SCHOOL OF PUBLIC HEALTH

COLLEGE OF HEALTH SCIENCES

UNIVERSITY OF GHANA

CHARACTERIZATION OF ELECTRONIC WASTE AT AGBOGBLOSHIE DUMPSITE - A WASTE STREAM ANALYSIS

BY

PRINCESS HARRIET AGBAVITOR

(10402657)

A DISSERTATION SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF SCIENCE IN OCCUPATIONAL HYGIENE DEGREE

JULY, 2018

DECLARATION

I, Princess Harriet Agbavitor hereby declare that apart from references to other people's works, which have been duly acknowledged, this dissertation is as a result of my own independent work and has not been submitted for the award of any degree in any institution.

………………………… ………………………

Princess Harriet Agbavitor **Date**

(Student)

………………………… ………………………

Dr. John Arko-Mensah **Date**

(Academic Supervisor)

………………………… ………………………

Prof. Julius Fobil **Date**

(Academic Supervisor)

DEDICATION

This work is first and foremost dedicated to God, Who has granted me success in this project. Secondly, it is dedicated to the following people in this order: my family, my teachers, academic peers, and field staff.

ACKNOWLEDGEMENT

My profound gratitude goes to God the Father for giving me the strength and inspiration to undertake this research. As said, 'cleanliness is next to godliness'. I would secondly want to acknowledge my academic supervisors, Professor Julius N. Fobil and Dr. John Arko-Mensah for their enormous contributions, tireless support and meticulous supervision during the research. I am very grateful to my lecturers at the School of Public Health, as well as the entire staff of the Department of Biological, Environmental, and Occupational Health Sciences for their contributions in many ways to the success of this project.

Special thanks go to my research assistants: Lawrence, Franklin, and Samson for their commitment to the work. I acknowledge also, the contributions of Awal of Agbogbloshie, Joseph, Obed, and Randy. I am very grateful. Many thanks to Pastor Benjamin Boateng and members of Kingdom Legacy Fellowship for the support and prayers they offered on my behalf during this study.

My utmost gratitude goes to my mum, three siblings, and the rest of my family for bearing me up throughout this research. God bless you all.

I acknowledge West Africa-Michigan Collaborative Health Alliance for Reshaping Training, Education and Research in Global Environment and Occupational Health (WEST AFRICA-MICHIGAN CHARTER II) for supporting this work. I am very much grateful.

ABSTRACT

Background: In Ghana, waste management authorities need to know the characteristics of waste. However, little or no research has been done on e-waste characterization thus, presenting a big challenge to any plans for design and implementation of recycling and management programs. Characterization of e-waste involves identifying and quantifying the types of waste, as well as the valuable and hazardous components, and understanding the nature of the waste. This study, therefore, characterized e-waste arriving at Agbogbloshie dumpsite, one of the largest in the country and the world.

Methods: Waste stream analysis was conducted at the e-waste dumpsite to characterize the components of the waste stream. Three routes of entry to the site were selected to be points at which waste entering the site was intercepted, segregated, with different components identified and described. A descriptive analysis was conducted on all e-waste items that end up at the site by describing their physical and chemical characteristics, and their hazardous and valuable components.

Results: E-waste components such as refrigerators, televisions, microwaves, computers, etc. were found at the dumpsite. It was observed that some components of the waste stream such as medical devices did not arrive at the dumpsite. We found an annual generation of e-waste averaging approximately 798.20 metric tons at the dumpsite. E-waste components characterized were observed to contain valuable contents such as gold, silver, etc. as well as hazardous contents such as mercury, ammonia, ozone, etc. Physical characteristics of some e-waste components characterized included sensors, valves, coils, etc. and the chemical nature of these e-waste components included polybrominated diphenyl ethers, carbon fluorocarbons, etc. as well as heavy metal components such as tin, copper, arsenic, zinc, etc.

Conclusions: The types of e-waste were identified, the hazardous and valuable components as well as the physical and chemical nature of e-waste found at the dumpsite were characterized. The quantity of e-waste generation in metric tons per annum is observed to be high at the dumpsite. The study concludes that e-waste at Agbogbloshie dumpsite was successfully characterized.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

EEE	Electrical and Electronic Equipment
WEEE	Waste Electrical and Electronic Equipment
LED	Light Emitting Diode
DVD	Digital Video Disc
VHS	Video Home System
CRT	Cathode Ray Tube
LCD	Liquid Crystal Display
IT	Information Technology
PBDEs	Polybrominated Diphenyl Ethers
PCBs	Polychlorinated Biphenyls
BFR	Brominated Flame Retardant
CFC	Carbon Fluorocarbons
PVC	Polyvinyl Chloride

DEFINITION OF TERMS

E-waste

End of life electrical and electronic equipment

Component

Electrical or electronic element with its functionality connected together with other components, usually by soldering to a printed wiring board, to create an electronic circuit with a particular function (for example, an amplifier, radio receiver or oscillator).

EEE (Electrical and Electronic Equipment)

Electrical and electronic equipment, which are dependent on electric current or electromagnetic fields in order to work properly.

End-of-life EEE

Electrical or electronic equipment that is no longer suitable for use, and which is intended for dismantling and recovery of spare parts or is destined for material recovery and recycling or final disposal.

E-waste/Scrap dealer

An e-waste worker who buys e-waste materials for re-sell or processing.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Electronic waste (e-waste) is a term used to describe all types of electrical and electronic equipment (EEE) that have or could enter the waste stream (StEP, 2014), including televisions, computers, mobile phones, white goods for example fridges, washing machines, dryers, household or business item with circuitry or electrical components with power or a battery supply. The equipment is made of various materials such as plastics, metals, elements on the periodic table, and glass.

Over the past two decades, attempts have been made to recover valuable and reusable materials from electronic waste. Various recycling management programs developed to make the process easier and profitable have made these attempts, but have faced challenges. However, the challenges faced are due to the high variability in the nature of incoming e-waste stream. The variability is seen in the design, return volume, age, and the condition of the e-waste.

In Ghana, waste management authorities need to know the characteristics of waste. However, little or no research has been done on e-waste characterization thus, presenting a big challenge to any plans for design and implementation of recycling and management programs.

Characterization of e-waste involves identifying and quantifying the types of waste, as well as the valuable and hazardous components, and understanding the nature of the waste (Cui & Forssbeg, 2003).

E-waste contains some hazardous heavy metals, as mentioned earlier. Some of these hazardous substances are lead found in Cathode Ray Tubes (CRT), used for soldering. Exposure to lead damages the nervous system and causes brain disorders. Mercury is found in television causing sensory impairment. Cadmium, also found in semiconductors causes liver and kidney problems, and Brominated Flame Retardant (BFR) in PCBs, cables and cases, generates brominated dioxin that is toxic to man. Also, some plastics used in the manufacturing of electrical and electronic gadgets form toxic dioxins and furans when burnt under uncontrolled conditions.

However, characterization of e-waste is made easier when the type, nature and quantities of e-waste are identified.

The process of characterizing e-waste generates a planning data that informs the design of a less costly and environmentally friendly management program. The efficient management program will further reduce the consequences of pollution in attempting to recycle these electronic waste materials at the end of their lifespan on human and the environment.

In an attempt to better understand the nature of e-waste composition, this thesis presents the results of an analysis of the data collected from Agbogbloshie, an e-waste dumpsite. Based on the results, further recommendations can be made for the design of more profitable e-waste recycling and management programs as well as proper methods of disposal.

1.2 Statement of Problem

The effects of recycling electronic waste on e-waste workers and the environment in the informal sector in Ghana have been looked at in several ways. These effects have been attributed to exposure to some components of the e-waste designated, as hazardous elements implying the waste must be handled with the appropriate protocols during disposal and recycling.

Informal sector e-waste workers have relied on methods of recycling waste without information relating to the current nature of electrical and electronic products. The choice of recycling and management options are affected, whiles exposure to unknown hazardous elements has negative impact on the health of e-waste workers and the environment. The current flow of electrical and electronic items produced by manufacturers has a complex and heterogeneous nature. Some components of these electrical and electronic products contain hazardous elements, which have public health implications when man and the environment are exposed to them. It is therefore relevant to look at the composition of e-waste materials.

However, no work has been done on the characterization of electrical and electronic devices in Ghana to give information on their types and nature. The lack of information on characterization of e-waste has been widely reported resulting in the challenges faced with developing e-waste recycling and management programs. Thus, the effects of recycling e-waste in the informal sector have caught the attention of the public.

Therefore, to inform a safe recycling process, there is the need to characterize the electronic waste into specific categories based on physical characteristics, hazardous components etc.

Systematic categorization of the waste dumped/recycled at Agbogbloshie will facilitate proper disposal or recycling, thus minimizing contamination to the environment.

1.3 Justification

The recycling and management of e-waste have been an issue of discussion for years in Ghana. The major dumpsite, Agbogbloshie which is a suburb of Accra has become the hub of scrap business in the country. However, the waste stream in Ghana has never been characterized to understand its composition. Attempts to design practicable recycling and management options have been made, but these attempts have faced challenges. This is because there are no information on e-waste characterization, hence policy makers willing to design management programs find it rather challenging. This study, therefore, hopes to address the gap existing in literature on characterization of e-waste at the Agbogbloshie dumpsite. Conduct of this study would also make available information that will inform planning authorities on the design of efficient management programs.

1.4 Objectives

1.4.1 General Objective

To characterize and quantify e-waste at Agbogbloshie dumpsite in order to generate planning data that informs the design of an efficient management program.

1.4.2 Specific Objectives

The study specifically sought to:

1. Collect, measure and record weights of various types of e-waste.
2. Quantify the different components of e-waste in the waste stream.
3. Characterize the e-waste components by their hazardous contents and valuable and reusable materials.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview

Electronic wastes can be classified based on materials and component makeups. The equipment's manufacturing process is also considered. This characterization is very pivotal in the development of an environmental friendly as well cost-effective recycling system (Cui & Forsbegg, 2003).

This chapter reviews relevant literature in the study area of e-waste characterization. The characterization dealt with; the nature of e-waste, with types considered in previous works, both physical and chemical characteristics, the hazardous components, and the valuable and reusable component of e-waste.

Figure 1: E-waste discarded at the dumpsite (Photograph by author)

2.2 The Nature of Electronic Waste

Electronic waste (e-waste) comprises plastics, glass, metals, and other elements of the periodic table as described by Husman et al., (2007). E-waste has also been described as "discarded electrical or electronic equipment" (Liu & Themelis, 2014).

In recent times, the nature of e-waste is made up mostly of a particular form of waste flow in terms of variation in products (Husman et al., 2007). Studies have shown that majority of e-waste are hazardous upon expiring due to the presence of heavy metals such as mercury, arsenic and lead (Liu & Themelis, 2014).

However, many researches into e-waste were focused on the components of the e-waste, neglecting the adverse effect it poses on the environment. This instance has made it very difficult to improve design methods for e-waste recovery (Kwak et al., 2011). Hence it is very expedient to proceed after identification to quantify valuable materials and hazardous substances. This will help to develop a cost-effective and environmentally friendly recycling system, whilst gaining better understanding of the physical characteristics of the waste stream (Cui & Forsbegg, 2003).

2.3 Classification of Electrical and Electronic Waste.

The idea of classifying waste electrical and electronic equipment (WEEE or e-waste) has been a complex waste stream to easily understand. This is as a result of its own heterogeneous and complex nature and also, e-waste encompasses a wide range of products with diverse functions associated (Wang, 2014). The scope of electronic waste is broad and covers the growing range of electronic devices from large household appliances such as refrigerators, air conditioners, and small household appliances like rice cooker, blender, IT and communication devices such as hand-held cellular phones, personal stereos, to consumer electronics and even automatic dispensers.

E-waste can also be classified by the types of goods, which include: white goods, brown goods and grey goods. White goods comprise household appliances associated with cooling, washing, cooking and comfort. Brown goods include consumer equipment such as televisions, radios, video recorders, etc., and grey goods cover IT and communications equipment such as computers, telephones, cellular phones, monitors, etc. Step Initiative according to StEP (2014) also classified e-waste into ten groups. They are large and small households, IT and telecommunication devices, monitoring and controlling equipment, toys, leisure and sports equipment, lighting equipment, medical devices, electrical or electronic tools, consumer equipment, and automatic dispensers.

Aside these classifications, components of electrical and electronic equipment such as batteries, circuit boards, plastic casings, cathode-ray tubes, activated glass, and lead capacitors are also classified as e-waste.

2.4 Hazardous Substances and Components

The electric and electronic equipment (EEE) production industry is considered among the fastest growing industries and this in effect has resulted in an increase of waste electric and electronic equipment (Cui & Forssberg, 2003). Nevertheless, E-waste has become a potential source for the recovery of precious metals such as silver, gold, platinum, copper, zinc, nickel, tin, and others. These metals, which are reused for manufacturing electrical and electronic components, are in high demand, likewise the lack of technologies for a selective recovery in many countries, informal and illegal removal of these residues are also on the rise. Electronic waste however consists of components that differ in shapes and sizes, with the most of them containing hazardous components that need to be treated separately during solid waste recycling process.

Some contents of e-waste include hazardous elements such as batteries, cathode ray tubes (CRT), printed circuit boards, toner cartridges, liquid crystal displays, carbon fluorocarbons (CFC) in equipment such as refrigerators, etc. These objects have contents such as lead, mercury, cadmium, and CFCs that have very adverse effect on the ecosystem when exposed to living organisms. (Cui & Forsbegg, 2003). About 60% of e-waste is made up of iron, copper, aluminium, gold and other metals, with about 2.70% being pollutants (Widmer, Oswald-Krapf, Sinha-Khetriwal, Schnellmann, & Böni, 2005), yet there is a release of high toxic pollutants into the atmosphere especially when e-waste is burnt or recycled in uncontrolled environments, one particularly being the Agbogbloshie dumpsite. Therefore, the characterization of e-waste according to the hazardous components will be of much benefit in the process of recovery or recycling of e-waste with reliable information on the negative effects of improper recovery processes and the severe environmental pollution and health treat on those working with the e-waste-derived chemicals.

2.5 Physical Characteristics of Electronic Waste

Electronic waste comes in different shapes and sizes, also in different materials and components makeup. The components makeup ranges from simple assemblies, like the iron with components pilot lamp, handle, cover plate, thermostat, heating element, capacitor, bimetallic switch simply assembled to more complex ones, compared to say a laptop with a complex assembly of individual components (processor, hard drive, system memory, LCD screen, external ports, optical drive, video card, etc.) with all these components being of different materials usually metals, plastics and glass. A thorough characterization of these materials goes a long way to help in developing a recycling system to reduce the quantity of waste generated as well as the sanitation of the environment, and health of people dealing with e-waste (Cui & Forssberg, 2003).

2.6 Chemical Composition of Electronic Waste

E-waste has been considered very hazardous by many environmental protection agencies. This is attributed to the fact that they have chemicals compounds in their composition that are toxic and disadvantageous to both human health and the environment (Robinson B.H, 2009). Chemical components of e-waste could be copper, iron, aluminum, brass and even precious metals, such as gold, silver and palladium, in addition to a mixture of polymers, such as polyethylene, polypropylene, polyurethane and others. There could be even ceramic materials, such as glass, and other inorganic and organic materials (Robinson, 2009). The chemical composition of electronic waste varies with each product. For example, LED TVs have a higher amount of polymer, while stoves and microwaves have a larger amount of metals. The chemical composition and concentration of chemical element in e-waste materials can be based on factors such as; the type of e-waste, year of manufacture, manufacturer's brand and country of origin. A good example is the use of other inert gas by manufacturers in new refrigerator models other than chlorofluorocarbon refrigerant in older models due to the development of the Montreal Protocol in 1989, and its ratification by member countries (Veit & Bernardes, 2015).

2.7 Valuable and Reusable Materials

Some components of electronic waste being precious metals like silver, gold, platinum, copper, zinc, nickel, tin and others have made e-waste to gain much value. (Cruz, 2016). In this paper e-waste were characterized according to these precious or valuable materials they contain. The electronic and electrical equipment (EEE) manufacturing industry has in recent times become a good market with demands for these precious metals. Both precious and special metals are contained in complex components of electronic and electrical equipment with only small concentrations per unit. Hence electronic and electrical equipment (WEEE) when no more in use becomes an important source of these “trace elements” (Chancerel, 2009). Recycling of e-waste will then be a very good source of revenue generation and much economic gain from the recovery of these precious metals. However, the content of electronic waste in these recent times are steadily decreasing. Therefore, a thorough characterization of the waste stream to know the material composition of precious metals and reusable materials will inform the e-waste industry on recycling processes thus, creating a better and more appropriate option aside the informal recycling methods. (Cui & Forssberg, 2003).

The studies reviewed in this research did not focus on the amount of e-waste in the general waste stream hence ignoring the composition studies of waste stream. This study will focus on analyzing the waste stream by characterizing the e-waste of the waste stream.

CHAPTER THREE

3.0 METHODS

3.1 Overview

In this chapter, the approach and techniques adopted to achieve the objectives of the study was presented. Firstly, information about the study area was presented indicating the routes of entry and exit of the dumpsite. The study design, which explains how waste stream analysis was employed as the approach for conducting the research, was also presented. Further discussed in this chapter was how sampling was done to collect quality data, and how the data were analyzed and interpreted.

3.2 Study Area

The research project was conducted at the e-waste dumpsite at Agbogbloshie, a suburb of Accra in the Greater Accra Region of Ghana. The site is reportedly one of the largest e-waste dumps in the world, with many tons of e-waste being processed each year (Akormedi et al., 2013). The site houses about 40,000 people with majority being migrants from the northern parts of Ghana (Feldt et al., 2014). Figure 2 is a map of Accra showing the dumpsite with coordinates (5.5545˚ N, 0.2257˚ W), and the routes accessed in and out of the site. The site can easily be located with these two major landmarks; Christ Temple church and the Old Fadama Police Station from the figure.

The dumpsite began as a market for the sale of basically onions and yams, until the growth of slums with activities of scrap dealers on the rise. The site then became the grounds on which used electrical and electronic equipment are brought for recycling.

The study site is a heavy industrial area consisting of scattered recycling workers performing their tasks under sheds and in the open. The dismantling and sale of metals are conducted at the frontage of the site adjacent to the Agbogbloshie market. Open burning of e-waste occurs at the rear of the market to recover valuable metals such as Copper (Itai et al., 2014).

The reason for the steady growth of the scrapyard is as a result of income earned from the recovery of valuable materials from discarded electrical and electronic equipment

(Amoyaw-Osei et al., 2011). A part of the land was then asked for from the custodians, The National Youth Council (NYC) according to Amoyaw et al (2011) to establish the scrap industry.

Figure 2. Map of Accra showing Agbogbloshie Scrapyard, and the routes accessed in and out of the yard (Source: Google map)

3.3 Study Design

Characterization of e-waste is a topic with little information available in Ghana. Therefore, in order to gather information on the topic, an analytical cross-sectional study design was adopted to collect relevant data through observation. This design allowed for a systematic approach to characterizing e-waste by knowing how e-waste enters the scrapyard and leaves the yard after processing.

The dumpsite has a number of entry and exit routes through which e-waste generated and collected from different parts of the region arrive and leave the site. Preliminary studies conducted indicated three routes of entry and exit where e-waste are transported in and out of the dumpsite.

The routes were given labels of 1, 2 and 3 representing the onion sale point, the junction to the area where burning takes place, and the point on the Graphic road where the scrap business is situated respectively. The routes are also outlets for processed e-waste to industries for further processing into finished products.

3.4 Sampling Technique

Every mode of transport identified to be carrying e-waste materials were observed and followed into the dumpsite. The e-waste workers were seen offloading materials been transported upon arriving at their stations of work at the site. The materials were further separated component by component, identified and weighed.

The different modes of transport were also measured to obtain their volumes. This was done with a tape measure, which took dimensions for length, breadth, and height. The volumes of other forms of transport such as hand carrying, bicycle and motor bike transport modes were estimated.

Measurements of weights and volumes of both e-waste materials and modes of transport were done daily until all materials as well as transport modes entering the site had weights and volumes recorded.

3.5 Waste Component Classification and Quantification

Data were collected for this study with questionnaires given the name electronic waste information data sheet. The data sheet allowed the researcher to view and take record of discarded electrical and electronic equipment when they were brought to the dumpsite as well as provided for interaction with the e-waste workers during times of arrival. The trucks especially were followed from the entry routes to their stations of offloading to observe and record. The types of products were recorded and also their quantity and the mode of transportation of the waste products. Each observation lasted for about two to ten minutes depending on the volume of the waste brought in at a time.

E-waste components were identified and classified according to Step Initiative (2014). This Initiative classified components into ten categories, which was based on their types and functions. The classification categories were large household appliances, small household appliances, IT and telecommunication devices, consumer equipment, lighting equipment, medical devices, electrical and electronic tools, toys, leisure and sports equipment, monitoring and control instruments, and automatic dispensers.

The weights of the e-waste items measured constitute the waste stream components at the dumpsite. The quantities of the various components were determined using analog scales available at the dumpsite. The components were carried one after the other from the bulk materials, and put on the scale for their weights to be measured in kilograms. The volumes of the components were also measured in cubic meters using tape measure. These two quantities were subsequently used in deriving densities of the waste components.

However, the data sheet contained slots to be filled with the required information that will answer the specific objectives of the research. The survey was conducted taking into account the arrival date, the product type and quantities, as well as volumes of the transporting trucks. The information data sheets were useful in gathering data that were classified for analysis.

3.6 Quality Control

In ensuring that the data collected during the study were of the best quality, the measures below were put in place, and the validity of the data guaranteed:

a. Four research assistants having the required background were recruited and trained for the study.

b. Data were crosschecked daily to ensure that all information were been properly collected and recorded.

c. The electronic waste information data sheet was pre-tested at the Agbogbloshie dumpsite to validate the data collection tool.

d. Vehicles entering the site were carefully taken notice of, and followed closely to avoid missing them.

3.7 Data Processing and Analysis

Data collected were entered into Microsoft Excel and Stata/SE 15 software. Quantities such as densities were derived from masses and volumes of waste components as per day, weekly and annual flow rates. Descriptive analyses were done for all e-waste by their physical and chemical characteristics, and their hazardous and valuable contents in the Word Processing software.

CHAPTER FOUR

4.0 RESULTS

4.1 Overview

In this chapter, the results of the research undertaken pertaining to the specific objectives to be achieved are presented. The various modes of transport of e-waste and their volumes are presented firstly followed by the electronic waste products that normally arrive at the dumpsite with their weights. Also, the quantities of waste generated are presented as well as characterization by physical and chemical characteristics, and by hazardous and valuable contents of the e-waste products.

The daily, weekly, and annual flow rates of waste that arrive at the dumpsite are presented. The flow rates of recycled e-waste materials leaving the site are also looked at. Densities derived from masses and volumes of components are presented in this chapter.

4.2 Modes of Transport of E-waste

E-waste is transported to Agbogbloshie dumpsite through different means of which ten were identified. Used and discarded electrical and electronic equipment are disposed of by individuals and companies either in trash bins or sold to scrap dealers who move from home to home in search of scraps. Some of the scrap dealers work also as rubbish collectors where waste collected are gathered and discarded electronic and electrical equipment are sorted out for recycling.

These waste collected and gathered arrive at the dumpsite in trucks of different sizes such as mini pickups, medium pickups, articulated trucks and trailers. Some others transport their waste in wheelbarrows, tricycles, and on manual pulley trucks made of four vehicle tyres. Bicycles and motorbikes are sometimes used for carrying small volumes of e-waste. And lastly carrying by hand to the dumpsite by the dealers was also observed.

The forms of transport all have different volumes contributing to the waste volume per day and annually. Tricycle had the highest frequency followed by the manual pulley truck and the mini pickup trucks.

The volumes of the transport systems, their frequencies, the daily, weekly, and annual flow rates are presented in Table 1.

Table 1 Mode of Transport

Transport Serial No.	Mode of Transport	Volumes (m^3)	Total Volume (n=15 days)	Frequency (f)	Daily Volume Rate (m^3)	Weekly Volume Rate (m^3)	Annual Volume Rate (m^3)
1	Manual truck	1.16	42.92	37	2.86	20.02	1043.9
2	Mini pickup truck	3.04	66.88	22	4.46	31.22	1627.9
3	Medium pickup	16.42	311.98	19	20.8	145.6	7592
4	Articulated	31.25	156.25	5	10.42	72.94	3803.3
5	Trailer	70.74	212.22	3	14.15	99.05	5164.75
6	Tricycle	4.36	200.56	46	13.37	93.59	4880.05
7	Bicycle	0.1	1	10	0.07	0.49	25.55
8	Motor bike	0.11	0.77	7	0.05	0.35	18.25
9	Wheel barrow	0.16	0.48	3	0.03	0.21	10.95
10	Hand carrying	0.1	1.3	13	0.09	0.63	32.85
	Total		994.36	165	66.3	468.1	24,199.50

4.3 Measurement and Recordings of E-waste Items

In order to quantify the amount of e-waste generated over a period at Agbogbloshie, the individual weights of the e-waste items were measured and recorded as seen in Table 2.

The weight of large household appliances was observed to be the highest, followed by consumer equipment, IT and telecommunication devices, electrical or electronic tools, small household appliances, automatic dispensers, lighting equipment and tools in descending order.

Table 2 shows the weights, volumes, and densities of e-waste items and the category of the e-waste collection they are grouped under.

Figure 3: Weighing a refrigerator with an analog scale (Photograph by author)

Table 2 Quantification of E-waste Items and their Categories

E-waste Item Code	E-waste Item	Weight (kg)	Volume (m³)	Density (kg/m³)	Type of E-waste
1	DVD Player	3	0.002621	1.85	Consumer equipment
2	Iron	2	0.004082	48.86	Small household appliances
3	Washing machine	99.8	0.436716	299.14	Large household appliances
4	Kettle	1	0.002616	1.22	Small household appliances
5	Ceiling fan	4	0.000463	8640.23	Small household appliances
6	Sewing machine	5	384405.631	0.04	Consumer equipment
7	Fridge	14.5	1.275554	11.31	Large household appliances
8	LCD monitor	5	0.024056	67.44	IT and telecommunication devices
9	System unit	15	0.005472	3.97	IT and telecommunication devices
10	Deep freezer	64	0.983458	14.76	Large household appliances
11	Rice cooker	1	0.007342	5905.12	Small household appliances
12	CRT monitor	10	0.127174	790.41	IT and telecommunication devices
13	LCD TV monitor	16	0.96332	225.4	Consumer equipment
14	Air conditioner	53	0.041523	127.2	Large household appliances

15	UPS	8			Electrical or electronic tools
16	Voltage regulator	10	0.005225	3828.4	Electrical or electronic tools
17	Radio set	4	0.000551	907.1	Consumer equipment
18	CRT TV monitor	30	0.127174	78.96	Consumer equipment
19	Standing fan	7.5	0.024044	17.12	Small household appliances
20	Speaker	1	0.000804	1.02	Consumer equipment
21	Printer	181.4	0.045131	60.09	IT and telecommunication devices
22	PC mouse		0.000266	23.3	IT and telecommunication devices
23	Blender	4.38	0.534083	82.12	Small household appliances
24	Oven	36.5	0.644806	57.31	Large household appliances
25	Laptop	2.3	0.00235	979.13	IT and telecommunication devices
26	Photo copier	66.2	3.244957	2.04	IT and telecommunication devices
27	Water dispenser	23	0.10656	215.43	Automatic dispenser
28	Microwave	19.5	0.053336	366.41	Small household appliances
29	Keyboard	0.9	0.001037	868.34	IT and telecommunication devices

30	Laptop charger	4.5	70528	0.000638	Electrical or electronic tools
31	Amplifier	5.15	0.051168	101.2	Consumer equipment

4.4 Quantification of E-waste at Agbobloshie Dumpsite

The Table 3 below, shows a breakdown of the daily and annual generation rates of inflow waste quantities in both kilograms and metric tons for the three points of entry to the dumpsite. The waste volumes for both inflow and outflow rates at each point are also presented. Route 1 generated 332.15 metric tons as inflow rate, an inflow waste volume of 13,735 cubic meters, and an outflow waste volume of 3,817.9 cubic meters. Route 2 generated 255.5 metric tons as inflow rate, an inflow waste volume 8,074 cubic meters, and an outflow waste volume 1,587.75 cubic meters. Route 3 also generated 211.7 metric tons as inflow rate, an inflow waste volume 3,968 cubic meters, and an outflow waste volume 2,398.05 cubic meters.

The quantity of waste generated was computed per day for the different points of entry and exit. This was done to guide waste management authorities find the best management options that are environmentally friendly to handle the amount of waste generated in the country. The generation rate was highest at Route 1, with an average of approximately 908.6 kg/day. The generation rate at Route 2 was approximately 701.3 kg/day, which was higher than generation rate at Route 3 of approximately 576.9 kg/day.

The largest contribution to the overall waste generated at the dumpsite was from entry Route 1, since it served as the main entry route to the site with most motorist carrying e-waste ploughing that route. It was also observed that the waste bulk density was highest at Route 3, followed by Route 2 and Route 1 in descending order. The total of waste generated putting together generation rate from Routes 1, 2 and 3, averaging approximately 798.20 metric tons annually.

However, there are no quantities of outflow waste either in kilograms or metric tons. This is because weighing of outflow processed e-waste materials was impossible as e-waste workers were seen busily loading their vehicles with no time to waste as they had to finish packing before dusk.

Table 3 E-waste generation rate at Agbogbloshie

E-waste Parameter	Routes		
	1	2	3
Inflow quantity in (kg)/day	908.64	701.32	576.9
Inflow quantity in (metric tons)/day	0.91	0.7	0.58
Annual inflow waste quantity in (metric tons)	332.15	255.5	211.7
Inflow waste volume in (m^3)/day	37.63	22.12	10.87
Annual inflow waste volume in (m^3)	13,735	8,074	3,968
Inflow Waste bulk density in (kg/m^3)	24	32	53
Outflow waste volume in (m^3)/day	10.46	4.35	6.57
Annual outflow waste volume in (m^3)	3,817.9	1,587.75	2,398.05

4.5 Characterization by Physical and Chemical Characteristics, and by Hazardous and Valuable Contents

Table 4 below is a descriptive analysis of the e-waste items that arrive at Agbogbloshie dumpsite.

The table presents the review of the e-waste items that normally end up at Agbogbloshie. The physical characteristics are presented, and the chemical compositions of these items as well.

The hazardous components of each item are also looked at with their negative effects when man is exposed to them. Valuable and reusable contents are presented with their respective uses in those items in which they are found. Their uses are also identified so as the components can be preserved, recycled and used for similar items since it is costly to use new materials all together.

Table 4 Characterization by physical and chemical characteristics, and hazardous and valuable contents

CATEGORY CODE	CATEGORY NAME	SPECIFIC ITEM	HAZARDOUS CONTENT	NEGATIVE EFFECTS	VALUABLE CONTENT	USES	PHYSICAL CHARACTERISTICS	CHEMICAL DESCRIPTION
1	Large household appliances	Refrigerator	i. Ammonia ii. CFC	Ammonia - irritant to nose and throat CFC- Greenhouse effect.	i. Steel ii. Ammonia	Steel- steel rods and bars Ammonia- Fertilizers	Made up of compressor, evaporator, expansion valve, water inlet valve, icemaker, light bulb.	Steel, Ammonia, CFC
1	Large household appliances	Printing machine	i. Ozone ii. Additives iii. Waxes iv. Titanium dioxide	Ozone- chest pain Titanium dioxide- eye irritation	Steel	Steel rods and bars	Toner unit, exposure lump, charge coroner, photoconductive drum, paper feed, registration roller	Ozone, Additives, Waxes, Titanium Dioxide, Steel
1	Large household appliances	Hair Dryer	PVC	Cancer	i.Nickel ii.Chromium	Nickel and Chromium- Manufacturing of wet cells and coins.	Motor, Heating coils, electrical wire, switch, bracket, side cover	PVC, Chromium, Nickel
1	Large household appliances	Washing machine	PVC	Cancer	i. Steel, ii. Ammonia	Steel- steel rods and bars Ammonia- fertilizers	Power supply, control panel,	Steel, Aluminum, PVC

1	Large household appliances	Photocopier	i. Ozone ii. Selenium	Ozone- chest pain Selenium- irritability	Glass, Tungsten	Glass- used with mirrors to send images	Roller, charge coroner, photoconductive drum, paper feed, exposure lump	Glass, Ozone, Selenium, Tungsten
1	Large household appliances	Air conditioner	i. CFC ii. PVC iii. Sulfur dioxide	CFC- damage to nervous system Sulphur dioxide- irritant to nose	Steel	Steel- steel bars and rods	Sensors, timers, valves, evaporator, compressor, expansion valve, condenser	CFC, PVC, Sulfur Dioxide, Steel
1	Large household appliances	Electric oven	i. PVC ii. Lead	PVC- cancer Lead- memory impairment	Steel	Steel rods and bars	Power cable, stove, electric grill system	PVC, Lead, Steel
2	Small household appliances	Kettle	Polypropylene plastic	Plastic- cancer	Aluminum	Aluminum- electrolytic capacitors	Spout, handle, body, lid, heating element, power base	Aluminum, Plastic, Stainless Steel,
2	Small household appliances	Blender	i. PVC ii. Glass	PVC- cancer Glass- cuts	i. Chromium, ii. Nickel, iii. Stainless steel	Chromium- stainless steel and other alloys Nickel- alloys	Jar lid, jar lid center cap, O-ring seal, bottom screw cap, motor, blender rubber drive clutch	PVC, Glass, Chromium, Nickel, Stainless Steel

	Small household appliances	Microwave	Electromag-netic radiation (microwave)	Cancer	Stainless Steel	Kitchenware	Metal enclosure, inside panel, magnetron, turntable/metal waveguide stirring fan, control panel	Stainless Steel, Electromagnetic Radiation(Micro wave)
2	Small household appliances	Electric Sewing machine	Iron	Metal fume fever	Stainless Steel	Kitchen ware	Handle bar, needle stitch, Interconnection of gear systems, motor	Iron, Stainless Steel
2	Small household appliances	Ceiling fan	i. Fiberglass ii. PVC	Fiberglass-throat irritation PVC- cancer	Steel	Steel rods and bars	Flywheel, motor, blades, rotor, blade iron, down rod, ball-and-socket system	Steel, Fiber Glass, PVC
2	Small household appliances	Iron	PVC	Cancer	Steel	Steel rods and bars	Handle, power cable, heating element	Pvc, Steel
2	Small household appliances	Water heater	Glass	Cuts	i.Nickel ii.Chromium	Nickel-Stainless steel and other alloys Chromium-pigments	Dip tube, thermostat, valve, heating element	Glass, Nickel, Chromium

2	Small household appliances	Standing fan	i. Fiberglass ii. PVC	Fiberglass- Nose and throat irritation PVC-cancer	Steel	Steel rods and bars for construction work	Motor, blade, blade iron, metal stand	Fiberglass, PVC, Steel
2	Small household appliances	Toaster	PVC plastics	Cancer	i. Aluminum ii. Steel	Aluminum- Electrolytic capacitors Steel- Steel rods and bars for construction purposes.	Heating element, electromagnet timing mechanism, trip plate, browning control, bread rack, heat sensor, spring	PVC, Steel, Aluminum
2	Small household appliances	Rice cooker	Arsenic	Cancer of kidney and lungs	i. Aluminium ii. Copper iii. Carbon(pure)	Aluminum- capacitors Copper- electrical wires Carbon-dry cells	Inner cooking bowl, heat source, thermostat	Arsenic, Aluminum, Copper, Carbon(Pure)
3	IT and telecommu-nication devices	LCD PC Monitor	i. Mercury ii. Silver bromide	Mercury- memory impairment Silver Bromide- liver and	i. Copper ii. Titanium	Copper- electrical wire Titanium- air craft.	Light emitting diode, light source, diffuser, crystal display	Mercury, Silver Bromide, Copper, Titanium

				kidney damage				
3	IT and telecommu-nication devices	PC Keyboard	i. Brominated flame retardants ii. PVC	BFR- damage to nervous system PVC- cancer	i. Silver	Silver- used for jewelry and mirrors	110 keys, key board membranes, cable	Brominated Flame Retardants, PVC, Silver
3	IT and telecommu-nication devices	PC mouse	i. Cadmium ii. Beryllium iii. PVC iv. Lead	Cadmium- damage to lungs and kidney Beryllium- chronic scarring and lung disorder PVC- cancer Lead-Lower IQ	i. Chromium	Chromium- used in stainless steel and other alloys	Cable, scroll button, left and right click buttons, rolling ball	Cadmium, Beryllium, PVC, Lead, Chromium
3	IT and telecommu-nication devices	System Unit	i. Lead ii. PVC	PVC- cancer Lead-lower IQ	i. Gold ii. Aluminum iii. Silicon	Gold- Connector plating in most computer equipment Aluminium- electrolytic capacitors	Hard drive, CPU, floppy disk drive, USB port, audio jack, DVD tray	Lead, PVC, Gold, Aluminum, Silicon

						Silicon- printing circuit board		
3	IT and telecommu- nication devices	CRT PC Monitor	i. Lead ii. Cadmium iii. Yttrium iv. Barium,	Lead- lower IQ Cadmium- damage to lungs and kidney Yttrium- cancer Barium- increased blood pressure	i. Silicon ii. Gold	Gold- Connector plating in most computer equipment Silicon- printing circuit board	Three electron emitters, focusing coils, deflection coils, phosphor layer	Lead, Cadmium, Yttrium, Barium, Silicon, Gold
3	IT and telecommu- nication devices	Mobile phone	i. Lead, ii. PVC	Lead- lower IQ PVC- cancer	i. Silicon ii. Gold	Gold- Connector plating in most computer equipment Silicon- printing circuit board	Touchscreen, audio jack, speakers, microphone, sim card slot, SD card slot	Lead, PVC, Silicon, Gold
3	IT and telecommuni cation	Cordless microphone	PVC	Cancer	Aluminum	Electrolytic capacitors	Coils, capacitor plates, diaphragm, sensors	PVC, Aluminum

3	IT and telecommunication	PA system	i.PVC ii.Lead	PVC-cancer Lead-memory impairment	Lead	Lead acid batteries	Cone, voice coil, permanent magnet, surround	PVC, Lead
3	IT and telecommunication	Laptop	i.Lead ii.PVC	PVC-cancer Lead-memory impairment	i.Aluminum ii.Gold iii.Silicon	Aluminum-Electrolytic capacitors Gold-Conductive plaiting in most computer equipment Silicon-Printed circuit boards	USB port, LCD screen monitor, keyboard, touchpad, power button, audio jack	Lead, Gold, PVC, Aluminum, Silicon
4	Consumer equipment	Decoder	PVC	Cancer	i. Aluminum ii. Gold iii.Silicon	Aluminum-Electrolytic capacitors Gold-Conductive plaiting in most computer equipment Silicon - Printed circuit boards	Disk tray, power cable, reflective silver layer, Aluminum housing	Aluminum, Gold, Silicon

4	Consumer Equipment	CRT TV monitor	i. Lead ii. Cadmium iii. Yttrium iv. Barium,	Lead- lower IQ Cadmium- damage to lungs and kidney Yttrium- cancer Barium- increased blood pressure	i. Silicon ii. Gold	Gold- Connector plating in most computer equipment Silicon- printing circuit board	Three electron emitters, focusing coils, phosphor layer	Lead, Cadmium, Yttrium, Barium, Silicon, Gold
4	Consumer Equipment	LCD TV monitor	i. Mercury ii. Silver iii. Bromide	Mercury- Memory impairment Silver- argyria Bromide- liver and kidney damage.	i. Copper ii. Titanium oxide	Copper- electrical wires Titanium oxide- aircraft	Light emitting diode, light source, diffuser, crystal display	Mercury, Silver Bromide, Copper, Titanium
4	Consumer equipment	Speakers	i.PVC ii.lead	PVC- cancer Lead- memory impairment	Lead	Lead acid batteries	Cone, voice coil, permanent magnet, surround	PVC, Lead

4	Consumer equipment	DVD Player	PVC	Cancer	i.Aluminum ii.Gold iii.Silicon	Aluminum- Electrolytic capacitors Gold- Conductive plaiting in most computer equipment Silicon- Printed circuit boards	Disk tray, power cable, reflective silver layer, Aluminum housing	Aluminum, Gold, Silicon
4	Consumer Equipment	Radio(stereo)	i.PVC ii.Lead	PVC- cancer Lead- lower IQ	i.Aluminum ii.Iron oxide	Aluminium- electrolytic capacitors	Capacitors, coils, transformers, transistors, antenna, printed circuit board, speaker	PVC, Lead, Aluminum, Iron Oxide
4	Consumer Equipment	Satellite dish	Polyethylene, fiberglass	Fiberglass- throat irritation	i.Aluminum ii. Steel	Aluminium- electrolytic capacitorsSteel rods and bars	Wire mesh, parabolic reflector, actuator, metal shroud	Mercury, Glass, Xenon
4	Consumer equipment	VHS player	PVC	Cancer	i.Aluminum ii.Gold iii.Silicon	Aluminum- Electrolytic capacitors Gold- Conductive plaiting in	Power cable, reflective silver layer, Aluminum housing	Aluminum, Gold, Silicon

						most computer equipment Silicon- Printed circuit boards		
5	Lighting equipment	Lamp(fluor escent)	Mercury	Mercury- sensory impairment	Xenon	Xenon- photographic flash	Lamp tube, light emitting phosphors, activators	Glass, Tungsten
7	Electrical or electronic devices	Voltage regulator	PVC	PVC- immune system abnormalities	i.Silicon ii.Gold	Gold- connector plating in most computer equipment Silicon- printing circuit board	Dimmer, buck boost, relay, carbon brush, electronic circuit, servomotor	
7	Electrical and electronic appliances	Laptop charger	i.PVC ii.lead iii.asbestos	PVC- cancer Lead- Memory impairment Asbestosis	i.Copper ii.Gold	Copper - Electrical wires Gold- conductive plaiting in most computer equipment	Assembly of more than one conductor, plug	PVC, Lead, Asbestos, Gold, Copper

7	Electrical or electronic devices	Electricity generator	i.Iron ii.Copper (high doses)	Iron- metal fume fever Copper- diarrhea	i.Iron ii.Copper	Iron- iron rods Copper- conductive pathways	Engine, alternator, regulator, cooling and exhaust systems, lubrication systems, control panel	PVC, Silicon, Gold
7	Electrical or electronic devices	Extension board	Plastic(PVC)	PVC- birth defects	i.Aluminum ii.Copper	Aluminium- electrolytic capacitors Copper- conductive pathways	Plug, socket, extension cord, board with screws	Iron, Copper
7	Electrical and electronic appliances	Uninterrup-ted Power supply	i.PVC ii.Lead	PVC- cancer Lead- memory impairment	i.Gold ii.Copper iii.Silicon	Gold- conductive pathway in most computer equipment. Copper- electrical wires Silicon- Printed circuit boards	Diodes, carbon brush, electronic circuit, relay, dimmer, buck boost transformer	PVC, Lead, Gold, Silicon

7	Electrical and electronic appliances	Mobile phone charger	i.PVC ii.Lead iii.Asbestos	PVC- cancer Lead- Memory impairment	i.Copper ii.Gold	Copper - Electrical wires Gold- conductive plaiting in most computer equipment	Assembly of more than one conductor, plug	PVC, Lead, Asbestos, Gold, Copper
7	Electrical and electronic appliances	Stabilizer	i.PVC ii.Lead	PVC- cancer Lead- memory impairment	i.Gold ii.Copper iii.Silicon	Gold- conductive pathway in most computer equipment. Copper- electrical wires Silicon- Printed circuit boards	Diodes, carbon brush, electronic circuit, relay, dimmer, buck boost transformer	PVC, Lead, Gold, Silicon
7	Electrical or electronic devices	TV Antenna	Steel (mechanical hazard)		Steel	Steel-Steel rods and bars	Metal rods, power cable	PVC, Aluminum, Copper
7	Electrical and electronic appliances	Car battery	i.Lead ii.Sulfur	Lead- Memory impairment	Lead	Ammunition, Lead crystal glass	Plates, separators, electrolyte,	Lead, Sulfur

				Sulfur- Nose and throat			container, connecting bar	
7	Electrical or electronic devices	Electric/electronic cables	i.PVC ii.Asbestos	PVC- cancer Asbestos- lung damage	i.Copper ii.Aluminum	Copper- conductive pathways Aluminium- electrolytic capacitors	Assembly consisting of conductors, stranded wires, plugs	Stainless Steel, Steel
7	Electrical or electronic devices	Amplifier	i.Mercury ii.Cadmium iii.Beryllium iv.Lead	Mercury- Dermatitis Cadmium- lung and kidney damage	i.Lithium ii.Tin iii.Silver iv.Gold v.Nickel	Silver- dental alloys Gold- connector plaiting Nickel- used in making stainless steel	Terminals, connectors, switches, resistors, magnetic and inductive components, diodes, transistors, ICs	PVC, Varnish, Asbestos, Copper, Aluminum
8	Toy, leisure and sport equipment	Game adapters	i.Lead ii.Beryllium iii.Silver	Silver- liver and kidney damage	i.Lead ii.Silver	Lead- cable sheathing Silver- brazing alloy	Directional pads, analog sticks, motion detection mechanism	Lithium, Tin, Silver, Gold, Nickel , Aluminum, Lead
10	Automatic dispenser	Water dispenser	Lead	Lead- lower IQ	Steel	Steel- steel rods and bars	Enclosed tank, chiller tank, heater tank,	Lead, Beryllium, Silver, Fiberglass

9	Monitoring and control instruments	Satellite dish	Polyethylene, fiberglass		i. Aluminum, ii. Steel	Aluminium-electrolytic capacitors Steel- steel rods and bars	Wire mesh, parabolic reflector, actuator, metal shroud	Polyethylene, Fiberglass, Aluminum, Steel
10	Automatic dispenser	Water dispenser	Lead		Steel	Steel-Steel rods and bars	Enclosed tank, chiller tank, heater tank, silicone tanks, heater tanks, water tap/valves	Lead, Stainless Steel

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Overview

In this chapter, the results of the study are discussed to add meaning to the findings of the studies presented in the previous chapter.

5.2 Modes of Transport of E-waste

From Table 1, trailers with the highest volumes, have also the highest annual flow rate although with less frequency at the site. Tricycles and manual trucks have higher frequencies meaning is normally used as most of the dealers own them, and are able to move easily through neighborhoods to collect e-waste items, but have lesser daily, weekly, and annual flow rates due to their volumes.

This observation suggests that annual flow rates will increase considerably with a few more trailers and articulated trucks transporting e-waste materials into the dumpsite. However, these modes of transport with greater volumes will be better regulated compared to several manual trucks, bicycles, motorbikes or transport by hand carrying within a day.

Unlike the trucks which have buckets for storing waste materials, and not easily visible to the public, materials transported by hand carrying, manual trucks, motorbikes are visible and can even be touched by passersby. In this way, materials do not have direct contact with people other than the workers in the community since there is a market with several buyers and sellers on the same road.

The relevance of identifying the modes of transport is that, it is the first step to characterizing e-waste at the Agbogbloshie dumpsite which is essential for proper management of e-waste.

The findings were consistent with the results reported in a study by Batteiger & Sekyere (2018) who reported small trucks, bikes, motorbikes, and hand carrying as part of the modes of transporting e-waste to and from the dumpsite.

5.3 Measurement and Recordings of E-waste Items

E-waste items were measured to obtain their volumes in cubic meters and masses in kilograms. From Table 2, the density of each item was calculated from the mass and volume. It was observed that DVD players that had reached their end-of-life were often dumped at the site compared to other components. However larger household appliances were of greater quantities as compared to other types of e-waste materials.

Similarly, the densities of large household appliances are lower than densities of other components. This observation suggests that waste management options such as landfilling will have to be reconsidered as an option for disposing off waste as landfill sites must be closed over short periods. Therefore, management options such as recycling must be fully adopted to reprocess waste materials into finished products

The e-waste items found at the dumpsite were categorized under ten groupings. Eight of the groupings were found at the dumpsite with the exception of Medical Devices and Monitoring and Control Instruments. This means that majority of waste stream component that end up at Agbogbloshie are either large and small household appliances, IT and telecommunication devices, consumer equipment, lighting equipment, electrical or electronic tools, toys and leisure equipment or automatic dispensers. Thus, issues pertaining to infections from exposure to medical devices is minimal. The categorization of e-waste under ten groupings was done as per the EU Directive (Gaidajis, Angelakoglou, & Aktsoglou, 2010).

The measurement results of the e-waste items are consistent with a study by (Nelson, Hall, & Todd, 1992) which further breaks down the key components or materials that can be extracted from each e-waste item. However, the findings are relevant to knowing the weights, volumes and densities of the e-waste items that arrive at the dumpsite. This knowledge is further used in determining the quantities of e-waste that arrive at the dumpsite.

5.4 Quantification of E-waste at Agbogbloshie Dumpsite

Table 3 shows the amount of waste generation in Agbogbloshie. The relevance of these findings is to guide waste management authorities to find the best management options that are environmentally friendly to handle the amount of waste generated in the country. From Table 3, it is observed that the volume of waste that enters and leaves the dumpsite of approximately 13, 735 and 3, 817.9 cubic meters per annum respectively through the onion sale point represented as route 1 is greater than waste volume that enters and leaves the dumpsite through the other two routes. This tells that probably that route is easier to use than other routes. It suggests the onion sale point route can probably have more attention in the case of policies made on regulating the inflow and outflow rates of waste materials at Agbogbloshie.

The net inflow rate was observed to be higher than the net outflow rate. This difference is as a result of the recycling process used at the site to process waste materials. The crude method used does not allow for all the elements in a material to be dismantled properly owing to the fact that the tools used are not technologically advanced. Another reason may be that, probably not all elements in a material may be useful to the e-waste workers, and as such are left unattended to as is in the case of refrigerators. It was observed that some parts like the styrofoam in refrigerators were left as rubbish on the floor after dismantling the refrigerators or used as fires for burning electric cables to recover copper.

Steel companies in Tema industrial area were identified as outlet point for receiving recycled waste materials from Agbogbloshie. One of the trucks carrying processed materials was joined to one of the companies in Tema by name Ferro Fabrik. It was reported that raw materials received were from scrap dealers from different parts of the city. However, Agbogbloshie is one of their major sources with just a large truck arriving on daily basis or sometimes no materials arrive from there. A magnetic equipment picks all materials containing iron upon arrival, and discard other non-ferrous materials such as aluminium, lead, and plastics. The iron is further processed by melting into pellets and rolled into rods for sale. Outflow rate from Agbogbloshie can be determined from this observation to be much lower than inflow rate of approximately 25, 777 cubic meters per annum. Also, this observation from the company indicates how much more waste materials are created as all materials are not recycled and efficiently used. Perhaps, there are not industries to receive materials from the informal sector to further process.

E-waste materials are recycled informally by first burning with fuels which include discarded car tyres, petrol or diesel to obtain metals such as copper, aluminium, iron, gold, and silicon. Thus, observations made were that the sector focuses mainly on metallic components. Plastics are mostly not accounted for as plastic casing of system units were seen on one occasion leaving the site during the study.

The quantification results of e-waste at Agbogbloshie dumpsite relates to results reported by several studies (Gomes, Souza, Yamane, & Siman, 2017; Jain & Sareen, 2006; Mmereki, Li, & Wang, 2012)

5.5 Characterization by Physical and Chemical Characteristics, and by Hazardous and Valuable Contents

As presented by Table 4, almost all components found at the dumpsite contained hazardous elements such as mercury, ammonia, arsenic, ozone, etc. Therefore, waste must be handled properly by putting in place safety measures to prevent exposure to man and the environment. These findings relate to the study by (Sonawane, Anushree, & Pranjali, 2016) which identified some hazardous components in e-waste items and effects on exposure to man. Observed from the table is how almost all e-waste materials contained valuable and reusable materials such as gold, silver, steel, nickel, etc. It is the reason for the rise in the scrap business since many depend on its economic gain. The valuable and reusable elements had their uses identified so as to preserve for recycling since it is costly to use new elements all together.

Valuable and reusable elements such as steel is used for steel rods and bars, chromium used for stainless steel and other alloys, and aluminium used for electrolytic capacitors. These findings are consistent with several studies (Bassanezi, 2014; Jharwal, 2015)

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study identified ten different modes of transport of e-waste to Agbogbloshie dumpsite. These included trucks of smallest size to greatest size, tricycles, bicycles, motor bikes, wheel barrows, manual pulley trucks and hand carrying. Their volumes were measured and recorded. Scrap dealers used these means to transport e-waste to and from the site.

The weights of the e-waste items found at the dumpsite for processing were measured with a scale and recorded. The items were grouped under the ten standard categories of e-waste classification and the overall weights compared. Large household appliances had the highest weight recordings as compared to the others. In addition, two of the categories namely medical devices and monitoring and control instruments were not identified at the site throughout the study suggesting that their waste products did not arrive at Agbogbloshie dumpsite.

The quantities of waste generated per day and annually were computed for the different points of entry at the site. Point 1 was observed to have the greatest amount of waste generated with the least waste bulk density. Whiles route 3 recorded the least amount of waste generated with the highest waste bulk density. The overall waste generated annually suggests a huge waste burden in the city of Accra. Inflow rate recorded was higher than outflow rate as a result of the processing technique used in retrieving materials from the waste stream. Also, some materials are not relevant to the e-waste workers, and thus reducing the material flow to metals such as copper, aluminium, iron.

Characterization was done for the e-waste items based on their physical characteristics, chemical compositions, hazardous and valuable contents. Literature was reviewed for the current products released into the system by manufacturers so as to identify the waste stream characteristics.

6.2 Recommendations

In view of the findings of the study taking into account the results addressing the objectives of the study the following recommendations are made to improve the informal e-waste sector of the country.

6.2.1 Implementation of Best Practicable Management Programs

The generation rate of e-waste indicates that a better management system of e-waste that can handle large quantities of waste needs to be implemented. This could be achieved by the provision of an improved method of disposing of e-waste instead of directing majority of the waste to the informal sector, which has limited technology to process the waste. Also, recycled e-waste materials that are sent to industries for further processing should not only be available to steel companies for iron rods and sheets. Aluminium, plastic and other materials should be made available to other industries with expertise to process them to avoid further generation of waste.

6.2.2 Provision of Improved Technology for Recycling E-Waste

Based on the findings of the study, the inflow rate of e-waste was higher than the outflow rate recorded. This difference is an indication that majority of the waste stream components are not utilized after processing and thus, disposed of. Observation made at the site indicated no proper means of discarding waste components that were not useful to recyclers after processing was done to obtain the needed components such as copper, iron and aluminium. This increases the health risks and environmental hazards as some of these components are hazardous to man and the environment.

There should be provision of an improved technology with training for the e-waste workers on how to use the technology. This is to ensure majority of the waste stream component are recycled for further processing. Thus, reducing the health risks and environmental hazards associated with the crude methods for recycling e-waste used by the e-waste workers.

6.2.3 Educating E-Waste Workers on Health Hazards and Safety Measures

Characterization of e-waste items revealed the nature of current electrical and electronic equipment manufactured. Their physical characteristics and chemical composition were taken into account. Their hazardous and valuable components were also considered. Based on this review, e-waste workers should be educated on the hazards associated with the materials they handle, and as such be trained by resource persons such as government officials from the health sector on health and safety measures that will protect them, others and the environment from hazardous contaminants present in the waste stream components.

REFERENCES

Akormedi, M., Asampong, E., & Fobil, J. N. (2013). Working conditions and environmental exposures among electronic waste workers in Ghana. *International Journal of Occupational and Environmental Health*, *19*(4), 278–286. https://doi.org/10.1179/2049396713Y.0000000034

Amoyaw-Osei, Y., Agyekum, O. O., Pawmang, J. A., Mueller, E., Fasko, R., & Schluep, M. (2011). Ghana e-waste country assessment. *SBC E-Waste Africa Project*, (March), 1–123. Retrieved from http://www.ewasteguide.info/files/Amoyaw-Osei_2011_GreenAd-Empa.pdf%5Cnhttp://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Ghana+e-Waste+Country+Assessment#0

Bassanezi, R. B. (2014). Economic Impact of Leprosis, (January).

Batteiger, A., & Owusu-Sekyere, K. (2018). Improving the e-waste management conditions in Agbogbloshie through a Material Flow Analysis. *Water Quality and Solid Waste Management*, *33*(1), 3–29. https://doi.org/10.1177/0734242X14557382

Binion, E., & Gutberlet, J. (2012). The effects of handling solid waste on the wellbeing of informal and organized recyclers: a review of the literature. *International Journal of Occupational and Environmental Health*, *18*(1), 43–52. https://doi.org/10.1179/1077352512Z.0000000001

Bras, B. (2007) Design for Remanufacturing Processes. Environmentally Conscious Mechanical Design, M. Kutz, ed., Wiley, Hoboken, NJ, pp. 283– 318.

Cui, J., & Forssberg, E. (2003). Mechanical recycling of waste electric and electronic equipment: a review. *Journal of Hazardous Materials*, *99*(3), 243–263. https://doi.org/10.1016/S0304-3894(03)00061-X

Cui, J., & Zhang, L. (2008). Metallurgical recovery of metals from electronic waste: A review. *Journal of Hazardous Materials*, *158*(2), 228–256. https://doi.org/10.1016/j.jhazmat.2008.02.001

Dalgren, K. E., Düker, A., Arwidsson, Z., von Kronhelm, T., & van Hees, P. A. W. (2011). Re-cycling of remediated soil – Evaluation of leaching tests as tools for characterization. *Waste Management*, *31*(2), 215–224. https://doi.org/10.1016/j.wasman.2009.12.021

Das, S., Yedlarajiah, P., and Narendra, R., (2000) An Approach for Estimating the EOL Product Disassembly Effort and Cost. *Int. J. Prod. Res.*, 38(3), pp. 657–673.

Duan, H., Li, J., Liu, Y., Yamazaki, N., & Jiang, W. (2011). Characterization and Inventory of PCDD/Fs and PBDD/Fs Emissions from the Incineration of Waste Printed Circuit Board. *Environmental Science & Technology*, *45*(15), 6322–6328. https://doi.org/10.1021/es2007403

Dunn, D., (2005) The PC Replacement Decision. *Information Week*. http://www.informationweek.com/news/hardware/showArticle. jhtml?articleID¼164900387.

Feldt, T., Fobil, J. N., Wittsiepe, J., Wilhelm, M., Till, H., Zoufaly, A., … Göen, T. (2014). High levels of PAH-metabolites in urine of e-waste recycling workers from Agbogbloshie, Ghana. *Science of the Total Environment*, *466–467*, 369–376. https://doi.org/10.1016/j.scitotenv.2013.06.097

Gaidajis, G., Angelakoglou, K., & Aktsoglou, D. (2010). E-waste : Environmental Problems and Current Management, *3*(1), 193–199.

Gomes, A. S. T., Souza, L. A., Yamane, L. H., & Siman, R. R. (2017). Quantification of E-Waste : A Case Study in Federal University of Espírito Santo, Brazil. *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering*, *11*(2), 171–179.

Guarnieri, P., e Silva, L. C., & Levino, N. A. (2016). Analysis of electronic waste reverse logistics decisions using Strategic Options Development Analysis methodology: A Brazilian case. *Journal of Cleaner Production*, *133*(Supplement C), 1105–1117. https://doi.org/10.1016/j.jclepro.2016.06.025

Jain, A., & Sareen, R. (2006). E-waste assessment methodology and validation in India. *Journal of Material Cycles and Waste Management*, *8*(1), 40–45. https://doi.org/10.1007/s10163-005-0145-2

Jharwal, M. K. (2015). E-waste_ Recovery & Reuse of Matter and Benefits (PDF Download Available), (March 2013).

Kahhat, R., Kim, J., Xu, M., Allenby, B., Williams, E., & Zhang, P. (2008). Exploring e-waste management systems in the United States. *Resources, Conservation and Recycling*, *52*(7), 955–964. https://doi.org/10.1016/j.resconrec.2008.03.002

Kiddee, P., Naidu, R., & Wong, M. H. (2013). Electronic waste management approaches: An overview. *Waste Management*, *33*(5), 1237–1250. https://doi.org/10.1016/j.wasman.2013.01.006

Kwak, M., Behdad, S., Zhao, Y., Kim, H., & Thurston, D. (2011). E-Waste Stream Analysis and Design Implications. *Journal of Mechanical Design*, *133*(10), 101003-101003–8. https://doi.org/10.1115/1.4004118

Kimura, F., Kato, S., Hata, T., and Masuda, T., (2001) Product Modularization for Parts Reuse in Inverse Manufacturing *CIRP Ann.—Manuf. Technol*., 50(1), pp. 89–92.

Kwak, M., and Kim, H. (2010) Assessing Product Family Design from an End-of-Life Perspective. *Eng. Optimiz*., 43(3), pp. 233–255.

Liu, S., & Themelis, N. J. (2014). Analysis of Electronic Waste Recycling in the United States and Potential Application in China, (December). Retrieved from http://www.seas.columbia.edu/earth/wtert/sofos/FINAL_Shumeng_Thesis_Dec 20_2014.pdf

Mantooth, B. A., & Weiss, P. S. (2003). Fabrication, assembly, and characterization of molecular electronic components. *Proceedings of the IEEE*, *91*(11), 1785–1802. https://doi.org/10.1109/JPROC.2003.818320

Mat Saman, M. Z., Blount, G., Jones, R., Goodyer, J., and Jawaid, A., (2005) Methodology for the Design Recyclability Assessment in Automotive Engineering. *Proceedings of the 4th International Conference on Design and Manufacture for Sustainable Development*, United Kingdom.

Mmereki, D., Li, B., & Wang, L. (2012). Estimation of waste electronic and electrical equipment arising in Botswana-A case study of Gaborone City. *International Journal of Environmental Sciences*, *3*(1), 441–452. https://doi.org/10.6088/ijes.2012030131043

Nnorom, I. C., & Osibanjo, O. (2009). Toxicity characterization of waste mobile phone plastics. *Journal of Hazardous Materials*, *161*(1), 183–188. https://doi.org/10.1016/j.jhazmat.2008.03.067

Oliveira, C. R. de, Bernardes, A. M., & Gerbase, A. E. (2012). Collection and recycling of electronic scrap: A worldwide overview and comparison with the Brazilian situation. *Waste Management*, *32*(8), 1592–1610. https://doi.org/10.1016/j.wasman.2012.04.003

Oteng-Ababio, M. (2010). E-waste: an emerging challenge to solid waste management in Ghana. *International Development Planning Review*, *32*(2), 191–206. https://doi.org/10.3828/idpr.2010.02

Perera, H. S., Nagarur, N., and Tabucanon, M. T. (1999) Component Part Standardization: A Way to Reduce the Life-Cycle Costs of Products. *Int. J. Prod. Econ*., 60–61, pp. 109–116.

Rose, C., Catherine, M., Ishii, K., and Stevels, A. (2002) Influencing Design to Improve Product End-of-Life Stage. *Res. Eng. Des.*, 13(2), pp. 83–93.

Rai, R., and Terpenny, J. (2008) Principles for Managing Technological Product Obsolescence. *IEEE Trans. Compon. Packag. Technol*., 31(4), pp. 880– 889.

Savvilotidou, V., Hahladakis, J. N., & Gidarakos, E. (2014). Determination of toxic metals in discarded Liquid Crystal Displays (LCDs). *Resources, Conservation and Recycling*, *92*(Supplement C), 108–115. https://doi.org/10.1016/j.resconrec.2014.09.002

Simpson, T. (1998) A Concept Exploration Method for Product Family Design. *Ph.D. thesis, Georgia Institute of Technology*, Atlanta, Georgia.

Sonawane, P. P., Anushree, P., & Pranjali, D. (2016). E-Waste Management : An Emerging Environmental Issue Department of Master of Computer Application, *4*(01), 964–966.

StEP Initiative, (2014). One Global Definition of E-Waste. *StEP Initiative: Bonn, Germany*.

Takeuchi, S., and Saitou, K., (2005) Design for Product-Embedded Disassembly. *Proceedings of ASME 2005 International Design Engineering Technical Conferences*, Long Beach, USA.

Robinson, B. H. (2009). Science of the Total Environment E-waste : An assessment of global production and environmental impacts. *Science of the Total Environment, The*, *408*(2), 183–191. https://doi.org/10.1016/j.scitotenv.2009.09.044

Veit, H. M., & Bernardes, A. M. (2015). Electronic waste: Recycling techniques. *Electronic Waste: Recycling Techniques*, 1–159. https://doi.org/10.1007/978-3-319-15714-6

Wang, F. (2014). *E-waste : collect more , treat better*. https://doi.org/10.4233/uuid:91404545-dc7b-48c8-b9b5-a37fbf74ce5c

Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., & Böni, H. (2005). Global perspectives on e-waste. *Environmental Impact Assessment Review*, *25*(5 SPEC. ISS.), 436–458. https://doi.org/10.1016/j.eiar.2005.04.001

APPENDICES

Appendix 1. Questionnaire on E-Waste Characterization

CHARACTERIZATION OF ELECTRONIC WASTE AT AGBOGBLOSHIE DUMPSITE- A WASTE STREAM ANALYSIS

ELECTRONIC WASTE INFORMATION DATA SHEET

Collected by: __________________ Date: _________

Inflow Route: (1) (2) (3)

Inflow Vehicle: (1) Truck (Specify) _______________________ (2) Motor bike
(3) Bicycle (4) Hand carrying (5) Other (Specify)

Estimated Volume of Vehicle (m^3)/Waste (Inflow):
(See Chart attached)

Types of Waste (List all that apply)

Type	Items
Large household appliances	
Small household appliances	
IT and telecommunication devices	
Consumer equipment	
Lighting equipment	
Medical devices	
Electrical or electronic tools	
Monitoring and control instruments	
Toys, leisure and sports equipment	
Automatic dispenser	

Specific Electronic Waste Item
(See Chart attached for estimated weight of each e-waste item)

ITEM	ESTIMATED WEIGHT (kg)	NUMBER	TOTAL WEIGHT (kg)

Chemical Characteristics of Electronic Waste Item

Item	Chemical Characteristics

Physical Characteristics of Electronic Waste Item

Item	Description

Hazardous Components in Electronic Waste Item

Electronic Waste Item	Hazardous Components	Negative Health Effects

Valuable and Reusable Electronic Waste Components

Electronic Waste Item	Valuable and Reusable Component	Uses

General Information on Inflow and Outflow Materials

____

____

____

____

Appendix 2. Chart on Weights of E-Waste Items

E-Waste Item	Weight (kg)

 **Kettle**	1
 **Ceiling fan**	2

 **Small Oscar (rechargeable florescent light)**	1
 **LCD PC monitor**	2

 **DVD player**	3
 **Iron**	2

 **UPS**	8
 **Voltage regulator**	10

 **CRT TV monitor (small size)**	9
 **Air conditioner**	45

 **Radio set**	4
 **CRT TV monitor (big size)**	30

 **LCD TV monitor**	16
 **Air conditioner**	8

 **Generator**	14
 **Water heater**	19

 **Car battery**	17/20
 **Refrigerator**	14.5

Appendix 3. Chart on Different Modes of Transport and their Volumes

Mode of Transport	Transport Serial No.	Volume (m^3)
 Manual truck	1	1.16
 Mini pickup truck	2	3.04

 Medium pickup truck	3	16.42
 Articulated truck	4	31.25

 Trailer truck	5	70.74
 Tricycle	6	4.36

 Wheelbarrow	9	0.16