid stakeholders in controlling e-waste management efficiently and appropriately through introducing an information exchange model that will enhance the sustainability of e-waste management in Nairobi.

The proposed solution would offer a means of communication between the different e-waste stakeholders in e-waste management process that is more reliable. The proposed solution will also raise the awareness of the public towards e-wastes and their disadvantages by enabling the public to access information concerning e-waste materials and the ways of disposing of them without causing harm to the environment.

Phase One: Requirement Planning

This stage includes:

- Researching on the existing problem
- Describing the specifications and requirements of the project
- Stakeholder approval of the specifications and requirements
- Evaluating the expectations and goals for the project and then weigh in

Phase Two: User Design and Prototypes

This stage mainly entails;

- Developing the client requirements and wireframes

- Applying the main user design deliverables
- Using prototype iterations to finalize on the design version.

Phase Three: Rapid Construction

This phase entails:

- Rapid construction preparation
- Development applications and programs
- Coding
- Unit and system integration and testing

This stage is crucial since it offers opportunities to give input in that changes or new ideas can be suggested at this stage. Problems are also solved at this stage.

Phase Four: Cutover

This is the phase for system implementation where the finished system is launched.

This stage entails;

- Conversion of Data
- Testing
- Getting the feedback form clients
- System finalizing

4.3 Prototype Design

The current information exchange approach in Nairobi is based on manual aspects that result in sometimes mixing of the e-waste material with the general waste for disposal. Below is the process flow;

Figure 4.3 Customer Process Flow

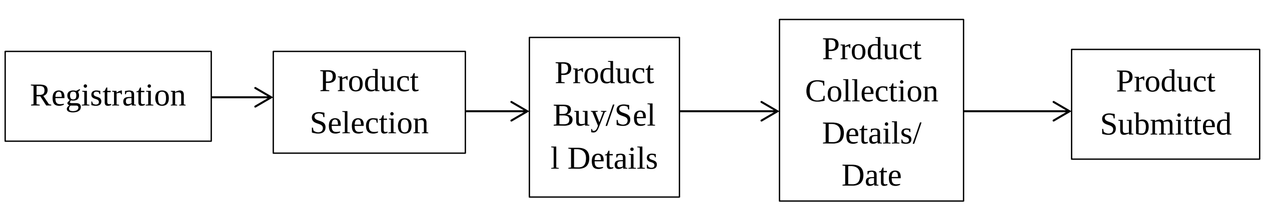
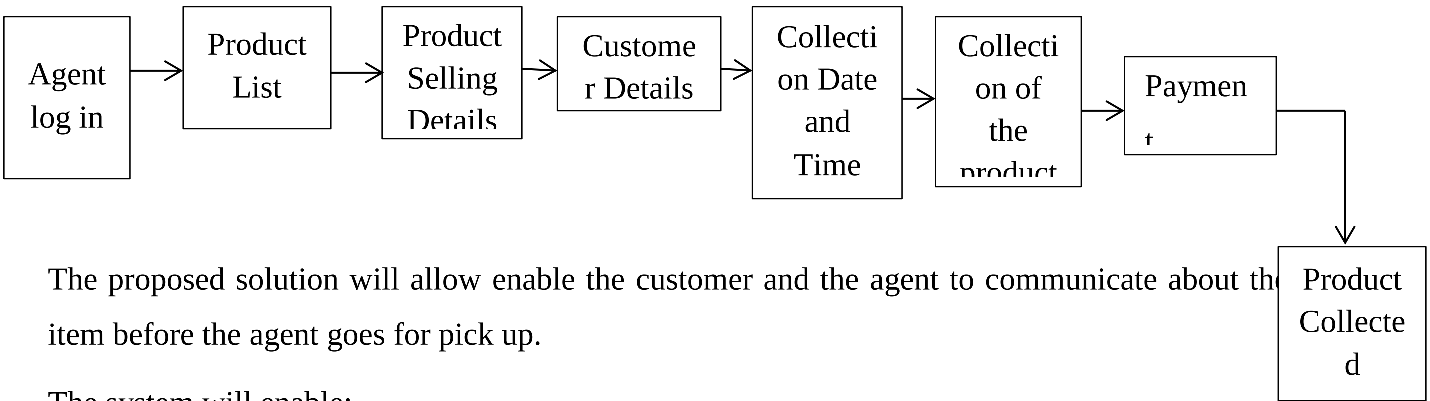


Figure Agent Process Flow



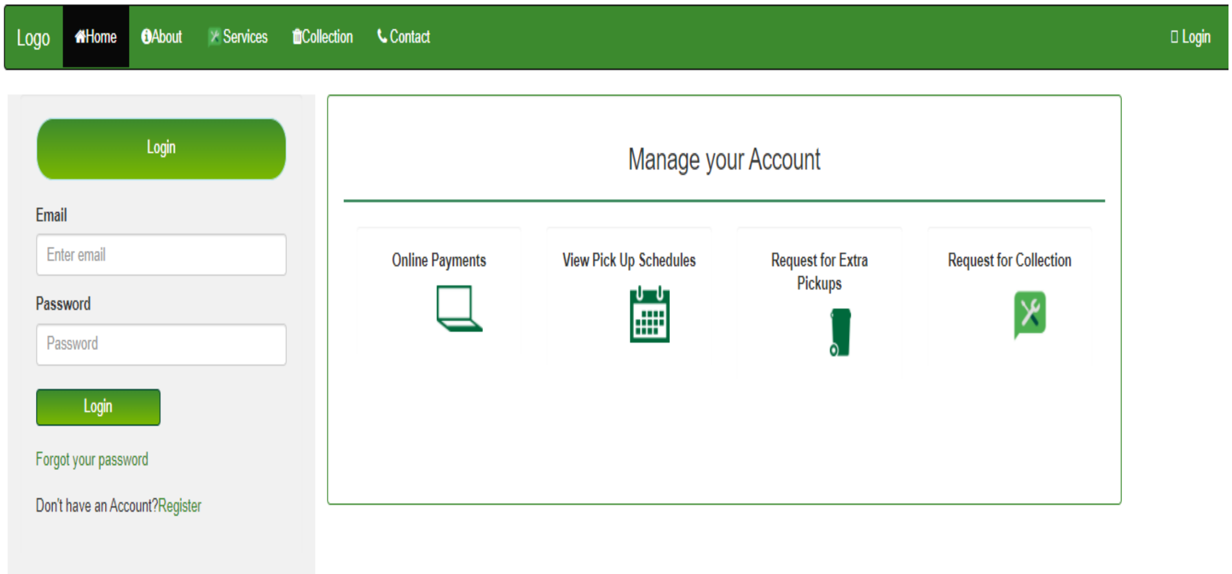
The proposed solution will allow enable the customer and the agent to communicate about the item before the agent goes for pick up.

The system will enable;

- Provide anytime anyplace service for the customer.
- Reuse of electronic waste material by recycling or deployment.
- Decrease the electronic waste material from the household.
- Obtain statistical information about the effect of the problem by the e-waste material.

The waste collection system is now on the online waste collection website. The public gets information about the e-waste material and is aware of the waste. We will collect the household electronic and electric equipment from the public and which will recycle or deploy waste. The recycling waste will be used in the other equipment, and industries can use the recycling equipment for new material.

LOGIN page



4.5 System Overview

The proposed/developed system is a web application that allows the public to be aware of e-waste and also access and retrieve information on e-waste material. The system aids in collecting the electronic and electric equipment from the households and which will deploy and recycle e-waste. The recycled e-waste will be used in other industries and equipment to make new materials. The developed web application will be hosted web where all clients (end-users) so long as they have access to internet and a web browsing software (at the client side) can immediately access and use the system.

System Users

The systems have the following users:

a) Consumers

Consumers register for disposing of the e-waste. They then log in to the system and upload the e-waste product by indicating their location, the type of the e-waste product, and the reason why the product is being disposed of. The e-waste uploaded will be visible by the collectors and the distributers.

b) Collectors

Collectors will be able to log in into the system and check the uploaded product, the collectors will be able to view the distributers and forward the collected e-waste to these distributers. The collectors also will be able to connect with the recyclers of the e-waste uploaded.

c) Distributer

The distributer will be able to log in and check any e-waste that needs to be distributed from the collector.

d) Administrator

The administrators log in and activate or deactivate the users of the system. The admin also track any activity performed by the users of the system

e) Report generation

The model intends to provide information through the generation of reports on clients' and the agent's files through the system. This will help the stakeholders monitor the progress and also go through to rectify any inconsistencies. The model also generates other reports such as; weekly or monthly pick-up schedules, as well as the quantity of the pick-ups from different clients, which will also be important in situations such as when the authorities want to see the trends.

4.6 Implementation tools

The system implementation tools include;

- Programming languages- HTML, PHP, CSS, jQuery, javascript and ajax
- WebRTC- this is for enabling the video and audio features
- MySQL for creating the database where information will be stored

PHP Triad

This installs a complete working PHP/MySQL server environment on Windows platforms (9x/ NT). Installs PHP, MySQL, Apache, and PHPMyAdmin.

Database Management System

MySQL database came in handy during database design because of its ease of use and guarantee of data security and integrity. MySQL DB avoids redundancies by allowing the use of primary keys. It also uses foreign keys to create relationships between entities. Web features of the prototype used a common MySQL DB. The web application and database were hosted live on Site Ground.

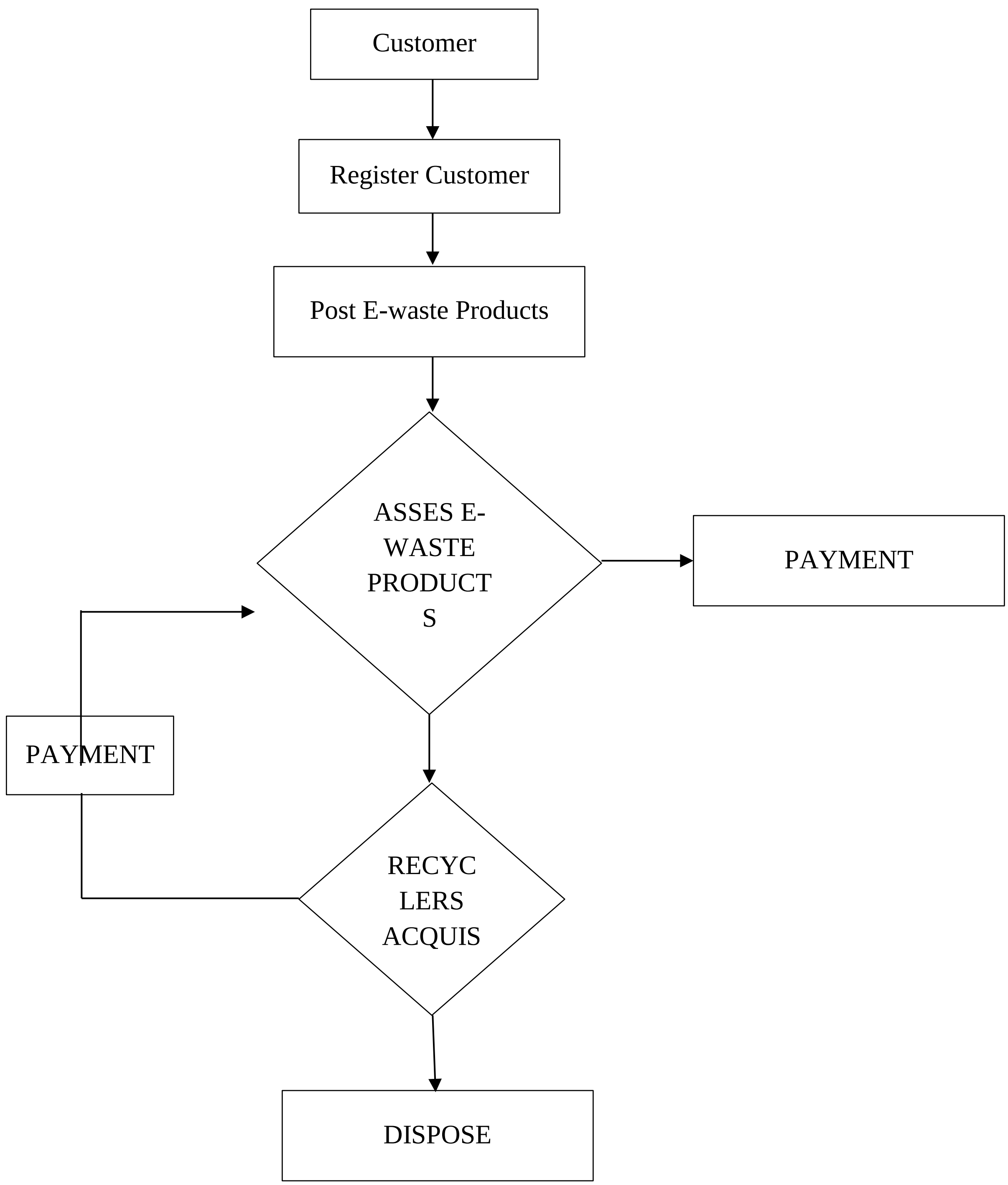
HTML5, CSS, JavaScript, PHP – This was used to develop the front end of the system developed. HTML in conjunction with Cascading Style Sheets (CSS) and JavaScript was employed to code the application's user interface (UI). Development of tables was done for the storage, display, manipulation and deletion of database records. Forms were also developed to enable users to input and retrieve data from the databases.

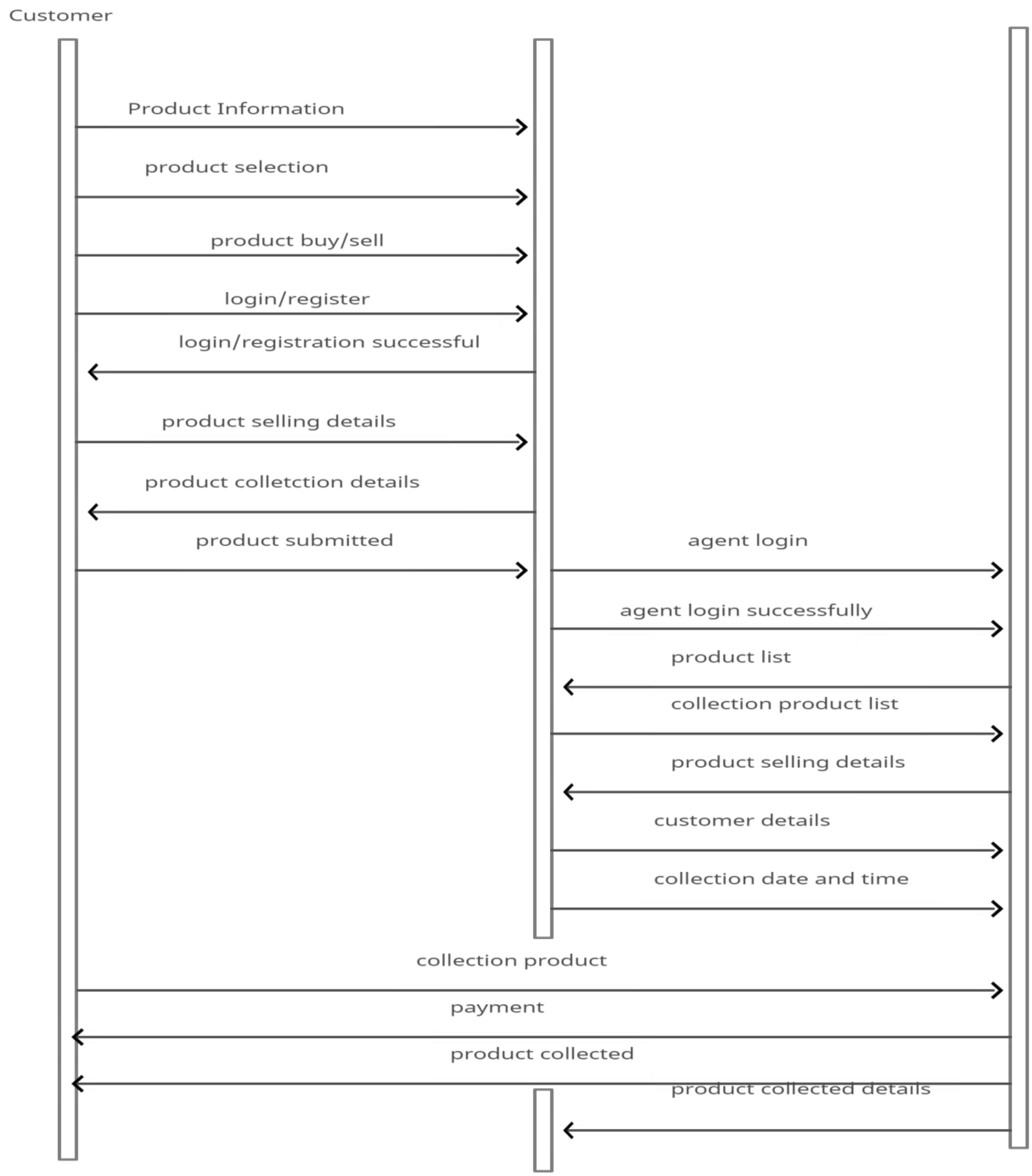
Apache webserver for hosting the application – Apache web server will make the system readily accessible to all the users. Also, they can be modified to suit the user's system needs.

SQL Server 2008 and SQL Lite - This was used to develop the backend of the system. SQL server 2008 was used because it is developed to interface with databases and it works by understanding and analyzing databases that include data fields in their tables. SQL Lite was used because enabling one to store data in a structured manner and has higher performance, Also SQLite databases can also be probed and the data recovery is much more vigorous.

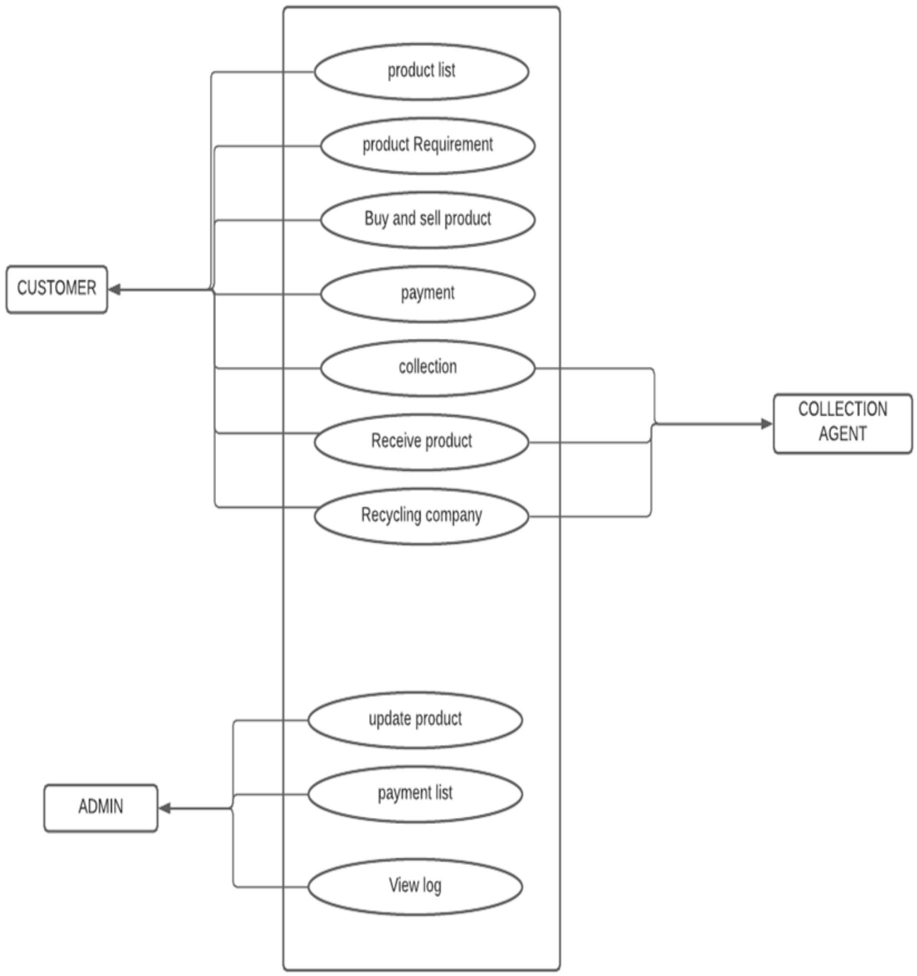
4.5 Model Flowchart Diagram

The flow chat diagram below demonstrates the process of information flow from when the e-waste materials are collected to when they are safely disposed off with all the parties involved in the process.


Customer
Register Customer
Post E-waste Products
ASSES E-
WASTE
PRODUCT
S
PAYMENT
PAYMENT
RECYC
LERS
ACQUIS
DISPOSE


Customer
Product Information
product selection
product buy/sell
login/register
login/registration successful
product selling details
product colletction details
product submitted
agent login
agent login successfully
product list
collection product list
product selling details
customer details
collection date and time
collection product
payment
product collected
product collected details

b) Use case Diagram



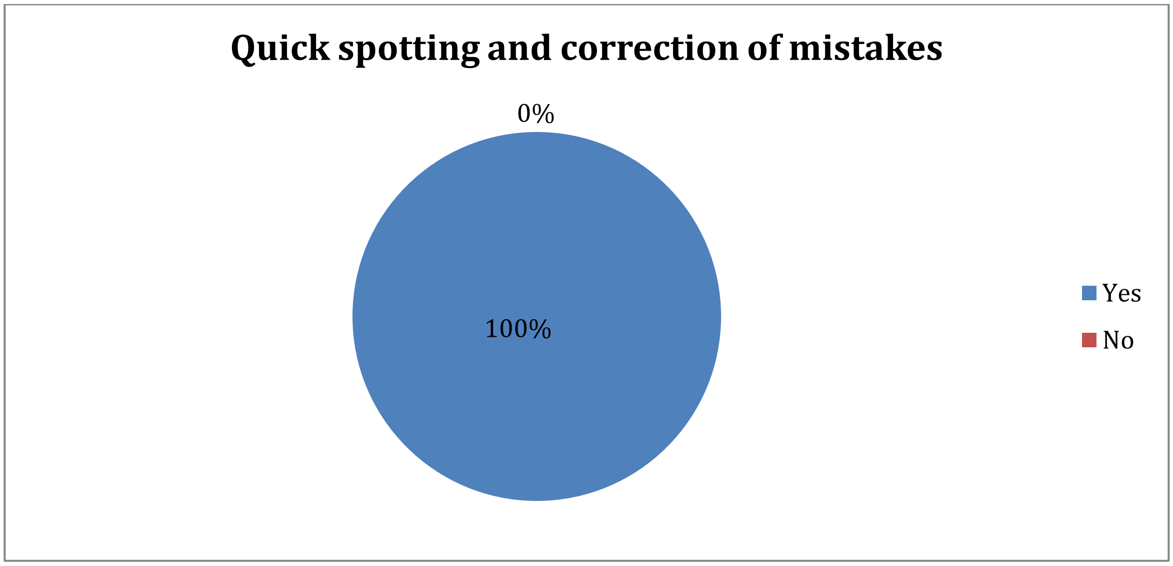
CHAPTER 5: RESULTS AND DISCUSSION

A survey was further carried out on the use of the information exchange model for the management of sustainable e-waste in Nairobi. The survey comprised of 4 respondents included 2 consumers, a collector, and a distributer who were involved in the old waste management system. 75% (3) of the respondents were male while 20 % (3) were male. 75% (3) of the respondents were in the age group between 29-39 while the rest 25% (1) belonged to the 40-50 age group. All the respondents registered, logged in, gave item selling details, collection date, and time, and product submitting. The respondents interacted with the model and used it after which they filled in a post-hoc questionnaire to validate the prototype system's usability. Below are the results of the survey.

Generally are you satisfied with the system the design, speed, and how easy it is?

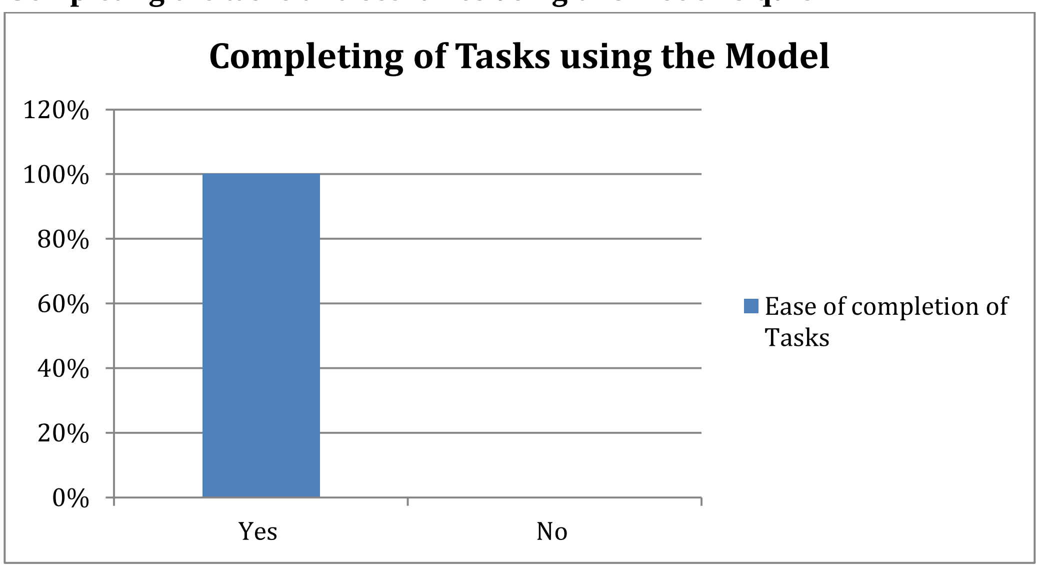
Source: Researcher (2021)

Whenever mistakes are made in the model, they can be detected and corrected quickly



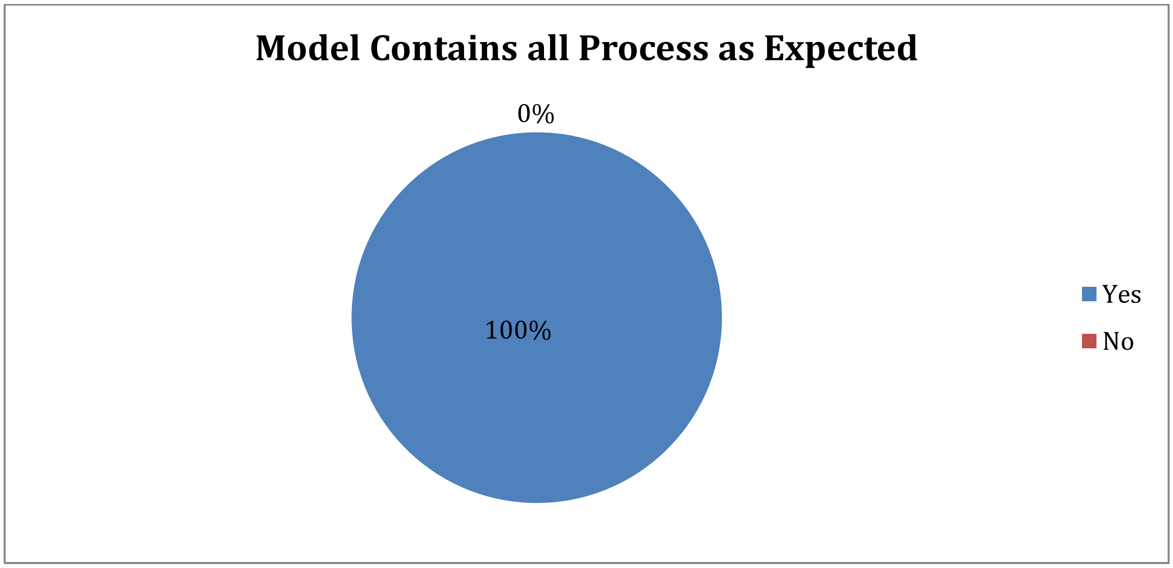
Source: Researcher (2021)

Completing the tasks and scenarios using this model is quick



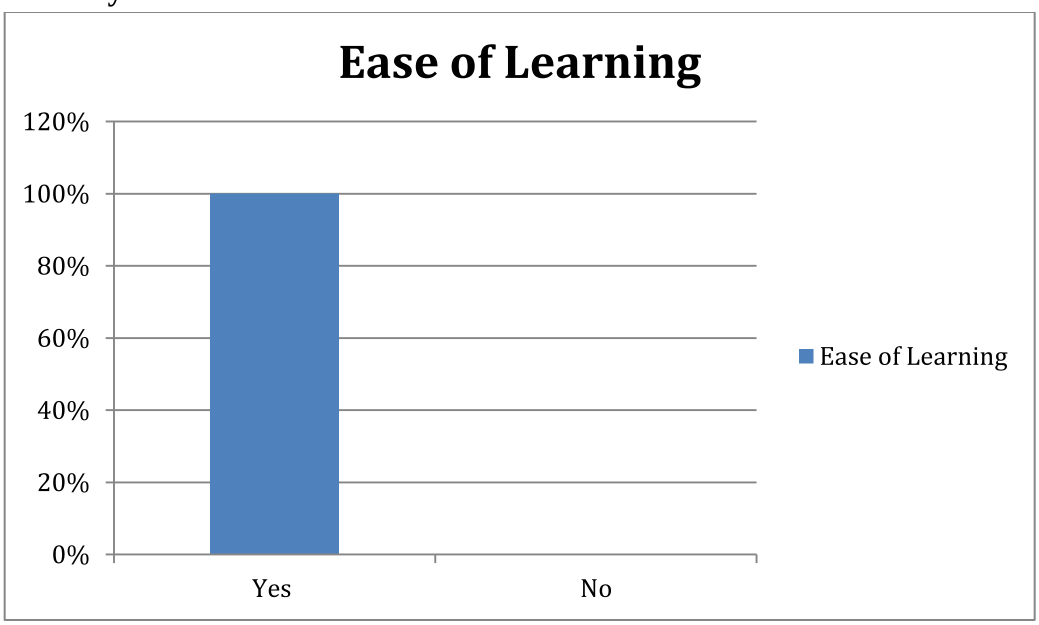
Source: Researcher (2021)

This model has got all the right processes, functions, and capabilities as I expected



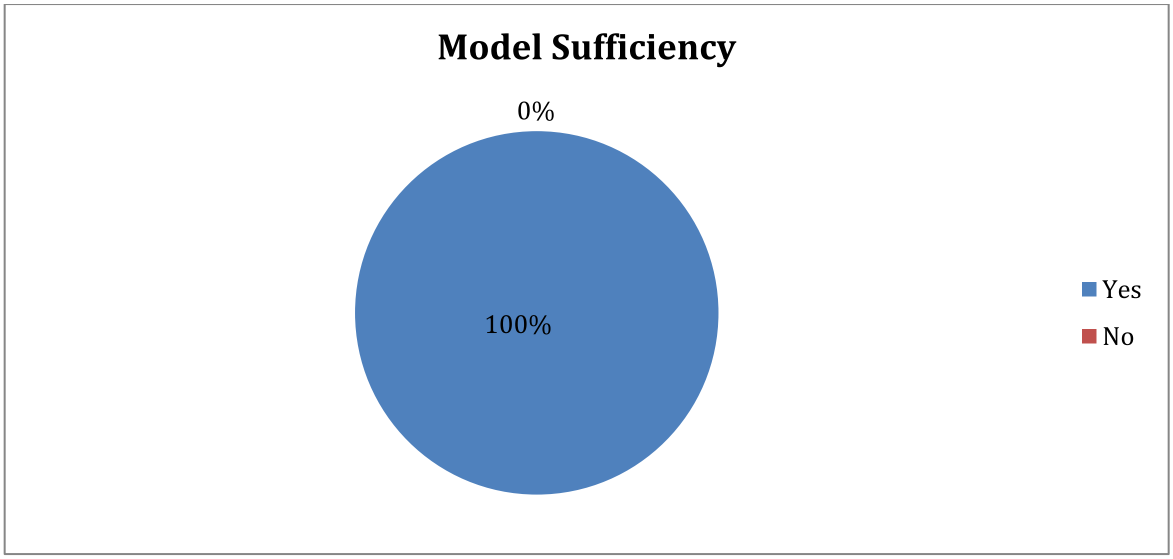
Source: Researcher (2021)

It is easy to learn how the model works



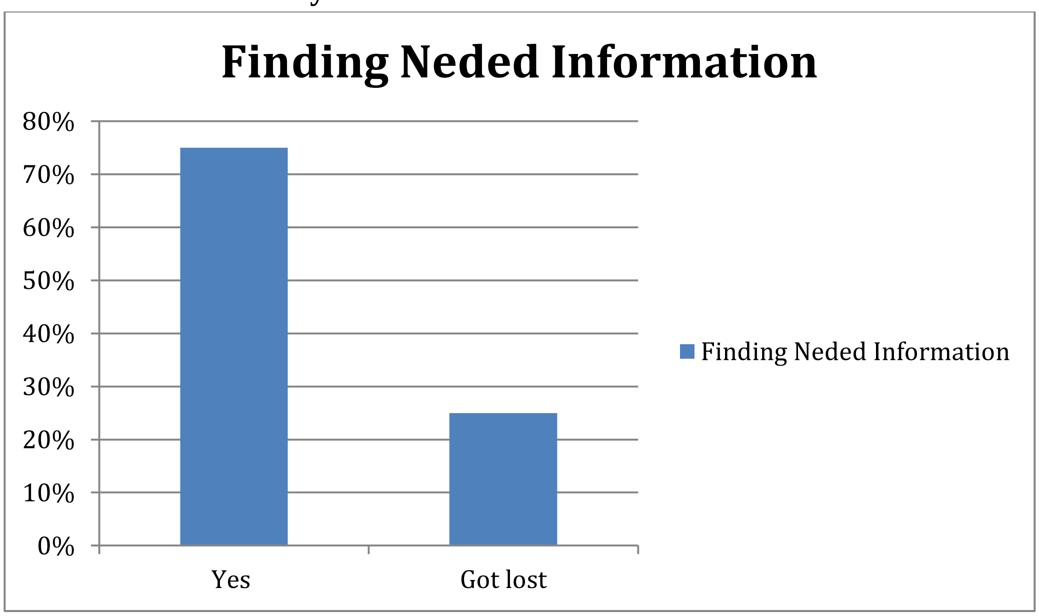
Source: Researcher (2021)

The model is sufficient for enhancing the sustainability of e-waste



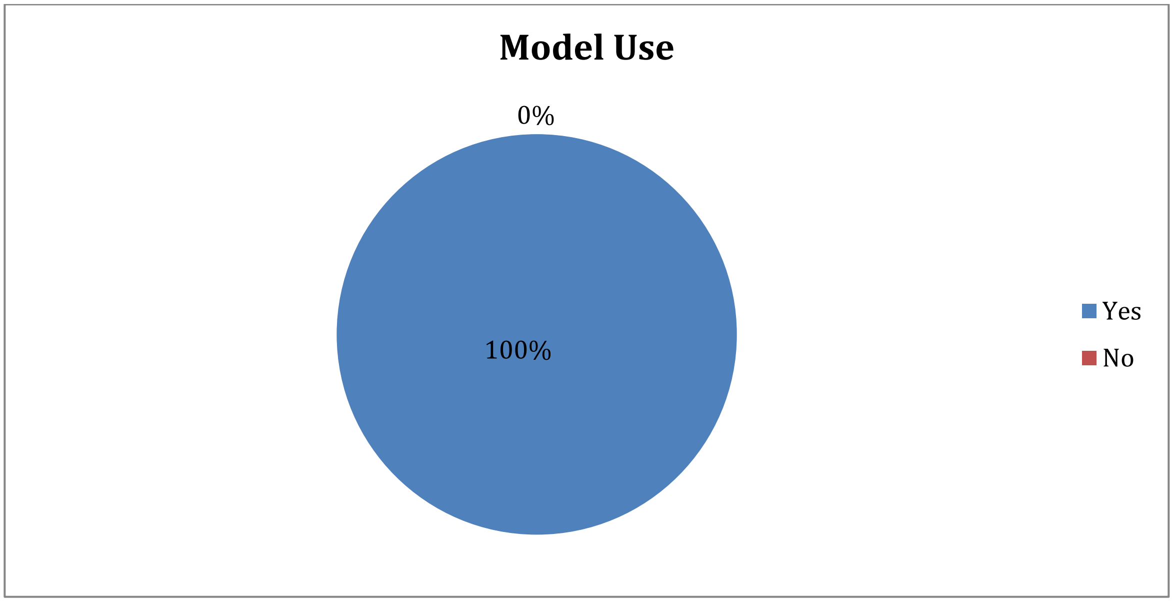
Source: Researcher (2021)

The model made it easy to find the information I needed



Source: Researcher (2021)

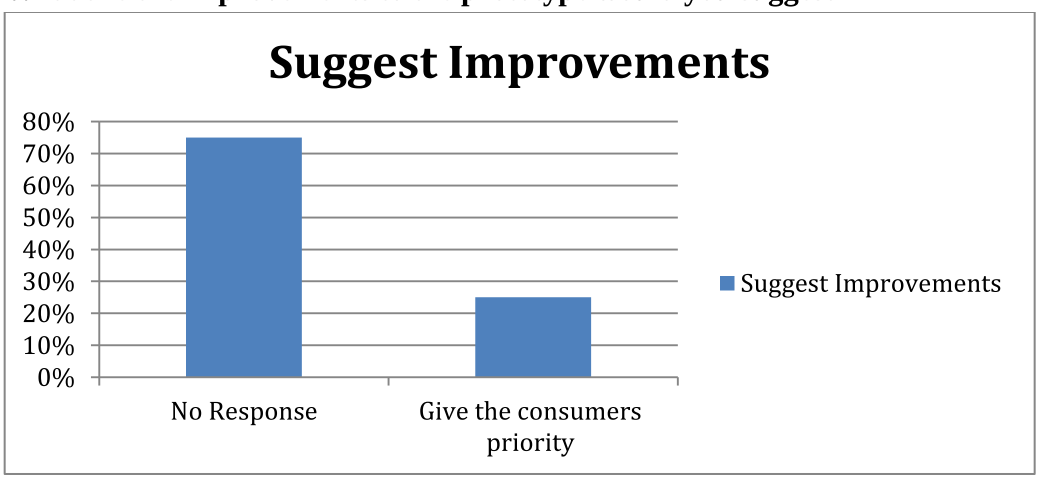
Given a chance, I look forward to adopting the information exchange model



Source: Researcher (2021)

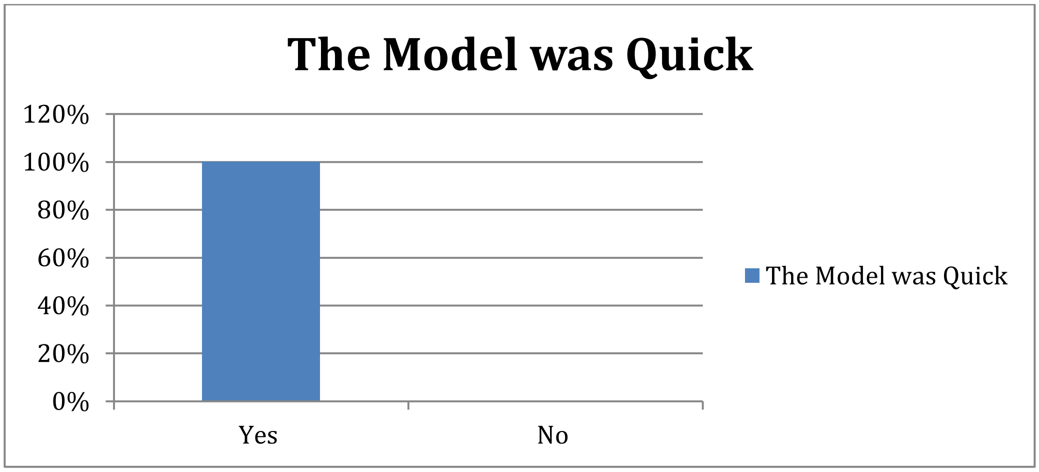
All the respondents opined that given a chance, they look forward to adopting the information exchange model in managing e-waste.

What are the improvements to the prototype would you suggest



Source: Researcher (2021)

The model was able to complete the process easily and quickly



Source: Researcher (2021)

Based on the results of the survey, the feedback given by the participants reveals that the information exchange model is useful and easy to use this will be able to enhance the sustainability of e-waste in Nairobi. The interface and information output from the model was also found to be of quality. The results further reveal that there is a willingness to embrace the information exchange model for the sustainability of e-waste management in Nairobi.

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The project was aimed at developing an E-waste information exchange model for the management of sustainable e-waste in Nairobi. The model will ease the work of tracking electronic disposable waste. This model will also work hand in hand with the recycling industry participant especially on information flow to help reduce or eliminate the amount of e-waste been left at the dumpsites to rot. The study began by reviewing the existing information flow challenges in the absence of an information exchange model for management of sustainable e-waste. The researcher found that the current e-waste disposal information exchange approach in Nairobi was inefficient which resulted in delays, inconsistencies, and inconveniences.

It was then concluded that there is an urgent need for Nairobi City County to adopt an information exchange model for the management sustainable e-waste. The model will help enlighten the participants in the e-waste management sector on the established policies, Institutional model, and infrastructures how to strengthen the existing policies, improvement of collection of e-waste, treatment, transportation, storage, disposal and recovery and the recognized centers for collection, exchange and recycling of e-waste.

The researcher then designed built a prototype that will enable improved information flow for sustainable e-waste management in Nairobi by eliminating communication breakdowns, delayed pick-ups, expensive disposal procedures, and lack of information and awareness concerning e-waste management. The researcher used Rapid Application Development (RAD) methodology to develop the prototype.

6.2 Limitation of the study

The limitations faced by the researcher include;

- The ongoing pandemic made it difficult for the data collection and testing process since the measures put in places such as keeping a distance and stay-at-home initiatives negatively influenced access to the respondents or the information.

- The study had a limited number of participants who responded to the survey.
- Most of the respondents were busy making it difficult for the researcher to wait until when the time was convenient for them

6.3 Recommendations

I would also recommend the following:

- Industries should put in place environmental, health and safety measures; to include corporate Information exchange platforms and also provide training and capacity building to equip their employees with knowledge regarding e-waste. This will emphasize the need of having a system where people in the industry can coordinate their ways of handling E-waste.
- Educate, train, and create awareness on e-waste menace by the county government and NEMA to manufacturing and processing industries and other stakeholders and also enforce existing legislation to realize environmental sustainability
- The Nairobi county government should allocate e-waste collection and disposal sites and centers and also implement systems and structures for monitoring and evaluating the projects of managing e-waste.
- The county government and the national government should develop an efficient e-waste recycling sector and also collect and manage data on e-waste at the industry level.

6.4: Recommended Areas for further research

6.4.1: Short-term recommendations.

(i) Impact of poor e-waste disposal on the human population and the environment.

(ii) Opportunities and prospects of activities of recycling e-waste in the country.

(iii) An analysis of methods of protecting the environment that applies to Nairobi County when it comes to management of e-waste.

(iv) Developing inclusivity for e-waste management to include other industries such as the assembly industries and service industries and incorporate them into stakeholders in e-waste management.

(v) Explore modern technological advancement in industrial electrical and electronic components and modules that have minimal toxic substances.

6.4.2: Long Term Recommendations

(i) The government should enact a new Information Exchange Model that will govern management of e-waste in the country i.e. ensure that the new Information Exchange Model is available even to the people in rural areas. The government can also review the available Information Exchange Model as they come up with the new model to improvise from county to county.

(ii) The county government and the national government should develop an efficient e-waste recycling sector. This should be enabled by having an effective Information exchange method whereby the Kenya National Bureau of Statistics (KEBS) should collect and manage data on e-waste at the industry level.

(iii) NEMA should create awareness to the industry and the general public and this will be an easy way to pass the information on e-waste.

REFERENCES

Anyango J, T, 2011, A framework for sustainable e-waste management in Kenya: the case of ICT, *An unpublished masters study of the University of Nairobi*.

Bekoe, E.K. (2015). E-Waste Management Practices in the Kumasi Metropolitan Area of Ghana: Status and Challenges. *Master Thesis of Norwegian University of Life Sciences*

Heeks, R, Subramanian, L, & Jones, C, 2015, "Understanding e-Waste Management in Developing Countries: Strategies, Determinants, and Policy Implications in the Indian ICT Sector. *Information Technology for Development*, vol. 21, issue 4, 653-667.

Israel, D.G. (2012). Sampling the Evidence of Extension Program Impact. Program Evaluation and Organizational Development, IFAS, University of Florida. PEOD-5. October.

Kothari, C.R (2004). *Research methodology: Methods and techniques* (2nd ed.). India: New Age International (P) Ltd.

Kothari, C.R. (2004). Research Methodology, Methods and Techniques, 2nd Edition. New Age International (P) Ltd., Publishers.

Kumar, B. & Bhaskar, K. (2016). Electronic Waste and Sustainability: Reflections on a Rising Global Challenge. *Markets, Globalization & Development Review:* 1(1), 5.

Mmereki, D., Baldwin, A. Li, B. & Liu, H. (2016). The Management of Hazardous Waste in Developing Countries, Chapters, in: Hosam El-Din M. Saleh & Rehab O. Abdel Rahman (ed.), *Management of Hazardous Wastes, Intech Open.*

Mugenda, O.M. and Mugenda, A.G. (1999) Research Methods: Quantitative and Qualitative Approaches. Acts Press, Nairobi.

National E-Waste Management Strategy (2019). Ministry of Environment and Forestry

Nuwematsiko,R. Oporia, F, Nabirye, A, Halage, A,A, MusokeD, & Buregyeya, B, 2021, "Knowledge, Perceptions, and Practices of Electronic Waste Management among Consumers in Kampala, Uganda." *Journal of Environmental and Public Health,* Vol. 2021

Ogula, P. A. (2005). "*Research Methods".* Nairobi: CUEA Publications.

Ongondo, F O, Williams, I D & Cherrett, T J. 2011 "How are WEEE doing? A global review of the management of electrical and electronic wastes" *Waste Management,* 31(4):714-30. doi: 10.1016/j.wasman.2010.10.023.

Orodho, A. J. & Kombo, D.K. 2002. Research Methods: Nairobi: Kenyatta University Open and E-Learning Module.

Otieno, I, & Omwenga, E, 2015, "E-Waste Management in Kenya: Challenges and Opportunities" *Journal of Emerging Trends in Computing Information Sciences,* Vol. 6. No 12

Owusu, E. S. (2017). Exploring the Dynamics of E-waste Disposal Strategies in Tamale, Ghana. *Ghana Journal of Development Studies,* Vol. 15 (2).

Polit, D.F. and Beck, C.T. (2003). Nursing research: Principles and Methods. 7th Edition, Lippincott Williams and Wilkins, Philadelphia.

Sepulveda, A., Schluep, M. Renaud, F.G. Streicher, M. Kuehr, R. Hageluken, C. & Gerecke, A. C. (2010). A Review of the Environmental Fate and Effects of Hazardous Substances Released from Electrical and Electronic Equipment During Recycling: Examples from China and India. Environmental Impact Assessment Review 30(1):28-41. DOI:10.1016/j.eiar.2009.04.001

Shamoo, A.E. & Resnik, B.R. (2003). *Responsible Conduct of Research.* Oxford University Press.

Sthiannopkao, S, & Wong, M, 2012' "Handling E-Waste in Developed and Developing Countries: Initiatives, Practices, and Consequences." *The Science of the total environment*. 463. 10.1016/j.scitotenv.2012.06.088.

UNEP (2009). *International Conference on Chemicals Management Second session Geneva, 11-15 May 2009 Item 4 (f) of the provisional agenda Implementation of the Strategic Approach to International Chemicals Management: emerging policy issues.*

UNEP (2010). *National stake holder's workshop on e-waste management,* 7h September, 2010, UN GIGIRI, conference room2. http:Avww.icwe.co.ke.

Waema, T., Mureithi M. Wanjira, A. Finlay A. & Schluep, M. 2008) "E-waste in Kenya. *Baseline Assessment. Proceedings of the 19th Waste Management Conference of the IWMSA (WasteCon 2008),* 6-10th October 2008. Durban: South Africa.

APPENDICES

Appendix I: Questionnaire

Questionnaire for the Households

I am a student of The University of Nairobi undertaking a master degree course in Applied Computing and I am carrying out a research on Sustainable information exchange model for E-waste management in Nairobi County. I am therefore collecting information for this purpose; I am kindly requesting you to answer the following questions as appropriate. All data collected will be treated with at most confidentiality and used exclusively for the purpose of the study

Section 1: Household Information and socio-economic factors [Tick where appropriate]

1) Name of area of Residence………………………………………………
2) Gender of respondent [1] Male [2] Female
3) Age of respondent [1] 18-28 [2] 29-39 [3] 40-50 [4] 51-60 [5][6] 61 and above
4) Marital status **[ ]** Single **[ ]** Married **[ ]** Separated **[ ]** Divorced **[ ]** Widowed
5) Education level [1] No Education [2] Primary education [3] Secondary education [4] Tertiary education
6) What is the family size? [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 [ ] More than 5 [ ]
7) Are you employed? [ ] Yes [ ] No
8) If employed, in which sector?
   [1] Government [2] NGO [3] Private sector [4] Self employed
9) If in private sector is it in manufacturing and processing industry [ ] Yes [ ] No
10) For how long have you lived in this area?
   [1] Less than 12 months [2] 1-5 years [3] Over 5 years

General: (Tick where appropriate)

1. a. Do you know what e-waste is? [1] Yes [2] No, if Yes
   b. Are you aware that some hazardous fractions in e-waste from passive elements need a special treatment in order to be safely disposed of?[1] Yes [2] No, if Yes
   c. What are some of the problems associated with poor e-waste handling

   ....

   ....

d. In your own opinion what has contributed to fast growth in e-waste in manufacturing and processing industries?

....

....

E-waste System and Facilities (Tick where appropriate)

1. How far is your house from nearest solid waste dumpsite? [1] Less than 1 Km [2] 1≤ but ≤2 km [3] 2≤but

   ≤3 km [4] 3≤but≤4 km [5] e) 4≤but≤5 km

2. Do you know of any case of poor e-waste disposal in your neighborhood?

   [1] Yes [2] No

3. State any disadvantages of poor e-waste disposal and handling under following categories

   a. environmental

   ....

   b. social

   ....

4. How do you assess degradation of the environment due to poor e-waste disposal

   [1] Low [2] Moderate [3] High [4] Excessive

5. Kindly give your overall assessment on e-waste management in processing and manufacturing industries

   ……

Communication Model

1. a. Does the constitution of Kenya and other national policies such as EMCA sufficiently address the problem of e-waste in manufacturing and processing industries?

   [1] Yes [2] No, If No

   b. what should be done to improve the situation

   ………

2. Please state any priority areas of improvement regarding to e-waste management from passive elements at the following levels?

(a) Central Government level

………………………………………………………………………………………………
………………

(b) County Government level

………………………………………………………………………………………………
……………

(c) Industry-level

………………………………………………………………………………………………
……………………

3. What recommendations would you make to achieve full support from all the relevant stakeholders on matters regarding e-waste management from passive elements?

A. Central Government

………………………………………………………………………………………………
……………………

B. County Government Level

………………………………………………………………………………………………
……………………

C. Industries

………………………………………………………………………………………………
……………………

D. Other stakeholders

………………………………………………………………………………………………
……………………

Appendix II: Interview Schedule for the Key Stakeholders-NEMA

I am a student of The University of Nairobi undertaking a master's degree course in Applied Computing and I am carrying out a research on Sustainable information exchange model for E-waste management in Nairobi County. I am therefore collecting information for this purpose; I am kindly requesting you to answer the following questions as appropriate. **All data collected will be treated with at most confidentiality and used exclusively for the study**

Details of Respondent(s):

Name of respondent: ……………………………………………………………………….

Position of Respondent………………………………………………………………………………………………

Date: ……………………………

General: (Tick where appropriate)

4. a. Do you know what e-waste is [1] Yes [2] No, if yes

   b. What are the roles and responsibilities of the NEMA with regards to e-waste management?

   ………………………………………………………………………………………………………

   ……

5. Describe in your own words the most important problems and needs the City is facing concerning e-waste management in Nairobi County

   ……

   ……

6. a. Do you have a department in NEMA dedicated to issues of e-waste management? [ ] Yes [ ] No, if No

   c. What are you contemplating doing about mitigating the issue of e-waste management concerning this?

……

……

E-Waste System and Facilities (Tick where appropriate)

8. Who is responsible for the collection and disposal of e-waste from stakeholders in Nairobi County?

………

9. a. Are there any designated areas for the dumping of e-waste?

[1] Yes [2] No, if No

b. How is e-waste disposed of?

………

10. What are the risks associated with poor e-waste disposal and handling?

c. Environmental

………

d. Social

………

11. a. Are there any laid down procedures provided by NEMA to the different stakeholders regarding e-waste handling? [1] Yes [2] No,

b. What should be done to mitigate the problem associated with e-waste handling in involved stakeholders?

………

12 .Problems encountered in e-waste management service. Please tick as appropriate

Problem	very serious	serious	not so serious	no problem
Inadequate service coverage				
Poor service qualities (not frequent enough.)				
Lack of authority to make a financial and administrative decisions				
Lack of financial resources				
Lack of trained personnel				
Lack of vehicles				
Lack of equipment				
Old vehicle/equipment frequent breakdown				
Lack of capability to maintain Vehicle and equipment				
No proper institutional set-up for e-waste management service				
Lack of legislation				
Lack of enforcement measure and capability				
Lack of planning (short, medium, and long term)				
Rapid urbanization outstripping service capacity				
Difficult to locate and acquire landfill site				
Poor cooperation by Government agencies				
Poor response to waste minimization				
Lack of control on hazardous waste				

12. What is the projected growth in e-waste generation in manufacturing and processing industries in the next 5 years? [1] <2% [2] 2%-4% [3] 5-7% [4] 8-10% [5] above 11%

13.

Questionnaire for E-Waste Recyclers and Handlers

I am a student of The University of Nairobi undertaking a master's degree course in Applied Computing and I am carrying out a research on Sustainable information exchange model for E-waste management in Nairobi County. I am therefore collecting information for this purpose; I am kindly requesting you to answer the following questions as appropriate. **All data collected will be treated with at most confidentiality and used exclusively for the study**

Education and awareness:

General: (Tick where appropriate)

7. What are the roles and responsibilities of your organization with regard to e-waste management?

   ……

   ……

8. What is your organization's capacity and capability in e-waste handling?

   ……

   ……

9. Describe in your own words the most important problems and needs the City is facing concerning e-waste management in Nairobi County

   ……

   ……

10. What are the different categories of e-waste handled by your organization?

   ……

   ……

E-waste System and Facilities

6. What is the average weight of e-waste do you handle monthly?

[1] Below 100kgs [2] 100-150kgs [3] 151-200kgs [4] 201-250kgs [5] Above 250Kgs

7. For the above-handled e-waste does your organization practice?

[1] On-site storage [2] Offsite storage If offsite storage

8. a. Do you collect e-waste from companies and other organizations for handling processes? [1] Yes [1] No

b) If No, how do you get the e-waste? ………

9. a. What are the main processes involved in e-waste handling/recycling?

………

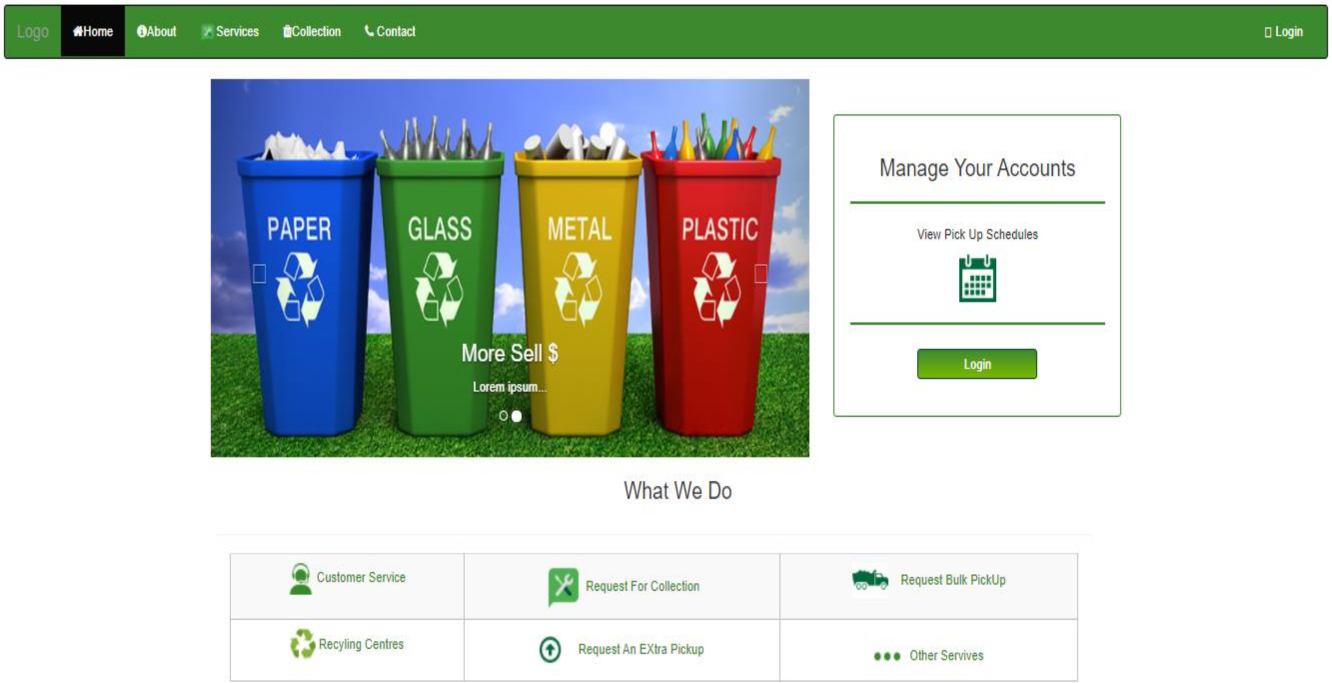
b. How do you dispose of the unwanted parts of e-waste?

………

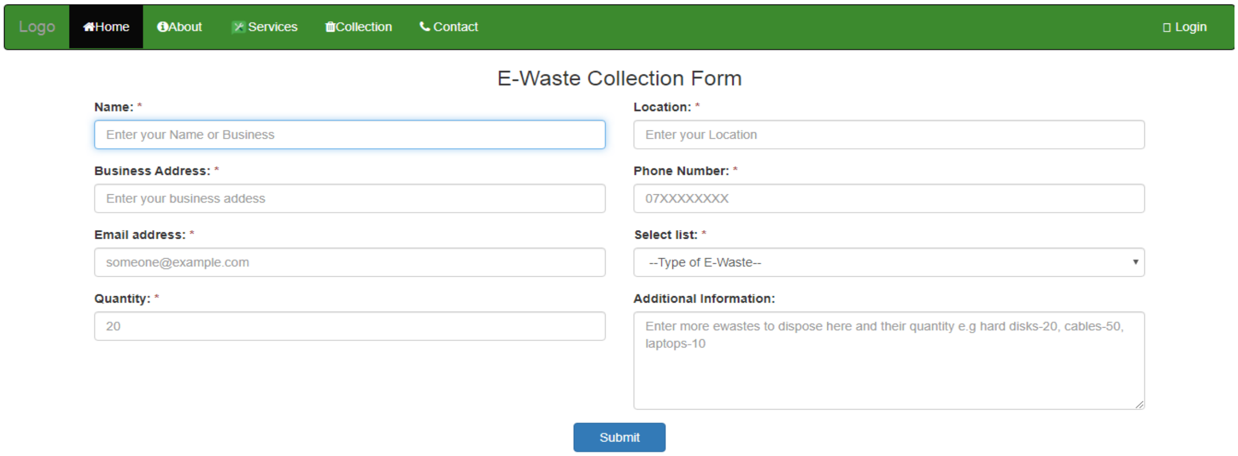
10. What are the main obstacles constraining proper e-waste collection, handling, and recycling processes in the country?

………

Appendix III: System Homepage



Appendix IV: E-Waste Collection Form



Appendix V: Activity Diagram

Activity diagrams explain the main activities/processes present in the project**.**