ASSESSMENT OF ELECTRONIC WASTE (E-WASTE) MANAGEMENT IN ETHEKWINI MUNICIPALITY, KWAZULU-NATAL PROVINCE, SOUTH AFRICA

by

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DECLARATION

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I declare that the dissertation titled “ASSESSMENT OF ELECTRONIC WASTE (E-WASTE) MANAGEMENT IN ETHEKWINI MUNICIPALITY, KWAZULU-NATAL PROVINCE, SOUTH AFRICA.” is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

______________ 28 February 2021

SIGNATURE **DATE**

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ABSTRACT

The demand for advanced technology, coupled with the reduced product lifespan, and the recent work / schooling from home triggered by COVID-19 has contributed to the increase in the consumption of electronic products. Waste generated from electronic equipment may contain hazardous components such as lead, mercury, cadmium, arsenic, beryllium and many more, that may be released during the treatment, and disposal processes. The release of hazardous substances to the atmosphere, water or ground poses a risk to both the environment and human health. The objective of the research study was to evaluate management of electronic waste in eThekwini Municipality, starting from the storage, collection, transportation, recycling up to the disposal phase. It also assessed the role of informal recyclers, participant's understanding of electronic waste hazards and compliance to the waste management statutory requirement at eThekwini Municipality, in Kwazulu-Natal Province, South Africa.

Participants in the research encompassed 350 households, industry, six recyclers (formal and informal), one landfill site and the eThekwini Cleansing and Solid Waste Department. Data was obtained from waste records, completed questionnaires, field observations and interviews. The study illuminated information regarding electronic waste generation rates, waste management practises and the underrated role of the informal waste collectors and recyclers. Results of the study suggested that information technology and telecommunication (ITC) waste was the highest waste stream, contributing 43% of the total e-waste; followed by entertainment equipment waste (28%). Waste from large equipment, lighting and small equipment collectively constituted 29% of total e-waste. The e-waste generation rate in the study area was estimated to be 6.77 kg per inhabitant per year, which is similar to other international cities in Brazil (7.1kg/inhabitant/year).

The household participant's understanding and knowledge of e-waste was relatively low, as only 33% of participants demonstrated some knowledge of e-waste. Interestingly, the businesses representing industry were more acquainted (69%) with e-waste hazards and statutory disposal requirements.

The research observed that compliance to waste regulations and standards was a challenge, especially at residential areas. Whilst current legislation prohibits disposal of some electronic appliances on landfill sites, the research exposed the prevailing non-compliance particularly in residential areas through disposal of hazardous waste (fluorescent lamps) with domestic, non-hazardous waste. eThekwini Municipality provides collection, treatment, disposal and recycling services for domestic, garden and some recyclable waste but excludes e-waste. Unlike most waste streams, electronic waste requires special pre-treatment prior to disposal as such manufactures and consumers need to work collectively for adequate management. Private waste companies provide e-waste collection services; however, affordability is a major factor particularly for the general public. eThekwini Municipality’s Cleansing and Solid Waste (DSW) representative acknowledged challenges with collection, recycling and disposal facilities as e-waste is currently not included in their scope of services. This has created opportunities for an informal recycling sector, which is very prevalent also in the city of Accra, Ghana. The researcher observed degradation of the environment associated with release of toxic emissions during the uncontrolled burning of waste and soil contamination from poorly managed informal facilities. Despite these observations, the contribution of the informal recycling sector is substantial. Waste pickers, and informal recyclers must be acknowledging and intergrated with the formal sector to further unleash the circular economy.

It is recommended that eThekwini Municipality should sharpen focus on focus on education and awareness; provide adequate resources and develop its infrastructure to strengthen its vision, “The circular economy”.

Keywords: *e-waste, recycling, extended producer responsibility, environment, legislation.*

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ABBREVIATIONS AND ACRONYMS

ARF	Advanced Recycling Fee
DEA	Department of Environmental Affairs
DEFF	Department of Environment, Forestry and Fisheries
DIT	Department of Information Technology
DTI	Department of Trade and Industry
EEE	Electrical and Electronic Equipment
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
E-WASTE	Electrical waste
EU	European Union
eWASA	e-Waste Association of South Africa
ICT	Information Technology and Communication
IT	Information Technology
IWMP	Integrated Waste Management Plan
NEMA	National Environmental Management: Act 107 of 1998
NEMWA	National Environmental Management: Waste Act 59 of 2008
NWMS	National Waste Management Strategies
UNEP	United Nation Environment Program
WEEE	Waste Electrical and Electronic Equipment

CHAPTER 1: INTRODUCTION JUSTIFICATION AND MOTIVATION OF THE STUDY

1.1 Introduction

The growing quantities of electronic waste (e-waste) and continued demand for more technologically advanced devices has triggered a global concern. The unparalleled e-waste concerns are associated with unsustainable production, consumption, and poor management of e-waste at end-of-life (Andeobu, Wibowo, and Grandhi, 2021). It is estimated that e-waste generated globally in 2014 was 41.8 million tonnes (Kumar, Holuszko and Espinosa*,* 2017). Due to continuous consumption of electronic equipment, by 2016 e-waste increased from 41.8 million tonnes to 44.7 million tonnes (Danciu, Greenley and Cobuz, 2018; Ilankoon*,* Ghorbani, Chong, Herath, Moyo, and Petersen, 2018; Asante, Amoyaw-Osei, and Agusa, 2019). Based on reviewed literature, e-waste is growing at an alarming rate of about 3-5% annually. However, in some areas e-waste is growing at a much higher rate (Kumar *et al.,* 2018). In Indonesia for example, e-waste is growing at a rate of 14.91% per year (Santoso, Zagloel, Ardi, and Suzianti, 2019). More recent research projects that e-waste will grow by a shocking 33% by the year 2030 and will exceed 74 million tonnes (Rene, Sethurajan, Ponnusamy, Kumar, Dung, Brindhadevi, and Pugazhendhi, 2021; Sajid, Syed, Iqbal, Abbas, Hussain and Baig, 2019; Hossain and Rahman, 2019). A research study conducted in African countries in 2014 found that the leading countries in e-waste generation were Egypt, with 0.37 million tonnes, followed by South Africa at 0.35 million tonnes and third highest was Nigeria with 0.22 million tonnes (Ledwaba and Sosibo, 2017). Latest research study conducted in South Africa and Nigeria showed that e-waste has increased significantly to 0. 42 million tonnes and 0.46 million tonnes respectively (Andeobu *et al.,* 2021). Despite the visible increase in e-waste generation, majority of e-waste is either landfilled or recycled informally, thus creating health and environmental problems (Andeobu *et al.,* 2021). The illegal exportation of e-waste by developed countries exacerbates the e-waste problem in developing countries (Miyamoto and Kobayashi, 2020). Owing to the lack of technology and infrastructure, informal e-waste recyclers are very prominent in developing countries. (Asante *et al.,* 2019).

E-waste equipment typically contains both valuable materials such as gold, silver, platinum, glass, plastic, as well as toxic substances such as lead, mercury, arsenic, antimony, beryllium, cadmium etc. (Suja, Rakmi, Rahman, Yusof. and Masdar 2014). The presence of reusable and valuable materials makes e-waste suitable for recovery and recycling. In the same breath, inappropriate management of e-waste will impact the environment negatively. Dismantled electronic equipment that release toxic substances could contaminate soil, surface water, groundwater and consequently impact human health. Hence, e-waste stream is becoming a persistent environmental challenge, necessitating policy review and human behavioural transformation (Ohajinwa, van Bodegom, Vijver, and Peijnenburg, 2018).

To assess environmental impacts associated with e-waste, subsurface soil samples were analyzed at one of the informal recycling villages in Northern Vietnam (Hoa *et al.,* 2020). The research assessed the presence of polycyclic aromatic hydrocarbons (PAH), and creosote pollutants predominantly released during incineration of waste, acid burning and dismantling processes (Hoa *et al*. 2020). The highest concentrations of PAH were discovered in samples taken closest to the open burning sites (10 000 ng g^{-1} to 18 600 ng g^{-1}) and decreased as you moved away from the source. The high concentrations of PAH in soil is a cause for concern as PAH can be toxic, carcinogenic and mutagenic (Sayara *et al.,* 2010). This also demonstrates a direct impact of burning waste. In another research study conducted in Hamburg, Germany, that was intended to investigate the presence of antimony (Sb) content in the plastic parts from electronic equipment Alassali, Abis, Fiore, and Kuchta (2019) discovered that antimony concentrations were significantly higher than the landfill limits. Whilst antimony landfill leachate limit was 0.7 mg/kg, the desktop antimony concentrations were between of 25 mg/kg and 1900 mg/kg. For microwaves, the antimony concentrations were as high as 830 mg/kg (Alassali *et al.,* 2019). Thus, discarding electronic appliances on landfill or bare ground could result in soil contamination and eventually environmental degradation. Communities near informal recycling centres that also consume groundwater for drinking may develop health problems due to leaching of various toxic substances present in electronic equipment (Hoa, Anh, Tue, Trung, Da, Quy, Huong, Suzuki, Takahashi, Tanabe, Thuy, Dau, Viet, and Tuyen, 2020).

In addition to environmental degradation, other risks associated with poor management of e-waste includes health impacts. A research aimed at identifying specific health risks related to the unregulated landfill in Elukwatini, South Africa, confirmed that the proximity of landfill sites to residents' homes, places of work, and to water sources, increased the chances of cancer and birth defects in nearby communities (Machete, 2017). Daum *et al.,* (2017) also reviewed and integrated over 40 e-waste research studies conducted in Agbogbloshie, Accra, with emphasis on human health impacts. Results from a study where blood samples from e-waste workers were analysed showed higher concentrations of lead, tin, zinc, barium, and manganese as compared to non-e-waste workers. Other studies reviewed showed that lead in ambient air quality near e-waste workplaces was 6 $\mu g/m^3$, which is four times higher than the permissible USEPA standard (1.5 $\mu g/m^3$) (Daum et al*.,* 2017). A separate research aimed at assessing prevalence of chronic, communicable as well as non-communicable diseases in e-waste waste pickers exposed the unhealthy status of workers. The most prevalent disease amongst e-waste workers was osteomuscular disorder (78.7%), followed by arboviruses (28.6%), episodic diarrhea (24.9%), hypertension (24.2%), bronchitis (14.3%), intestinal worms (12.6%) and diabetes (10.1%) (Cruvinel *et al.,* 2019).

Research has shown that inappropriate management of e-waste has a direct impact on the environment and human health. The increasing hazardous waste stream is a persistent environmental challenge, necessitating extensive research, policy review and human behavioural transformation (Ohajinwa, van Bodegom, Vijver, and Peijnenburg, 2018). Precise data concerning the type of e-waste, the quantities generated, and recycling rates, is lacking in South Africa (Lydall, Nyanjowa and James, 2017). A study conducted by Finley (2005) estimated that South Africa generates between 1.12 million tonnes and 2.1 million tonnes of e-waste annually. Forte *et al.* (2020) reported that 416 000 tonnes of e-waste was generated in South Africa in 2019. The 2019 data seems more realistic and consistent with recently reported data as compared to the first estimation made by the Finley. The worrying growth of e-waste is not an unforeseen phenomenal, as studies completed two decades ago revealed that e-waste was growing rapidly (UNEP, 2007). However, there has been very limited research conducted in the selected study area of eThekwini Municipality.

Due to limited research, there are shortcomings on data such quantities of e-waste generated, e-waste recycling and management in eThekwini Municipality. The research provides a comprehensive overview on management of e-waste including collection, transportation, treatment, recycling, disposal and overall legal compliance with statutory requirements.

1.2 Research problem

Used electronic equipment presents a challenge in South Africa and other African countries (Orlins and Guan, 2016; Owusu-Sekyere, Peprah and Demuyakor, 2018; Orhorhoro and Oghoghorie, 2019; Mouton, 2020). eThekwini Municipality is not any different from other cities in developing countries. eThekwini Durban Cleansing and Solid Waste Department is responsible for the collection, disposal and recycling of general, garden, paper, plastic, glass and cardboard. E-waste is excluded from their scope, as a result, majority household e-waste is either managed informally by recyclers, discarded illegally as part of domestic waste or illegal dump sites (eThekwini Municipality, 2018).

The lack of e-waste management services is partly responsible for the rise in informal recyclers (Godfrey and Oelofse, 2017). Informal recycling plays a significant role in collection, recovery and recycling of e-waste (Mouton, 2020). However, some informal recycling practise are unsafe, unorganized, illegal and environmentally unfriendly (Ohajinwa *et.al.,* 2018). Informal recyclers utilise basic methods like acid digestion, incineration and open burning for the extraction of metals like copper, steel and silver (Botello-Alvarez, Rivas-Garcia, Fausto-Castro, Estrada-Baltazar, and Gomz-Gonzalez, 2018). These methods pose a threat to the environment and human health as toxic chemicals are released during open burning and may leach into soil and groundwater (Tran and Salhofe, 2017). As demonstrated in historical studies, mishandling of e-waste can have severe and irreversible environmental and health issues, as such there is a need to evaluate e-waste management practices in eThekwini Municipality.

1.3 Research aim and objectives

1.3.1 Aim of the study

The aim of the research was to assess the management of e-waste within eThekwini Municipality in KwaZulu-Natal Province, South Africa.

1.3.2 Research objectives

- To identify different types and sources of e-waste in eThekwini Municipality.
- To establish e-waste management practices such during collection, storage, transportation, disposal and recycling in eThekwini Municipality.
- To determine the role of informal recyclers on e-waste management in eThekwini Municipality.
- To determine eThekwini Municipality's policies and compliance with current and future e-waste legal requirements.
- To evaluate the level of awareness of stakeholders on risks of e-waste.

1.4 Delineation of the study

1.4.1 Chapter 1: Introduction

This chapter provides the background of the study, its motivation and justification for a research. It provides high level introduction to the e-waste issue. The significance of the study, main aim and the objectives of the study are also explained in this chapter.

1.4.2 Chapter 2: Literature review

This chapter provides a detailed review of the literature on management of e-waste. It focuses on e-waste generation, management practices, reviews of international and local legislation on e-waste, evaluates the role of informal recyclers and also evaluates participant's awareness of e-waste issues.

1.4.3 Chapter 3: Research methodology and design

This section provides an overview of the study area, elaborates on the research methodology used during the study, sampling methods, data collection, data analysis and highlights limitations of the study.

1.4.4 Chapter 4: Results and discussion

In this chapter, detailed results are presented, supported by discussion of similar studies. Graphical illustrations, tables and photographs are used to present some of the findings.

1.4.5 Chapter 5: Conclusion and recommendations

This chapter summarises key outcomes, conclusion and provides recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents an overview of literature on the research topic and was completed by evaluating and reviewing various journals, articles and legislation pertaining to e-waste. This literature reviewed includes e-waste creation, e-waste management, e-waste policies across the globe, and associated impacts in the study area.

E-waste consists of diverse substances, both valuable and potentially hazardous (Lando *et al.,* 2020). E-waste is classified internationally and locally as hazardous waste and as such requires proper treatment prior to disposal (DEA, 2013). Electrical equipment such as televisions, cathode-ray tube, refrigerators, and washing machines contain both valuable and toxic substances which when discarded at end-of-life pose a threat to the environment. Toxic substances contained in equipment include arsenic, lead, cadmium, antimony, dioxins, POPs (persistent organic pollutants), 3-hexavalent chromium, brominated flame retardants (poly brominated diphenyl ethers) and precious metals such as copper, gold, platinum (Cucchiella *et al.,* 2015). Examples of some toxic constituents found in electronic and electrical equipment are shown in Table 2.1.

Table 2.1: Representation of some e-waste components and basic constituents

Components	Key Constituents
Data tapes and Floppy disks	Chromium (Cr)
Television sets, PC monitors, batteries, light bulbs, lamps.	Lead (Pb)
Fluorescent lamps, Lighting devices for flat screen displays, CRTs, PCBs, thermostats.	Mercury (Hg)
Computer batteries, ink or toner photocopying machines.	Cadmium (Cd)
Capacitors and transformers	Poly chlorinated Bb-phenyls
lubricants and coolants in generators, fluorescent lighting, ceiling fans, dishwashers, electric motors	POPs including brominated flame retardants (Penta- ,Octa-, Deca-BDE)
Radio, amplifier, and stereo	Lead and chromium, brominated flame retardants
CRTs, metal coatings, batteries	Zinc (Zn)

(Source: Ilankoon *et al.,* 2018)

The majority of equipment displayed on Table 2.1 is in use at most households. The existence of toxic chemicals presents a challenge and means that electronic waste cannot be discarded similar to other household waste.

The reported 3 % to 5% year-on-year increase in e-waste generation is attributed to continuously increasing demands in the markets for better and technologically advanced equipment, reduced costs, and reduction life span of products (Mouton, 2020; Ilankoon *et al.,* 2018; Dias, Machado, Huda, and Bernardes, 2018). The high volumes of e-waste together with the highly hazardous nature of e-waste pose a risk to both the natural environment and humans (Akhlayel, 2017). However, precious metals recovered from e-waste provide economic and environmental benefits through resources conservation, avoidance of emissions (Godfrey and Oelofse, 2017; Dias *et al.,* 2018).

2.2 Definition of e-waste

Electrical waste refers to obsolete, broken or discarded electronic equipment (Wath, Vaidya, Dutt and Chakrabarti, 2010). While there is no standard definition for e-waste, the European Union (EU) defines it "as waste including all components, sub-assemblies and consumables, which are part of the product at the time of discarding" (Sushant *et al.,* 2020). Another definition of e-waste is "any end-of-life or end-of-use piece of equipment which is dependent on electronic currents or electromagnetic fields to work properly" (Ilankoon *et al.,* 2018). Widmer, Oswald-Krapf, Sinha-Khetriwal, Schnellmann, and Boni, (2005) clarify that e-waste is also a common term for electronic waste. The United Nations Environment Program defines e-waste as "any appliance using an electric power supply that has reached its end-of-life" (United Nations Environment Program [UNEP], 2017). The Electronic Waste Association of South Africa (eWASA) defines e-waste as "anything that runs on electricity" (eWASA, 2011).

At end-of-life, e-waste must be treated prior to disposal or recycling, owing to the inherent physical, chemical or toxicological characteristics that could have a detrimental impact on human health and the environment if mismanaged (DEA, 2014). E-waste covers a wide range of equipment that can be grouped into household appliances, information technology and communications equipment, lighting equipment, medical devices, monitoring and control instruments, electronic and electrical tools, toys, leisure and sports equipment (Forti, Balde, Kuehr and Bel, 2018).

The European Commission (EC) categorises e-waste into ten classes/groups namely: large household appliances, small household appliances, information technology and communications (ICT) equipment, consumer equipment, lighting equipment, and electronic tools, toys and leisure and sports equipment, medical devices, monitoring and control instruments and automatic dispensers (Okorhi, Amadi-Echendu, Aderemi,. Uhunmwangho, and Agbatha 2017).

2.3 E-waste legislation

Legislation is an instrumental tool in shaping management of waste across the globe (Rajaram, and Pekeur, (2014). The legislation and policies are aimed at enabling consumers, manufactures, as well as retailers to correctly discard their waste at end-of-life (Rene *et al.,* 2021). The impact of having inadequate policies on electronic and electrical waste management is demonstrated in countries such as Ghana, India, and Egypt, which have become dumping grounds for e-waste (Rajaram, and Pekeur, (2014).

2.3.1 International policies and conventions on e-waste

Policies, laws and guidelines provide a legal framework for the protection of the environment and public health. Initiatives and discussions to protect the environment and to secure human health commenced as far back as 1980's in the United States of America (USA). Consequently, in 1989, the Basel agreement was convened (Li*,* 2013). The various guidelines, treaties, and policies that have been developed over the years include Extended Producer Responsibility (EPR), Basel Convention, Bamako Convention and will be discussed next (Long, Kokke and Lundie*,* 2016).

2.3.1.1 Basel Convention

The Basel Convention is an international agreement on movement and disposal of hazardous waste across national borders (Alter, 2000). It was originally intended to prevent uncontrolled dumping of hazardous waste into developing countries (Ardi and Leisten, 2016). Australian and European countries such as Sweden, Italy, Switzerland, and Germany are leaders in adopting treaties and regulations on management of e-waste (Long *et al.,* 2016).

The Basel Convention treaty was adopted on 22 March 1989 at the conference of Plenipotentiaries held in Basel, Switzerland and was affected on 5 May 1992 (Tansel, 2017). At its introduction, the Basel Convention was universally accepted by 116 countries, and continued to gain support (Stone, 1999). By 19 June 2002, the number of countries that had adopted it had increased to 151, including South Africa (Rummel-Boska, 2004; UNEP, 2013).

Since its introduction, the Basel Convention has undergone several amendments. The 1995 amendment prohibits transboundary movement of waste for disposal and recycling of specific wastes to nations not registered in annexures VII of the Basel Convention (UNEP, 2013). The 1998 amendments provided characterisation and classification of hazardous waste (Rummel-Buska, 2004). The amendments proposed during the 2019 conference of the parties, comes into effect in 2021 and expands the scope of the Basel Convention to transboundary movement of plastic (UNEP, 2020).

The Basel Convention is known to be the first international legal framework on transboundary movement of hazardous waste (Miyamoto and Kobayashi, 2020). It is based on principles which support hierarchical management of waste that promotes prevention, reduction, recycling and endorses waste reduction through avoidance (UNEP, 2020). Most importantly, the Basel Convention prioritises the management of waste within the country of origin and only where export of waste cannot be avoided, strict trade conditions, which includes receiving consent from the receiving country prior to shipment and demonstrating that waste will be managed in an environmentally sound manner (Alter, 2000). The Basel Convention played a pivotal role in raising awareness on transboundary movements of hazardous waste; placed prohibition of import and export of hazardous waste to non-member states; provided guidelines for export or import to and from non-member states through agreements; and specified requirements for all exported waste to be managed in an environmentally friendly manner, thus protecting the environment (Rummel-Boska, 2004).

The first shortcomings of the Basel Convention are the failure to completely prohibit the export or import of hazardous waste, particularly by none-signatory countries (Tansel, 2017). The second one is in its ambiguous definition of environmentally sound management systems. The requirement for environmentally sound waste management system is inadequate as it does not set strict operational standards (Rummel-Boska, 2004). The environmentally sound system is defined under the Basel Convention section 2.8 as taking all possible steps to ensure that hazardous wastes are managed in such a way as to prevent adverse human health and the environment against adverse effects which may result from wastes (Alter, 2000). This statement is subjective and open to misinterpretation thus is viewed as a missed opportunity in setting good standards that ensure all exported waste is adequately managed to meet internationally accepted and recognised practises (Rummel-Boska, 2004).

2.3.1.2 Bamako Convention

The Bamako convention focused on the ban of transboundary movement of waste into Africa and was deliberated in 1991, in Bamako, and came into effect in 1998 with only 29 signatories and 25 member countries (UNEP, 2018). The Basel Convention was negotiated by 12 nations from the African Unity, now known as the African Union (UNEP, 2018). It was developed following the discovery and acknowledgement that some developed countries were still exporting their hazardous waste to countries such as Mexico, Nigeria, India, and China (UNEP, 2018). This agreement was also intended to address the gaps and shortfalls of Basel Convention. The Bamako Convention has been enacted by fewer countries when compared to the Basel Convention. Gambia, Congo, Nigeria and Mozambique are some of the leading African countries that signed the Bamako Convention (UNEP, 2013). Interestingly, South Africa is not a signatory to the Bamako Convention. The next discussion provides an overview on chronological developments over the years in Europe, China, and South Africa.

2.3.2 E-waste legislation in Europe

The European Union (EU) is a political and economic community of 28 countries, established in 1993 by the Maastricht (Gitman, 2018). In 2003, the European Parliament passed a directive on e-waste that was aimed at minimising generation of e-waste, promoting reuse as well as recycling (Lundgren, 2012). The 2002 Waste electronic and electrical equipment (WEEE) regulatory framework was based on the EPR principles where manufacturers are responsible for funding of take-back mechanisms, technology and resources for successful waste management (Borner and Hegger, 2018).

Some of the shortcomings of the European WEEE legislation was enforcing compliance. The WEEE Directive prescribed a recycling target of 4 kg per person per year; but did not consider that there was also going to be an increase in waste generation over the years (Kumar, Holuszko and Espinosa*,* 2017). What was evident in the early years of introduction of the WEEE Directive in Europe was that up to 67% of e-waste generated could not be accounted for, meaning that e-waste was still being landfilled or illegally exported (Lundgren, 2012).

Consequently, six years later, in 2008, work on reviewing the 2002 European Directive started and was aimed at developing a legal framework that would address illegal trade on e-waste as well as promote the increase in recycling targets (Ibanescu *et al.,* 2018). In 2012, the EU's WEEE recast Directive was enacted, as an amendment of the 2003 WEEE Directive (Borner and Hegger, 2018). The amendment was a positive progress in that it promoted reuse, recovery and recycling which encouraged manufactures to strengthen the design for recycling concept (Mazahir, Verter, Boyaci. and Van Wassenhove, 2019). Incentivizing and recognition for reuse of waste contributed immensely to increased recycling efforts (Kumar *et al.,* 2017). This was achieved by setting product-specific recycling targets as opposed to the generic recycling targets (Mazahir *et al.,* 2019). A comparison of the 2002 and 2012 WEEE Directives clearly demonstrates the compelling benefits of incentives as well as devising product specific recycling strategies and laws.

2.3.3 E-waste legislation in China

According to Long *et al.* (2016) China is one of the largest producers of electronic equipment that imports and exports large quantities of electronic equipment. China's e-waste legal framework is formulated on three laws namely the Circular Economy Promotion Law, Solid Waste Pollution Control Law as well as Clean Production Promotion Law (Matter, Dietschi, and Zurbrugg, 2013). These are referred to as a framework as they do not provide specific requirements but are more like guidelines on managing e-waste. The common principle amongst these laws is the one on prevention of pollution. Over two decades ago, China signed its first agreement to the Basel Convention, which was driven by growing concerns over poor management of hazardous waste in China (Long *et al.,* 2016). Successively, various standards, laws and regulations were published in China, including the following:

- In 1996, the Chinese government approved environmental protection legislation that prohibited the import of hazardous waste and solid municipal waste (Long *et al*., 2016)

- In 2000, a catalogue for managing the import of waste further reinforced the ban of export of e-waste (Wang, Guo and Wang, 2013).
- In 2005, Management Method on Prevention and Cure of Environmental Pollution was implemented (Long, Kokke and Lundie*,* 2016). This legislation was meant to strengthen the measures concerning the recovery, reclamation, and end-of-life treatment of company's hazardous substances (Long *et al.,* 2016).
- In 2006, the Technical Policy on Pollution Prevention and Control of e-waste was promulgated promoting the principle of 3R (reduce, reuse and recycle). This development encouraged eco design (Reagan, 2015).
- In 2007, Administrative Measures on Pollution Prevention of e-waste. These regulations prohibit and condemn pollution caused by e-waste. It also introduced the licensing of recycling companies (Wang *et al.,* 2016).
- In 2009, Regulations on Recovery Processing of Waste Electrical and Electronic Products was passed into law (Wang *et al.,* 2016).
- In 2011, Regulations on Management of Recycling and Disposal of Electrical and Electronic Equipment was published. This policy / legislation regulated the recycling and treatment of disposed WEEE. These regulations introduced EPR schemes in China (Long, Kokke and Lundie*,* 2016). Additionally, a special fund was established to financially support the formal recycling sector. This approach was like what the European Union had implemented, but with some variations. This was aimed at formalizing the e-waste recycling sector by creating formal collection stations, administering licenses and providing financial grants to the formal sector (Wang *et al.,* 2016).

Whilst China has made some progress, prescribing laws for e-waste to be collected, recycled, and treated, there are still some gaps. The 2011 legislation did not prescribe who is responsible for collection of e-waste, it only encourages producers to take back their products or entrust sellers, customers and collectors of waste with responsibility (Matter, *et al.,* 2015). Collection is a first step towards correct management of waste and without it, waste may end up being disposed inappropriately.

The second gap in Chinese policies is the poor integration of the informal sector with the formal sector, despite there being large groups (over 270 000 people) involved with e-waste collection and treatment. They should be recognized an intergrated into the formal sector for a more robust and sound management system (Matter *et al*., 2015).

2.3.4 E-waste legislation in South Africa

Chapter 2 of the constitution of South Africa pronounces the citizen's right to protection of the environment they live in such that it is not harmful to their health and wellbeing (Republic of South Africa, 1996). Various laws at national, provincial and local level have been established for realization of this right. The National Environmental Management Act 107 of 1998, also known as NEMA, is the main framework for environmental legislation in South Africa. Under NEMA umbrella, there are specific sections of legislation on subjects of air quality, waste, biodiversity, environmental impact assessment etc. The Waste Management National Waste Management Act No. 58 of 2008 also well-known as the Waste Act governs the management of waste in South Africa. The Waste Act is intended to provide standards for waste generators and managers (DEA, 2008). Table 2.2 provides a high-level overview of legislation development in South Africa.

Table 2.2: Legal framework developments in South Africa

Year	Legislation/ Activity	Summary
1989	Basel Convention	• South Africa adopted the Basel Convention in 1989 and entered into agreement with this treaty in 1994 (UNEP, 2009).
1998	National Environmental Management Act (NEMA) 1998	• NEMA sets out principles for waste management in South Africa. These include avoidance, minimization and the remediation of pollution. • This act places emphasis on the 'polluter pays' and 'cradle to grave' principles (DEA, 1998).
2000	The White Paper on Integrated Pollution and Waste Management	• The white paper indicated the need to develop a National Waste Management Strategy and refers to holistic waste and pollution management (DEA, 2000).
2008	National Environmental Management: Waste Act, 2008 among others.	• This act regulates waste management in the country to protect health and the environment by providing reasonable measures for the prevention of pollution and ecological degradation (DEA, 2008). • The act further requires that certain activities should not be conducted without a waste management license.
2011	National Waste Management Strategy	• The national waste management strategy was aimed at identifying the country's challenges pertaining to waste and gives framework on how these can be addressed (DEA, 2011).
2013	Waste Norms and Standards for Assessment and disposal of Waste to Landfill	• Introduced prohibition of disposal of certain waste streams including WEEE. Prescribes storage, classification and storage of waste (DEA, 2013).

Year	Legislation/ Activity	Summary
2014	National Environmental Management Waste Amendment Act, 2014 (Act No. 26 of 2014).	• The act is the result of the amendment of the 2008 waste act as well as the National Waste Management Strategy report. It provides for measures to deal with hazardous waste and specifically refers to e-waste as hazardous waste; this is in line with the precautionary principle (DEA, 2013). • The 2013 act goes further to list specify that hazardous electric lamps are prohibited from being disposed of at landfills as from August 2016 (DEA, 2013). • This waste regulations bans disposal of electric waste will be allowed at landfill (DEA, 2013).
2017	Notice to paper, packaging and lighting electronic industry.	• This gazette notice prescribes that all electric and electronic industries must submit a waste management plan (DEA, 2017).
2019	Withdrawal of notice to paper, packaging and lighting industry	• Minister of Environment, Fishery and Forestry withdraws notice published in 2017 and reports that an industry waste plan will be published and will be built on EPR, making manufactures responsible for management of e-waste (DEA, 2019)
2020	Waste Picker Integration Guideline for south Africa Guidelines	• Aimed at providing guidelines to stakeholders who may want to partner with waste pickers and develop waste pickers integrated plans and strategies (Department of Environment, Forestry and Fisheries [DEFF], 2020a).
2020	National Waste Management Strategy	• Prioritizes circular economy and hierarchical management of waste. Its key focus is on waste minimization, effective waste management, as well as compliance and monitoring (DEFF, 2020b).
2020	Extended Producer Responsibility Regulations	• Minister of Environment, Forestry and Fisheries signs into law the EPR for listed to ensure to ensure the effective and efficient management of the identified end-of-life products (including electronic and electrical products) and to promote circular economy in South Africa (DEFF, 2020c).

As outlined on Table 2.2, the norms and standards for disposal of waste to landfill ratified in 2013 was the first legislation on e-waste. Waste norms and standards amongst other things prescribed methods for classification of waste, set timelines for management of waste and most importantly placed restrictions on disposal of waste such as e-waste, brine, liquid waste etc. (DEA, 2013). Though ratified in 2013, prohibition was not immediate, there was a transition period allowed for various waste types to allow waste generators and managers to develop essential infrastructure to manage the waste (DEA, 2013). Lead acid batteries, compressed gases and explosive, corrosive waste was immediately banned from landfilling 2013 (DEA, 2013). Waste of electronic and electrical equipment specifically florescent lamps were banned from 2016, and the remainder of all types of e-waste will be as from 23 August 2021 (DEA, 2013). The transition from disposal at landfill forces consumers and waste generator to find alternatives.

In preparation for compliance to a full ban of landfilling of e-waste, in 2017, the then Minister of Environmental Affairs published a notice calling for electric and electronic, paper and packaging sectors as well as lighting industries to submit to the Minister an integrated waste management plan for approval in December 2017 (DEA, 2017).

The industry waste management plans had to provide recycling targets and indicate prioritization to ‘reduce, re-use, recycling’, as well as recovery of e-waste amongst other requirements (DEA, 2017). It also had to identify measures to minimize the generation and disposal of waste. To enhance recovery and recycling, the plans had to establish an incentives programme to encourage the end user to practice best management of waste. For this reason, plans had to indicate how awareness regarding management of e-waste was going to be enhanced in the public domain (DEA, 2017).

Whilst the industry waste plan was an ideal and most appropriate step considering the role of manufactures in generation of waste, industries failed to deliver waste management plans that met the set requirements, and as a result in December 2019, the Minister of Environment Forestry and Fisheries announced that the management plans submitted by industries did not meet the set requirements explained earlier (DEA, 2019).

The industry’s failure to convince the Minister with their submitted industry waste plans resulted in promulgation of the long awaited EPR regulations in November 2020. EPR is an extension of the "polluter pays" principle, which traditionally justifies charging producers for all the pollution caused by production (Ogungbiyi, Nnorom, Osibanjo, and Schluep, 2012). EPR as a principle encourages producers to take responsibility post the point of sale (Ilankoon *et al.,* 2018).

EPR encourages producers to design products and packaging for reuse to enable recovery of waste thus offering high utilisation rates. This will in turn promote innovation in recycling technology (Ilankoon *et al.,* 2018).

The revised National Waste Strategy and the ratified EPR regulations in 2020 came at a time when it was most needed due to the upcoming legal requirements (Department of Environment, Forestry and Fisheries [DEFF], 2020c). The 2020 National Waste Management Strategy outlines the philosophy for waste management and puts emphasis on circular economy and effective waste management (DEFF, 2020b). The strategy also provides direction on the key focus areas to achieve sustainable management of waste whilst strengthening the balance between socio-economy and resource conservation (DEFF, 2020b). Integration of informal waste sector such as waste pickers and informal recycling organizations is recognized as the key initiative in transforming circular economy. Lastly the strategy promotes the design for environment by packaging and producers to addresses the transport of waste to recycling amenities amongst other resources (DEFF, 2020b).

EThekwini Municipality has its own bylaws which governs management of waste and related activities such as disposal, recycling and recovery of waste. EThekwini Municipality has responsibility to oversee implementation and enforcement of compliance of national and provincial legislation (eThekwini Municipality, 2018). EThekwini Municipality Scheduled Activities By-Laws of 2018 requires that any facility undertaking waste material salvaging, collecting, sorting, storing, treating, processing or recycling/reclaiming to have a Schedule Trade Permit (eThekwini Municipality, 2018). The Scheduled Activities permit is an eThekwini specific requirement over and above the requirement as set out in the Waste Act for activities which require a waste license through the DEFF. Examples of activities as prescribed in the waste act which require a Waste Management License include treatment of hazardous waste in lagoons, general waste recycling in an area exceeding 500m^2, hazardous waste recycling in in excess of 500kg / day (monthly average); storage of hazardous waste in excess of 80m^2; storage of waste tyres in excess of 500m^2 to name a few (DEA, 2013). Whilst the waste licensing process is a great tool to administer and enforce compliance, it has its challenges as the process is costly and long drawn process which discourages participation in the circular economy. (DEA, 2018).

2.4 Sources of e-waste

According to Kalani and Samarakoon (2010) majority of e-waste emanates from excess materials during production of electronic equipment and broken equipment. The

European Union (2013) classifies e-waste into categories. Examples of e-waste from each category are presented below:

- **Large household appliances**
  Large appliances include air conditioning appliances, microwaves, electric stoves, washing machines, electric fans, large cooling appliances, freezers, clothing dryers, refrigerators, dish washing machinery, large appliances used for cooking, food processing appliances, electric heating appliances, and large appliances for heating (Govender, 2016).
- **Small household appliances**
  Examples include small kitchen appliances, clothing irons, kettles, toasters, television sets, DVD players, coffee machines fryers, grinders and other, LED screens; vacuum cleaners, appliances for hair-cutting hair, other appliances for cleaning; appliances used for sewing other equipment for hair drying, tooth brushing and shaving (Govender, 2016).
- **Information technology and telecommunication equipment**
  Examples include cellular telephones laptops, computers, desktop computer screens, photocopier equipment, printing machines, personal computing, calculators, equipment for processing, presentation and communication of information, telephones, pay telephones, cordless telephones, and equipment for transmitting sound and video (Govender, 2016).
- **Lighting and rechargeable batteries**
  Examples include fluorescent lamps, industrial lights, high intensity discharge lamps, and other equipment for lighting.
- **Medical equipment**
  Examples include equipment for radiotherapy, cardiology, dialysis, pulmonary ventilators, nuclear medicine, laboratory equipment for in-vitro diagnosis, analysers, freezers, fertility tests, other appliances for detecting, preventing, monitoring, treating, alleviating illness, injury or disability (Govender, 2016).
- **Electrical and electronic tools**
  Examples include drills, saws, grinders, cutting and shearing equipment; equipment for drilling; tools for welding, soldering or similar use; equipment for spraying, spreading, dispersing; tools for mowing or other gardening activities (Govender, 2016).

- **Toys, leisure and sports equipment**
  Examples include electric trains or car racing sets, hand-held video game consoles, video games, and sport equipment with electric or electronic components, coin slot machines (Govender, 2016).

Table 2.3 shows types of electronic and electrical equipment, their average mass and lifespan, in the order of lowest to highest mass (Gaidajis, Angelakoglou and Aktsoglou, 2010). In the recycling process, valuable products including plastic, iron, aluminium, gold and copper are recovered. This contributes positively to resource conservation and mitigates environmental impacts associated with disposal of waste.

Table 2.3: Source of e-waste, average mass and life span

Electronic Equipment	Mass (Kg)	Estimated Lifespan
Cell phone	0.1	4.7
Smartphone	0.3	2
Telephone	0.3	5
Hair dryer	0.5	6
Kettle	0.6	3
Tablet	0.7	5.1
Smartphone	0.3	4.6
Food mixer	1	5
Toaster	1	5
Iron	1	3
Radio	2	10
DVD player	5	6
Laptop	2.3	5.5
Fax Machine	3	5
Microwave	15	7
Vacuum cleaner	10	10
Flat panel Television (TV)	12	7.4
Desktop computer	15	6
Television cathode-ray tube	30	5
Dish washer	30	10
Tumble dryer	35	10
Freezer	35	10
Air conditioner	35	12
Photocopier	60	10
Washing machine	65	8

Source**:** Gaidajis, Angelakoglou, and Aktsoglou (2010)

Sources of e-waste in South Africa, including the study area (eThekwini Municipality) is obsolete electronic and electrical equipment from households, private business and government sectors, retailers and manufactures (Lydall *et al.,* 2017). The top four provinces contributing to the most e-waste are Western Cape, Gauteng, Eastern Cape and Kwa-Zulu Natal (KZN) and together contribute about 50% of the country's total e-waste (Lydall *et al.,* 2017). Figure 2.1 depicts the movement of e-waste from various provinces to Gauteng, the epicentre of e-waste recycling.

KZN, the province of the study area, contributes 12% of total e-waste generated in South Africa (Lydall *et al.,* 2017). According to Lydall *et al.,* (2017) 50% of e-waste generated in 2017 was from local and provincial government departments and constituted information communication technology (ICT) 79%, followed by waste from large and small equipment at 15% and 4% respectively (Lydall *et al., 2017*). As the world transitions into a global community, the information economy also evolved creating more dependence on electronic and electrical equipment (Maphosa and Maphosa, 2020). With an increase in demand for better and more advanced equipment, that has reduced appetite to keep equipment or to repair it when broken, thus resulting in added waste generation.

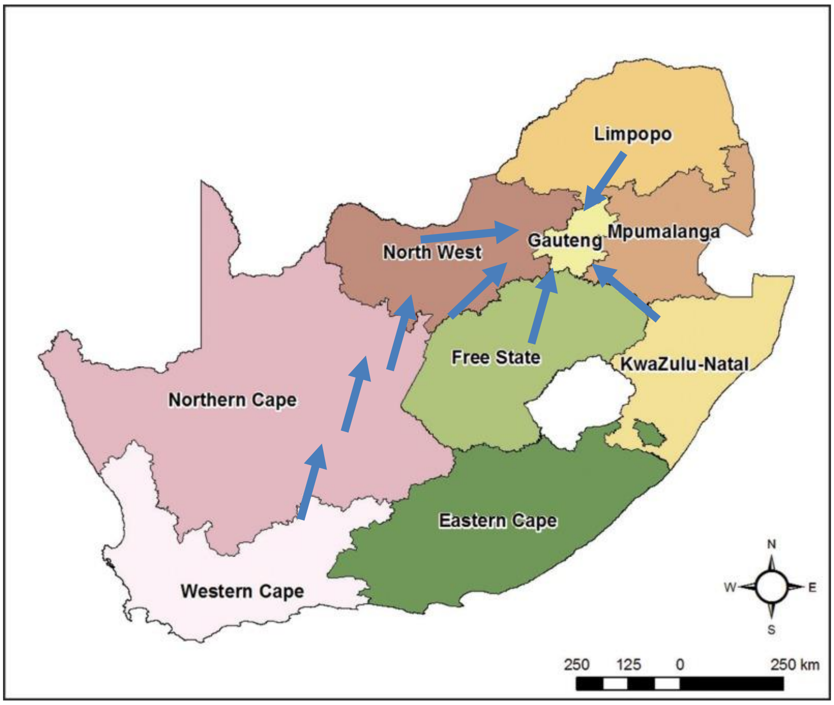

Figure 2.1: Map showing movement of e-waste in the South Africa

(Source: https://www.google.com/search?q=map+of+south+africaandsaf)

2.5 E-waste generation across the globe

The quantities of e-waste generated across the globe was approximately 53.6 million tonnes in 2019 (Kumar, Holuszko and Espinosa, 2017; Rene *et al.,* 2021). E-waste is projected to increase by 33% in the next decade due to the increase in the use of modern electronic and electrical equipment (Rene *et al*., 2021). The rapid advancement in information technology, frequent release of new devices, reduced cost of appliances, and the shorter lifecycle of electronic products has contributed to the increase in consumption and creation of e-waste. In a study conducted in four continents to quantify e-waste as reflected in Figure 2.2, Asia was the highest generator (18.2 million tonnes), followed by Europe (12.3 million tonnes), America (11.3 million tonnes) and the lowest generator was Africa (2.2 million tonnes) (Kumar *et al.,* 2017).

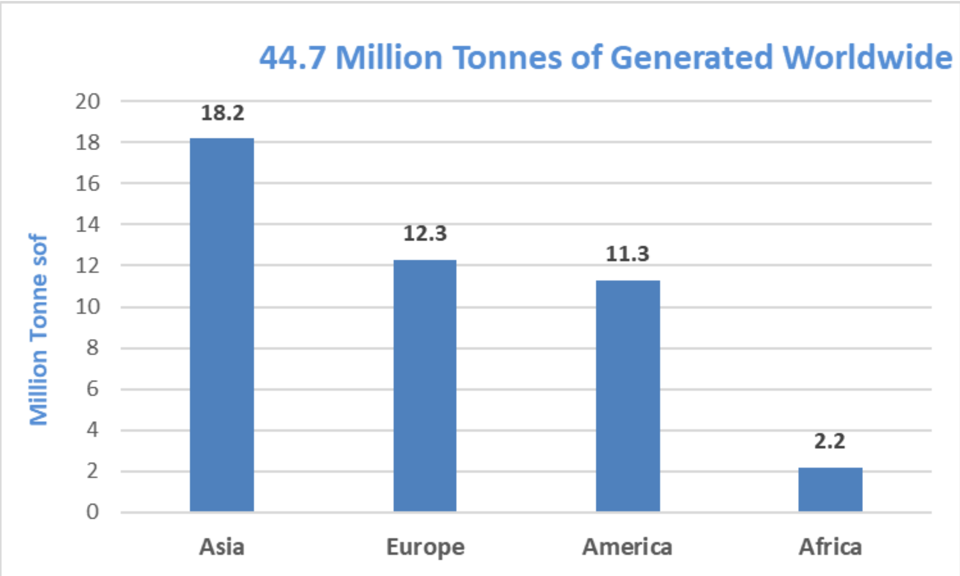

Figure 2.2: E-waste generation across
Source: Kumar, Holuszko and Espinosa (2017)

In a recent research conducted by Andeobu *et al.* (2021) by reviewing of published research statistics on e-waste from Canada, France, UK, USA, Nigeria and South Africa. The results revealed that the United State was the highest generator (6.9 million tonnes) and South Africa the lowest (0.42 million tonnes).

A decade ago, many leaders and businesses were not aware of the emerging crisis that would be brought about by technological advancements and waste emanating from electronic equipment (Clark and Clark, 2019). The rate at which e-waste is growing outperforms the world's capacity to dispose of it and threatens both human health and the environment. Unfortunately, in the new global economy, evolution of technology is instrumental for economic growth (Haron, Sidique, and Radam, 2018). To change the current trajectory of waste generation requires transition from the current consume and discard approach, to a responsible and sustainable production and consumption model. Clark and Clark (2019) assessed the role of marketers and suggests that they should be advocates for promoting the culture of repair and recycling (Clark and Clark 2019).

Andebou *et al*. (2020) further recommend that marketers and producers should be held accountable for recycling of their products at end-of-life. Whilst this may be a challenge in developed countries where residents can generally afford to replace appliances, research shows that in developing countries like Nigeria there is interest in purchasing second hand electronic devices. In these areas, marketers can play a role in creating awareness about alternatives to new products (Ejiogu, 2013). Developed countries should focus on responsible production by insisting on recyclable material use as opposed to virgin and non- recyclable material.

2.6 E-waste generation in South Africa

E-waste contributes approximately 8% of the municipal solid waste in South Africa and is anticipated to grow at much higher rates in the next few years (Andeobu, Wibowo, and Grandhi, 2021). In the last 50 years, technology in South Africa has advanced rapidly, and the population has increased from 30 million people in 1970 to 58.8 million people in 2019 (Department of Statistics South Africa [StatsSA], 2019). The 2018 waste information report released by the then Department of Environmental Affairs (DEA) shows that 44 million tonnes of general waste was produced in South Africa in 2017 (DEA, 2018). Of the 44 million tonnes, e-waste contributed about 360 000 tonnes. Of 360 000, only 12% of e-waste was recycled, most of it was landfilled, recovered by waste pickers or dumped illegally (eWASA, 2019). A more recent study reported that South Africa generated 461 000 tonnes of e-waste in 2019 (Forti *et al.,* 2020). Despite the increasing numbers of recyclable waste generated, the e-waste recycling rate is below 10% and this situation is not unique to South Africa only, but to most developing countries (Andeobu *et al.,* 2021).

To demonstrate the impact of technology advancement on waste generation, a review of the trends affecting the global TV ecosystem was conducted by Aggarwal, Arthofer, Rose, Lind, Rosenzweig, and Stephan (2016). The review revealed the impact of technological advancement since the early the 1950s up to the twenty first century (Aggarwal *et al*., 2016). The review covered TV evolution from the black-and-white TVs in the 1950s, to colour in the 1960s, and then the big boxes TVs which later evolved to flat screen TVs in the late 90s. In the 2000s high definition TVs contended with 3D TVs which are now being replaced by online and mobile devices (smart TVs) (Aggarwal *et al*., 2016). This has contributed directly to the generation of e-waste as the older devices were replaced (Tansel, 2017). This illustrates the complexity of the e-waste problem as many electronic appliances become obsolete and newer and better technology devices emerges at the same time.

Figure 2.3 illustrates the quantities of waste generated per country in 2009 (UNEP, 2009). The research was conducted by UNEP on five different types of electronic equipment. As can be seen, at that time China was the leading country mainly as China is one of the leading countries in the production of electronic equipment (UNEP, 2009).

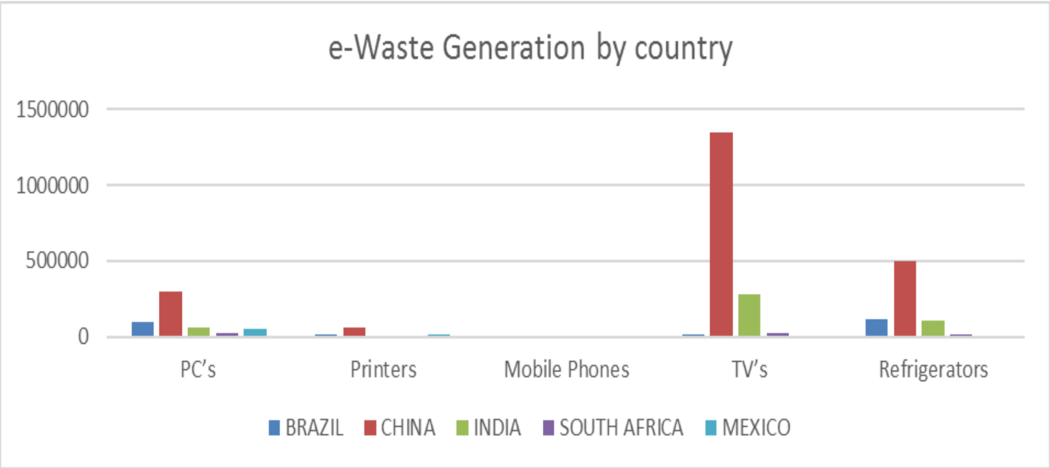

Figure 2.3: Quantities of e-waste generated per country
Source: UNEP (2009)

Whilst most research confirms that e-waste is growing exponentially, Tansel (2017) points out that a significant portion of e-waste generated is not documented. In South more than 29% of waste from rural areas is not accounted for (Lydall *et al.,* 2017). In the rural areas, waste is managed by burning or burying it underground, so it's generally not accounted for (Lydall *et al.,* 2017). Lydall *et al.,* (2017) further explained that private dumping was a norm in 94% of households in rural areas.

The research study revealed gaps in available e-waste data and potential underreporting of e-waste and therefore understating the impact of e-waste.

2.7 E-waste management across the globe

E-waste management across the globe is guided by international laws, policies, principles and national legislation. According to Zhang Du, Wang, and Wang (2019) less than 20% of e-waste generated worldwide is managed formally through national take-back systems and recycling schemes. Majority (80%) of the waste is either discarded in landfill, incinerated or managed informally by recyclers where precious metals are recovered in environmentally unfriendly manner (Zhang *et al.,* 2019).

Developed countries like Canada and the USA have reasonable mechanisms in place for managing e-waste locally, yet studies show that they export a large percentage of their waste to developing countries like Nigeria, India, Egypt, South Africa, etc (Wideman, 2019). The imported waste negatively impacts the receiving country's already burdened environment (Borthakur, 2019). This notion indicates a much more complex challenge.

Switzerland was the first country to develop formal e-waste recycling initiative and has over the years provided support and partnership to developing countries including South Africa to improved management of e-waste (eWASA, 2011). South Africa, in partnership with the Swiss state Secretariat for Economic Affairs, developed the E-waste Association of South Africa (eWASA) in 2008 (eWASA, 2011). EWASA is one of the active non-profit organisations in South Africa, working closely with consumers, manufacturers, distributors and recyclers of electronic and electrical goods (including refurbishers) to ensure effective management of e-waste.

eWASA provides solutions where a customer can obtain information on nearby e-waste collection points or recyclers and various centres across South Africa. eWASA's e-waste governance model is based on collaborative management with diverse stakeholders including manufacturers and waste generators (eWASA, 2011). The customer pays advanced recycling fee / green fee (ARF) upfront to support the financial requirements to enable recovery and recycling of electronic waste (Turaga, Bhaskar, Sinha, Hinchliffe, Hemkhaus, Arorsa, Chatterjee, Khtriwal, Radulovic, Singhal, and Sharma 2019).

2.7.1 Storage of e-waste

South Africa's waste management is governed by the National Environmental Management: Waste Act 2008 (Act No 59 of 2008) also known as the Waste Act. The Waste Act prescribes requirements for management of waste from classification, storage, import, export, treatment that applies to both generators of waste as well as managers of waste (e.g. landfill sites). The Waste act is also supplemented by additional standards such as the Waste Management Activities and Licensing Regulations which prescribes activities requiring waste management licenses; the Norms and Standards for Waste Management prescribes acceptable practises for storing waste; the Waste Classification and Management Regulations prescribe procedures for analysing and classifying waste; and Norms and Standards for Assessment and Disposal of Waste to Landfill provides guidance on suitable disposal facilities for waste (DEA, 1998; DEA, 2013; DEA, 2014).

As hazardous waste, e-waste mut be stored strictly in impermeable surfaces and the generator must discard it within 6 months of its generation (DEA, 2014). However, research indicates instances where storage of e-waste for periods longer than 6 months transpires. A study conducted by Finlay (2005), showed that about 70% of e-waste generated in South Africa was stored and not disposed, mostly at government departments, who first must undergo the asset write off process before equipment can be discarded (Finlay, 2005). In households, the decision to store or discard is largely dependent on availability of disposal options as well as perceived value of the item (Yokoo, Kawai and Higuchi, 2018).

A more recent research conducted in South Africa also concluded that the public's lack of awareness on what to do with their e-waste as well as the lack of collection and disposal processes is the reason why majority of e-waste is stored for prolonged periods (Mouton, 2020). Convincingly, perhaps 6 months storage limit needs to be reviewed as in some cases waste equipment may be stored beyond the 6 months whilst deciding whether to replace, resell, repair.

2.7.2 Formal collection of e-waste

Collection of waste is the most crucial step of effective waste management (Mouton, 2020; Chung *et al.,* 2011). Depending on the country's legal requirements, collection methods may be formal (through government provided services), take back mechanisms, or informally by waste collectors (Ilankoon *et al.,* 2018).

South Africa places the responsibility of managing solid waste on the government, and in the case of the study area it is the responsibility of eThekwini Municipality. The Durban Cleansing and Solid Waste Unit (DSW) eThekwini collects waste on average a weekly basis from households. However currently DSW does not provide formal collection services for e-waste from households. Opportunely, the collection of waste as prescribed in the EPR regulations, will become the responsibility of the manufacture (DEFF, 2020). In the interim, formal e-waste collection in eThekwini Municipality is currently undertaken by private companies (Asante *et al.,* 2019).

Private waste service providers collect and manage e-waste at a fee. Desco, an e-waste recycling company, collects e-waste at no charge provided that there is minimum volume of 1000 kg of e-waste (Mouton, 2020). Since it almost impossible for a single household to accumulate such large quantities of e-waste, illegal dump sites and informal waste recyclers are the only alternatives for household residents who cannot afford to pay for disposal costs of e-waste in eThekwini (Mouton, 2020). Informal recyclers and waste collectors collect waste that is unwanted from households, dump sites, and landfill sites, to recover precious materials such as metal and plastic (Asante *et al.,* 2019).

2.7.2.1 Collection of e-waste through take-back mechanism

Take-back mechanisms include a collection system where the customer can take their electronic products back to the manufacture when it reaches end-of-life. Products are collected through initiatives that are administered either by government, municipality, retailer etc. (Kumar, Holuszko and Espinosa*,* 2017). Take back mechanisms have been implemented worldwide in countries such as Germany, Italy, Romania, Europe, USA, and China, (Ciocoiu and Tartiu, 2012). For such a system to be effective, coordination between the producers, waste generators and the recyclers is imperative (Ciocoiu and

Tartiu, 2012). This methodology has been recognised to be effective mostly when there is incentive for taking back the product at end-of-life (Ciocoiu and Tartiu, 2012).

In South Africa whilst not popular, there are manufactures and retailers that have introduced the take-back systems and would allow customers to bring back old or obsolete products for recycling. The first back mechanisms were through the voluntary

EPR programme led by PET recycling company (PETCO) and the Glass Recycling company led by Coca-Cola company (Godfrey and Oelofse, 2017). The collect-a-can recycling initiative saw an increase in recycling from 18% in 1993 to 74% in 2016 and is a classic example of potential for increased waste recovery especially with involvement of producer in the reverse logistic chain (Mouton, 2020). The information communication technology company, Apple, offers take back and rebate options to its customers. South Africa has very limited buy back schemes, however the rates of e-waste recovery through take-back mechanism is expected to expand and expand to other products through the introduction of EPR as take-back has become mandatory for some listed products (DEFF, 2020).

2.7.3 Transportation of e-waste

Transportation of e-waste presents a major challenge in the current waste management system. As mentioned previously, collection of e-waste both at private sector and government sectors is largely undertaken by private waste service providers (Mouton, 2020). Informal recyclers have identified this gap and currently provide collection solutions at household though they have their own challenges when it comes to larger size and quantities (Asante *et al.,* 2019).

The transportation systems utilised by the formal recyclers for movement of e-waste proper vehicle, whereas informal recyclers rely on home-made trolleys that are small in size and thus restrict the scope to only sizeable equipment that can be dismantled and transported in the trolley for a short distances (Mouton, 2020). On the other hand, whilst formal recyclers have proper transportation, the logistical costs render recycling as a non-profitable business profitable (Lydall *et al.,* 2017). Costs associated with logistics include fleet costs, fuel, toll and wages (Lydall *et al.,* 2020). However, with the promulgation of EPR regulations, transportation costs will become the responsibility of the producer (DEFF, 2020). Benefits of EPR, once implemented, will be apparent not only towards customers as they will have free services for waste collection, but also for informal and formal recycling businesses through opportunities to generate revenue by managing waste on behalf of producers.

The 2017 waste report showed that only 9.3% of e-waste was recycled. This highlights urgent interventions to increase the recycling rate and promote circular economy (DEA, 2018). Switzerland has achieved higher recycling rates through systems such as EPR, Advanced Recycling Fee (ARF) and take back mechanism amongst other mechanisms (Haron *et al.,* 2018). The introduction of EPR regulations in South Africa is much needed. EPR was signed into law on 5th November 2020 and requires the lighting, electronic, paper and packaging industries to set up financial schemes to support the collection, sorting, refurbishing, reusing, recycling and/or disposing of their products and packaging in a sustainable manner (DEFF, 2020c). Though it can be expected that there may be difficulties in shifting consumer behaviors and enforcing waste separation at source, as the system matures, there is great potential for increased recycling.

2.7.4 Disposal of e-waste

South Africa's waste management model is based on a consume and discard approach (Sentime, 2010). This method dates back from 1983 and is the most prominent option of managing waste in South Africa (Godfrey and Oelofse, 2017). When explaining South Africa's waste management development, Godfrey and Oelofse (2017) explained that there are four phases. The first stage is "the age of landfilling" which dates as far back as 1989 and is self-explanatory. The second phase, known as the era of "emergence of recycling" started around 2001, but is not yet fully implemented as recycling rates in South Africa are relatively low (below 10%) (DEA, 2017). The African Pacific Waste Consultant (APWC) (2020) reports that about 90% of waste generated in South Africa is landfilled. The third stage is called "flood of regulation" and is associated with progression of legal policies and regulations.

South Africa's environmental framework, the National Environment Management act (Act 107 of 1998) is based on the polluter pays principle and provides for adequate management of waste through recycling, treatment reduction, and disposal (Andeobu *et al.,* 2021). The introduction of Waste Norms and Standards for Disposal of Waste to Landfill in 2013 heightened the requirements of diversion of waste from landfill and promoted recovery and recycling of waste (DEA, 2013). Despite the emergence of recycling era and waste regulations, low landfilling costs made it easy for the waste generators to continue to opt for disposal instead of alternative waste solutions (Godfrey and Oelofse, 2017). Landfilling costs for general waste in 2011 were as low as R200 to R300 per tonne. Due to limitations in space they have since increased by almost double to R500 to R800 / tonne of waste in some municipalities (Godfrey and Oelofse, 2017). Despite the price increase in landfilling fees, disposal remains the preferred method (Mouton, 2020). Large quantities of e-waste are landfilled in South Africa and to address this challenge, drastic measures including access to waste, infrastructure development, reduced licensing cost and statutory compliance requirements needs to be considered to attract businesses to the waste sector (Andeobu *et al.,* 2021)

2.7.5 Formal Recycling of e-waste

Recycling is a process of collecting and processing unwanted waste and converting it into new raw materials. It involves dismantling, pre-processing and processing waste (Tran and Salhofer, 2018). In a study aimed to understand the generation, composition and material flow of e-waste in 19 computer service centres in Indonesia, it was established that waste from the computer service centre was mainly 60.34% plastic, followed by 23.88% metal, and the remaining 16% was rubber, glass and a mixture of metal and plastic (Lando, Abdurrahman, Arifin, Utami, and Lavrakas, 2020). The presence of reusable and valuable materials such as gold, platinum, steel makes e-waste suitable for recovery and recycling.

Recycling of waste is predominantly driven by socio-economic benefits, but it also environmental issues, and contributes towards the preservation of natural non-renewable resources (Rene *et al.,* 2021). Electrical equipment possesses an eternal lifespan that renders them valuable, as they can be recovered and reused repeatedly (Tran and Salhofer, 2018). However, due to the complexity of e-waste, recycling processes are complex and involve intense work from waste transport, segregation, dismantling, and is not a very attractive job, hence a lot of e-waste is shipped to developing countries as opposed to being recycled at source (Rene *et al.,* 2021).

Research aimed at evaluating e-waste recycling rates between developed countries (Italy, Germany and Sweden) and developing countries (Romania and Bulgaria) revealed how each country performed between 2011 and 2014. Romania significantly improved their recycling rate from 11% in 2011 to 87% in 2014 (Ibanescu *et al.,* 2018). Similarly, Bulgaria a developing country also enhanced its e-waste recycling rate from 63% in 2007 to 85% in 2014. Italy, a developed country, improved from 70% in 2007 to 88% in 2013. Germany and Sweden already had high recycling rates so showed a much lower improvement in recovery rates from 80% in 2011 to 83% in 2014 (Ibanescu *et al.,* 2018).

Research shows that developing countries have managed to significantly improve their recycling rates through collection and treatment facility initiatives (Ibanescu *et al.* 2018). On the other hand, developed countries already had high recycling rates and their improvement initiatives were targeted at improved product design (Ibanescu *et al.,* 2018). It is interesting to note the difference in the focus areas due to maturity of the waste management systems in different countries. The less developed countries with poor infrastructure put more effort into collection of resources whereas the developed countries focus on product design.

Waste recycling in developed countries such as France and the UK is governed by the extended producer compliance schemes, similar to EPR principles, where the manufacture takes responsibility for managing waste at end-of-life. E-waste in France is classified as business and household e-waste and becomes the responsibility of the manufacturer to manage until the end-of-life (Vadoudi, Kim Laratte, Lee, and Troussier, 2015). Unfortunately, despite having implemented more advanced systems and regulatory policies such as EPR, France and the UK still have relatively low e-waste recycling rates of 38% and 17% respectively. Some of the challenges in France are that the majority of e-waste is managed through informal collection recycling and treatment systems (Vadoudi *et al.,* 2015).

The UK's e-waste, on the other hand, is largely exported to countries in Asia and Africa (Powell-Turner, Antill and Fisher, 2016). Export of e-waste is a direct violation of the UK's WEEE Directive that governs its generation, re-use, treatment, recycling and disposal however it still continues (European Parliament and The Council of the European Union, 2012). The WEEE directive delegates the responsibility for management of e-waste including the finance, treatment and reporting through the EPR schemes to the manufactures.

The formal recycling industry in South Africa is diversified, with over 100 formally registered companies that operate across the recycling value chain (from collection to processing) in the private sector (Lydall *et al.,* 2017). The well-established companies, handle most of the waste recycling and processing (85%), whereas the small to medium firms focus mainly on earlier stages of the recycling process (i.e. collection and transportation) (Lydall *et al.,* 2017). According to the then Department of Environmental Affairs (2017), the waste economy contributed above R24.3 billion to the South African GDP in 2016 (GreenCape, 2019). Additionally, 36 000 formal jobs and approximately 80 000 informal jobs/livelihoods were supported in 2016 through recycling programmes across South Africa.

Recycling in eThekwini Municipality is largely through kerbside recycling, multi-material recycling centres, buy back and drop off centres (eThekwini Municipality, 2009). Kerbside recycling in eThekwini Municipality was initially an initiative of Mondi (a paper company). In this scheme, large orange plastic collection bags are provided to households to encourage separation of waste from source and recycling. Separated recyclable waste (paper, plastic, cardboard) is placed in orange bags which is collected as part of waste removed by eThekwini Municipality Solid Waste services. (eThekwini Municipality, 2009). In addition, there are drop-off centres within the study in high-income suburbs such as Hillcrest, Mhlanga and Waterfall, but are scarce and limited if any in the townships such as KwaMashu, Ntuzuma, and Inanda. In industrial areas near townships, recyclers purchase materials such as copper, steel, plastic, and cans from waste collectors and this provides a form of income. EThekwini Municipality Solid waste Management Unit does not offer services for collection and recycling of e-waste. According to StatsSA (2018), only 5% of households in South Africa participate in recycling of e-waste.

2.7.5.1 Extended Producer Responsibility (EPR)

EPR is a policy which places some responsibility on producers for management of waste when product reaches end-of-life (Walls, 2006). All EU member states have adopted EPR and are required to ensure that there are adequate collection schemes in place, in close proximity to citizens. Manufactures are required to take back all e-waste products at no cost to citizen and without them having to purchase new products (Rijkswaterstaat Ministry of Infrastructure and Environment, 2018). The EU had 39 compliance operational schemes solely for managing e-waste and other waste like batteries, tyres, packaging, oil, medical waste (Rijkswaterstaat Ministry of Infrastructure and Environment, 2018). Implementation of EPR subsequently leads to environmentally sound management of waste and encourages a circular economy and conservation of resources.

The DEFF in South Africa worked for almost a decade to develop a national policy on EPR and has been well received. South Africa's EPR regulations require producers in the paper, packaging, electronic and lighting sector to register by 5th of November 2021; establish EPR schemes which include the entire value chain or to join an existing scheme; pay the appropriate fees; report on performance; and meet collection and recycling targets amongst other requirements. The established schemes will be responsible for collection, treatment and recycling of products to meet the prescribed yearly and five yearly targets for collection and recycling. For example, manufactures and importers of lightbulbs must collect 50% of all used bulbs from consumers (DEFF, 2020c).

After five years, this target will increase to 70%. Whilst positive, EPR has come at the most challenging time for businesses and organisations due to the state of the economy post COVID-19. South Africa's Gross Domestic Product (GDP) from the first and second quarters of 2020 was reduced by 16%, and manufacturing was also reduced by 74.9% for the period (StatsSA, 2020). COVID-19 pandemic had negative impacts on business performance included the identified sectors (paper, electronic, lighting and packaging), as such they may not be able to implement EPR yet due to funding required to establish and maintain the schemes.

The EPR regulations gazetted are aligned with the principles in the Integration of Waste Pickers Guidelines in that it acknowledges the need to integration of informal waste collectors, reclaimers and pickers into the post-consumer collection value chain (DEFF, 2020c). The recycling rate trajectory can be expected to increase once all mechanism and schemes as prescribed in the EPR regulations are fully implemented. The proposed collection and recycling targets as well as the compensation to informal recyclers (through living wage payment to all registered informal recyclers, reclaimers and pickers for the activities performed on behalf of the producers) is expected to create new jobs and will boost circular economy (DEFF, 2020c).

The adoption of legislation and policies alone as seen internationally, does not resolve waste management issues. The USA adopted EPR some years ago, but they still export hundreds of thousands of e-waste every year (Andeobu *et al.,* 2021). In 2002, the UK implemented EPR policy through the EU WEEE Directive, yet only 17% of its waste is recycled (Powell-Turner *et al.,* 2016). Whilst the adoption of EPR is welcomed, it needs to be supplemented by enforcement, infrastructural development and must be regularly reviewed to ensure relevancy, adequacy and effectiveness.

2.7.6 The role of Informal Recyclers in Management of e-waste

Informal recycling is defined as unregulated activities involving individuals, families, groups or small enterprises engaged in the recovery of waste materials with revenue generation as the motivation either on a full-time or part-time basis (Cao *et al.,* 2016). A waste picker is someone who collects re-usable and recyclable materials from residential and commercial waste bins (DEFF, 2020a).

Informal recycling may take place in different forms, in some cases, scavengers would retrieve the recyclables from household or retail bins or skips before they are collected for disposal. It is thereafter transported to the informal recyclers designated areas for sorting before transporting for selling to either buy-back centres or any other buyers (DEFF, 2020a).

Lack of free services for collection and transportation of waste gave birth to the informal sector (Godfrey and Oelofse, 2017). The informal recyclers are well-known for gathering and recovering primary materials (copper, gold, platinum), and selling it to recyclers, second-hand shops and willing buyers (Anwesha *et al.,* 2019). Like in many cities in the developing countries, informal recyclers play a crucial role in the collection, sorting and recycling of waste in South Africa (Anwesha *et al.,* 2019). Informal recyclers have access to some waste which formal recyclers cannot access, for example household waste. According to Godfrey and Oelofse (2017) South Africa achieved a recovery performance of 57.1% partly due to the role of informal recyclers and waste pickers. Waste pickers contribute 80% to 90% of total recovery rate (Godfrey and Oelofse, 2017).

Waste pickers are recognised in countries such as Serbia, Brazil, Tunisia and the Philippines as an integral part of a waste management model and best practice (Dias, 2018). Waste pickers offer flexible, convenient and free waste management (Mouton, 2020; Godfrey and Oelofse, 2017). Other cities where waste pickers are recognised and integrated as part of waste management system include Bogota in Colombia, Diadema in Brazil, Buenos Aires in Argentina and Pune in India (Dias, 2018). Following the best practise from these leading cities, South Africa in 2020 published its first guidelines for integration of waste pickers into the formal waste management model (DEFF 2020a). The integration of waste pickers needs a formally planned recycling system that values the strengths of the existing informal system for collecting materials.

2.7.6.1 Economic, Social and Environmental Benefits of Informal Recycling

Informal recycling in eThekwini Municipality provides social, environmental and economic relief (Mouton, 2020). Socio-economic benefits associated with recovery and recycling of e-waste are also prevalent in countries, such as China, India, Nigeria and Ghana (Kumar, Holuszko and Espinosa*,* 2017; Asante *et al*., 2019). The informal recycling sector provides employment opportunities for many young and unskilled youth who participate either through collection, dismantling and sale of recovered materials. On the contrary, negative environmental impacts associated with mismanagement of e-waste includes release of ozone depleting substances such as chlorofluorocarbons (CFC's) from inadequately managed waste (Zeng, Xu and Qin, 2019). Examples of electronic equipment comprising CFC's include air-conditioners, refrigerators, and air-conditioned cars. Recycling reduces greenhouse emissions and energy utilisation that would have been realised during material extraction and manufacturing process (Zeng, *et al.,* 2019). A study conducted by Owusu-Sekyere *et al.* (2018) evaluated the carbon contributions of three different waste treatment options, namely recycling, thermal treatment and landfilling. The study was based on extensive data (2007-2014) and showed negative carbon dioxide (t/year) through emission avoidance (Owusu-Sekyere *et al.,* 2018). Research conducted in China's e-waste management system demonstrated how recycling contributed to savings of 1800 tonnes of lead emissions, 2.1 tonnes of CFC refrigerant, and over 1.5 million tonnes of CO_2-equivalent emissions (Zeng *et al.*, 2019).

2.8 Environmental impacts associated with poor e-waste management

E-waste is comprised of complex chemical and physical properties and may contaminate soil, as well as groundwater when leached into the ground (Song, Wang, and Li, 2013). Typically, electronic equipment consists of 60% metals; 15% plastics, 11% screens [Cathode-ray tube (CRT) and Liquid crystal display (CD's)], and the remaining14 constitutes a mixture of pollutants, cabling, metal-plastic cabling, metal plastic as shown in Figure 2.4 (Ilankoon *et al.,* 2018).

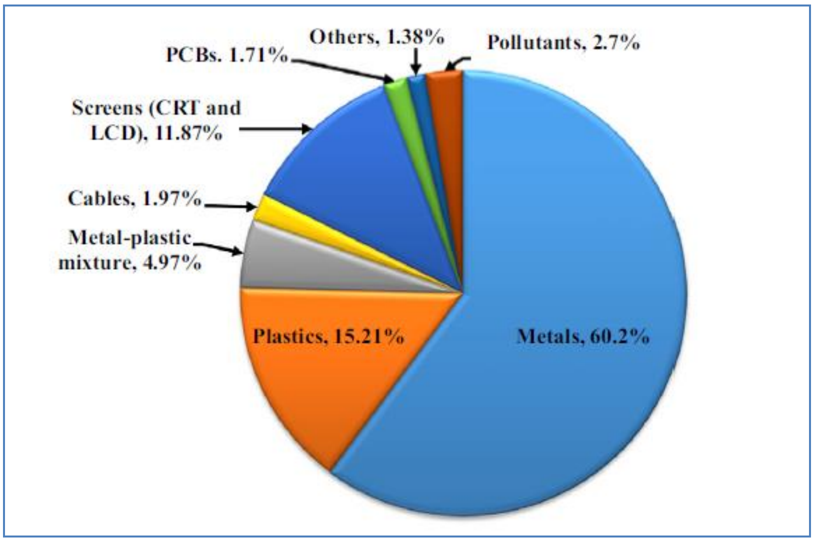

Figure 2.4: A general composition of e-waste
(Source: Ilankoon *et al.* 2018)

Metals, which are the highest constituent in typical electronic equipment and once dissolved in water, may be absorbed by aquatic organisms, contaminating surface and groundwater and posing a health threat (Ohajinwa *et al*., 2018). Management of e-waste requires cautious and safe handling from storage, up to treatment and final disposal to mitigate both health and environmental risks (Ardi and Leisten, 2016). Unfortunately, in developing countries, the waste management systems are inefficient due to weak legal requirements and lack of resource (Botello-Alvarez *et al.,* 2018). Consequently, waste emanating from e-waste is managed informally by informal recyclers. Environmental and health impacts associated with poor management of e-waste are discussed next.

2.8.1 Air pollution

Recovering precious metals may result in release of emissions such as particulate matter ($PM_{2.5}$, PM_{10}), sulphur dioxide (SO_2) Furans, dioxins, cadmium (cd), etc. into the atmosphere thus impacting ambient air quality (Pradhan and Kumar, 2014). Toxic airborne pollutants such as nitrogen oxide and carbon monoxide may also be released during the melting process (Ardi and Leisten, 2016). Dust is a major air pollutant generated during the shredding, open burning and incineration process and other e-waste contaminants may spread into the atmosphere through dust (Pradhan and Kumar, 2014).

Hazardous substances such as aerosols, gas vapours, liquid and semi-liquid waste, mercury, cadmium, lead, chromium, ozone-depleting chemicals, at end-of-life of waste may come into contact with humans and the environment (Pradhan and Kumar, 2014).

The World Health Organization (WHO) has defined tolerable levels of pollutants that can, when exceeded, cause acute and chronic diseases. Annual standards for $PM_{2.5}$ and PM_{10} are 10 μg/m^3 and 25 μg/m^3 respectively and the 24-hour average limit is 25 μg/m^3 and 50 μg/m^3 respectively (WHO, 2005). Sulphur dioxide ambient air quality standards are set at 10-minute interval average as well as 24-hour average and are 500 μg/m^3 and 20 μg/m^3 respectively (WHO, 2005). Ozone standards on an 8-hour average and is 100 μg/m^3. Lastly, nitrogen dioxide standards on 1 hour- average is 200 μg/m^3 annual limit is 40 μg/m^3 (WHO, 2005). An air quality assessment conducted in 2016 by the WHO disclosed that 91% of the world population was living in places where air quality guidelines levels were not met (WHO, 2018). The research concluded that policies and investments supporting cleaner transport, energy-efficient homes, and better municipal waste management would reduce key sources of outdoor air pollution (WHO, 2018).

Figure 2.5 and Figure 2.6 illustrates air quality standards and actual ambient air quality in over 170 countries worldwide (Joss, Eeftens, Gintowt, Kappeler, and Kunzli, 2017). Parts of South America, Europe, Asia and Africa recorded the highest concentrations of PM_{10} and NO_2 respectively. PM_{10} ranges between 30 μg/m^3 to 50 μg/m^3 which is above the WHO standard of 25 μg/m^3. This demonstrates a positive relationship between poor air quality and waste generation/imports. Interestingly, where high e-waste is generated or imported there is also high PM_{10} concentrations. The USA and Europe are known as leading e-waste generators and similarly Africa and Asia which receive a lot of e-waste imports record poor ambient air quality (Long, 2016).

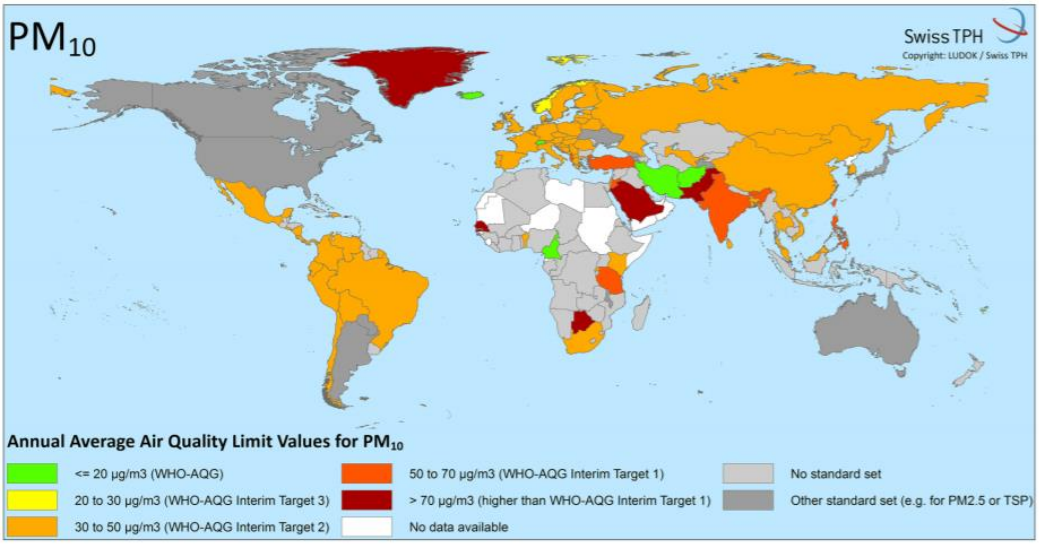

Figure 2.5: World map of national ambient air quality standards
Source: Joss *et al,* (2017)

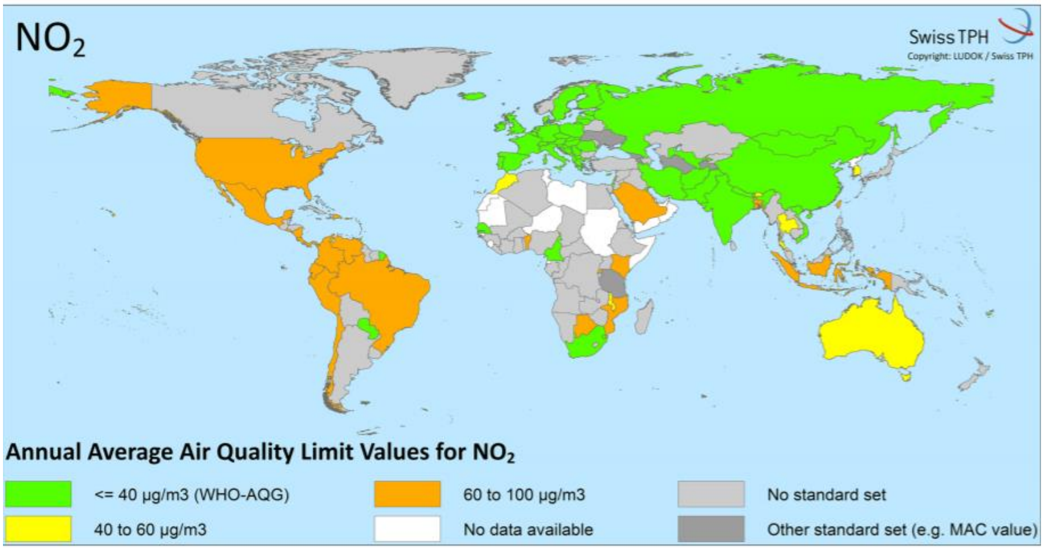

Figure 2.6: World maps of national ambient air quality standards
Source: Joss *et al.* (2017)

The ambient air quality research study conducted in China on sites located near informal e-waste recycling facilities also showed elevated PM_{10} concentrations of between 100 and 243.2, exceeding the WHO limits (Li, Yao, Xie and Zhu, 2020).

Similarly, results of a health study conducted to evaluate human exposure risk, by characterisation of indoor air quality near e-waste recycling facilities showed that lead concentrations in dust samples were 16 to 18 times higher than other locations sampled away from e-waste recycling facilities (He, Zheng, Yan, Zheng, Wang, Tan, X. Qiao, Chen, Yang, and Ma, 2017).

Whilst there are adequate studies completed in countries such as India, China, Ghana and Nigeria, particularly on informal recycling, there are gaps in eThekwini Municipality empirical research.

2.8.2 Soil and groundwater contamination

In the process of recovering precious metals, organic and toxic substances may come into contact with waste handlers and ultimately the physical environment (Prithiviraj and Chakraborty 2019). During the disassembling, shredding, open burning, acid leaching processes there is a risk of soil and groundwater contamination (Daum, Stoler and Grant, 2017). Agbogbloshie, in Ghana as well as Guiyu in China are some well researched informal recycling hubs where the environment has been significantly depleted by the informal e-waste recycling practises.

Research conducted in Agbogbloshie in 2016 confirmed high concentrations of chlorinated, and brominated dioxin related compounds (Tue, Takahashi, Asante, Nomiyama, Tanabe, and Kunisue, 2017). Leaching of metals into groundwater affects the quality of groundwater (Ilankoon *et al.,* 2018). Subsequently, high concentrations of heavy metals in groundwater affect quality of watercourse such as rivers, streams and in some cases drinking water.

Tran and Salhofer (2017) discovered that informal recycling facilities produce double the quantities of wastewater when compared to formal recycling facilities. This is mainly because of unavailability of efficient systems and technologies that enable storage, recycling, and pre-treatment of wastewater prior to discharge (Tran and Salhofer, 2017). The excess water generated may end up entering surface water or groundwater, impacting the water quality.

Race*,* Marotta, Fabbricino, Pirozzi, Andreozzi, Cortese and Giudicianni, (2016), in a separate study based on soils profiles in the recycling facilities, where 26 samples were taken, results indicated exceedingly high concentrations of lead (Pb) and aluminum (Al) on 17 and 20 of the samples respectively. Additionally, the water quality from the sampled area did not meet both the drinking and industrial wastewater quality standards (Race *et al.,* 2016).

2.8.3 Climate change

Climate change is a process caused by retention of solar radiation on the earth's surface (Lackner and Jospe, 2017). The fundamental climate change difficulties are caused by dumping of carbon dioxide and other greenhouse in the atmosphere and result in gradual warming (Lackner and Jospe, 2017). The amount of greenhouse gases released from earth is not only due to human activities but also due to a natural process known as Milankovitch cycle comprised of the eccentricity, precision of the earth and precision of the equinoxes (Nnaji and Utsev 2011).

The increasing demand for production of electronic equipment has a direct impact on energy consumption due to the high energy requirements during the manufacturing process and at end-of-life during the recycling process (Owusu-Sekyere, Peprah and Demuyakor*, 2018).* Examples of electronic equipment containing CFC's include air-conditioners, refrigerators, air-conditioned cars, etc. (Tran and Salhofer, 2017). A study conducted by Owusu-Sekyere, Peprah and Demuyakor (2018) evaluated the carbon footprints of three different e-waste treatment options, namely recycling, thermal treatment and landfilling.

Results showed that solid waste contributed to 350 000 tonnes of $CO_{2\text{-eq}}$. Landfilling was a major contributor with 350 000 tonnes $CO_{2\text{-eq}}$ and incineration contributing 150 000 tonnes $CO_{2\text{–eq}}$. Recycling on the other hand contributed positively by avoiding 128 000 tonnes $CO_{2\text{–eq}}$ (Istrate, Galvez-Martos, and Dufour, 2020). The 2015/2016 annual report for Malaysia estimates that 4400 tonnes of ozone depleting substances present in the refrigerants from old freezing and cooling appliances (Ilankoon *et al.,* 2018). Inherently, the contribution of waste to climate change and irreparable damage to the environment is acknowledged in research studies (Istrate *et al*., 2020; Owusu-Sekyere *et al.,* 2018; Peprah and Demuyakor*,* 2018*;* Tran and Salhofer, 2017). Thus, credible waste management strategies, based on waste avoidance, recycling and design for reuse are essential for sustainable future.

In a separate research study aimed at understanding impacts of renewable energy, particularly, solar powered energy systems and associated materials, including photovoltaic panels it was found that renewable energy also has its own challenges (Akram, Chen, Khalid, Ye, and Majeed, 2020). Unexpectedly, negative environmental impacts associated with solar energy can be expected during transportation, installation and operation of the solar power equipment (Safdar, Khalid, Ahmed, and Imran, 2020).

2.9 Human health impacts associated with poor e-waste management

An exposure pathway refers to the way a person may come into contact with a hazardous substance (WHO, 2016). Exposure pathways could either be through inhalation of coarse or fine dust particles ($PM_{10}$and $PM_{2.5}$), ingestion of contaminated dust, or skin contact with harmful substances (Li and Achal, 2020). In a study conducted in China's famous informal recycling hub, Guiyu explains how employees working with e-waste were directly exposed to toxicants both through work and indirectly through the environment (Li and Achal, 2020). Exposure to e-waste toxic substances may cause adverse health impacts such as cancer, kidney /liver dysfunction, hormonal imbalance, immune system suppression, musculoskeletal disease, birth defects, premature births, impeded nervous and sensory system development, reproductive disorders, mental health problems, cardiovascular diseases, genitourinary disease, and old-age dementia (Ilankoon *et al.,* 2018; Carlson, 2016).

Some metals known to cause cancer include arsenic, cadmium, chromium VI, beryllium and nickel (McAllister, Magee, and Hale, 2014). Long term exposure to toxic chemicals found in e-waste can damage the physiological systems such as the central nervous, reproductive and endocrine systems (McAllister *et al*., 2014). Research conducted on workers in e-waste recycling facilities showed some traces of toxic substances in their blood, human hair, fetuses and urine (Ilankoon *et al.,* 2018).

Many occupationally related noises exposures were generated by impacts such as hammering and chiselling resulting in occupational induced hearing loss (Carlson, 2016). Research conducted by Carlson (2016) on occupational hearing loss induced by metal recovery process outlines exposures and health effects in a population of Ghanaian e-waste workers. The study evaluated impact of Pb, Cd, Mn, As and Hg, and noise exposure on the audiometric status of e-waste workers and found that 60% of a population of young e-waste workers suffered occupational induced hearing loss (Carlson, 2019).

2.9.1 Arsenic

Arsenic is a naturally occurring metal in the environment and can be released in larger quantities through natural activities such as volcanoes and forest fires and may come into contact with humans through food and water, particularly in certain areas where the groundwater is in contact with arsenic-containing minerals (CHSR, 2009). Car batteries are an example of e-waste containing Arsenic. Arsenic cannot be degraded or destroyed, and accumulates in groundwater and vegetation, which eventually makes its way to humans through the food chain. The most common exposure pathway for Arsenic is inhalation, however, can also be through leachate.

Papadopoulou, Marouli and Misseyanni (2019) studied a population in a rural community of India and Bangladesh that depends on groundwater which is contaminated with arsenic concentration. Results showed that concentrations exceeded the recommended WHO limits and may cause acute and chronic health effects (Papadopoulou *et al., 2019).* Health complications induced by exposure to high concentrations of arsenic may result in acute respiratory illnesses such as bronchial pneumonia and tracheae bronchitis, and reproductive system injury resulting in fertility issues (Chikkanna, Mehan, Sarath, and Ghosh, (2019). Chronic effects may result in reproductive complications such as stillbirth, respiratory chronic illness such as rhinitis and fibrosis, chronic neurological effects such as anxiety attacks; and carcinogenic effects such as lung, bladder, liver, skin, leukemia and kidney cancers (Papadopoulou *et al.,* 2019).

A study conducted in Bihar, India, shows that groundwater systems including drinking water are highly contaminated with arsenic (Kumar *et al.,* 2016). Research participants displayed diseases like diabetes, hypertension, loss of appetite, loose motions, abdominal pain, breathlessness, hormonal imbalance, mental disability and cancer (Kumar *et al.,* 2016). The study demonstrated a high correlation between high arsenic and chronic illnesses (Kumar, Rahman, Iqubal, Ali, Niraj, Anand, G. and Kumar, 2016).

2.9.2 Lead

Lead exists in three states: Pb (0), Pb (II) and Pb (IV). In the environment, lead primarily exists as Pb (II) and Pb (IV) and is only formed under extremely oxidising conditions (Abadin, Ashizawa, Llados, and Stevens, 2007). Lead is mostly found in electronic equipment such computers, lead-acid batteries, cable sheathing and in the glass of cathode-ray tubes in TVs, cellphones, and LCD TVs (Fiore, Ibanescu, Teodosiu, and Ronco, 2019).

When electronic equipment reaches end-of-life or are discarded in the open environment or landfill, lead may be released and accumulate in air, soil, and water and make its way to human through inhalation or ingestion of contaminated water (Zheng, ChenYan, Chen, Hu, Peng, and Yang, 2013). Lead is particularly dangerous to young children because it can damage nervous connections and cause blood and brain disorders (Yang *et al.,* 2012). A recent study conducted by Wu, Leung, Du, Kong, Shi, Wang and Xiao, *(*2019) on health risks from consumption of rice growing near an abandoned e-waste recycling site found that the sites are still highly contaminated with metals such as Sn, Sb and Ag. These metals can disperse to the nearby field and rivers (Wu Leung, Du, Kong, Shi, Wang and Xiao, 2019). The study showed that there was a risk of exposure to excessive lead through rice consumption. Another study conducted in China found that children near informal recycling sites had higher levels of lead in their blood than children living in areas away from e-waste recycling facilities (Guo *et al.,* 2014). Risks associated with exposure to lead as well as its detrimental effects on humans and the environment are a cause for concern.

2.9.3 Cadmium

Cadmium is a silver-white metal that is found in the earth's crust. It is extracted during the production of metals such as copper, lead, and zinc (Cruvinel *et al.,* 2019). Cadmium is also released through by fossil fuels such as coal, smoking cigarettes, and burning waste. In waste, cadmium is mostly found in batteries and electronic equipment (CHSR, 2009). The intake of high levels of cadmium may greatly irritate the stomach, leading to vomiting and diarrhea. Cruvinel, Marques, Cardoso, Novaes, Araujo, Angulo-Escalda, Galato, D. Brito and da Silva (2019) in Brazil, evaluated landfill workers who pick up e-waste and established that they were regularly affected by diarrhea, vomiting, and high glucose heath issues (Crunivel *at al.,* 2019). Working long hours as waste pickers exposes waste pickers to cadmium and its health-related complications. The reported symptoms may explain the related illnesses such as kidney disease, lung damage, and fragile bones (Crunivel *at al.,* 2019). However, the challenge is that cadmium health hazards are not as well researched globally, and as such its full acute and chronic impacts remain unidentified (Crunivel *at al.,* 2019).

2.9.4 Mercury

Metallic mercury is used in thermometers, dental fillings, switches, light bulbs, and batteries (CHSR, 2009). Whilst research has been conducted on health risks associated with exposure to mercury, however awareness levels remain very low. A typical example is in how mercury containing fluorescent lamps used in most households is carelessly disposed of together with municipal waste, though it is hazardous waste (Yang *et al.,* 2012). Research on health risks of metal exposure due to consumption of contaminated fish was conducted on the Caribbean coast (Fuentes-Gandara, Pinedo-Hernández, Marrugo-Negrete, and Diez, 2018). The researched population generally consumed a lot of fish and the study was aimed at evaluating risk of exposure to mercury due to consumption of fish. Results demonstrated that mercury levels were higher, with values approximately 100% to 300% higher than the normal levels (Fuentes-Gandara *et al.,* 2018). The elevated mercury concentrations did not present health risks for healthy personnel, however remained a concern for the vulnerable groups such as children and pregnant woman (Fuentes-Gandara *et al.,* 2018).

Research conducted near a coal mine in Sonbhadra, India, evaluated exposure risks in an area where coal mines and thermal power plants have caused pollution (Sahu, Saxena, Johnson, Mathur, and Agarwal 2014). The research was completed by analysing mercury in samples of soil, and water, as well as blood and nail samples of residents (Sahu *et al.,* 2014). The results found that drinking water contained mercury from three to twenty-six times the permissible limit at the time. Mercury concentrations in the blood of participants were much higher than the standard set by the WHO Mercury exposure can cause neurological deficits and reduced cognitive ability in foetuses (Fuentes- Gandara *et al.,* 2018).

2.10 Conclusion

Firstly, from the review of the relevant literature, one aspect that is comparable in countries across the globe is the drastic increase in rate of e-waste generation. However, management practices and challenges, legislation and awareness levels vary from one country to the next (Bakhiyi, Gravel, Ceballo, Flynn, and Zayed, 2018). When comparing South Africa's e-waste legislation to countries like Europe and Sweden, Switzerland, South Africa is behind. For example, Europe prohibited landfilling of e-waste in 2012 (European Parliament and The Council of the European Union, 2012). South Africa, on the other hand, only published legislation banning landfilling of e-waste in year 2013 with a provision for parts of the law to only come into effect in year 2021, resulting in a gap of almost a decade (DEA, 2013).

Secondly, European countries such as Sweden first introduced EPR in 1990 (Long *et al.*, 2016). In South Africa, EPR regulations was only ratified in 2020 (DEFF, 2020c). The EPR regulations directs waste producers to take accountability for management of waste at end-of-life (DEFF, 2020c). It requires allocation of resources and revenue towards safe and correct management of waste. With its introduction in 2020, waste model in South Africa will gradually shift from towards a circular economy.

However, when compare with similar countries such as Ghana and Nigeria, South Africa is taking the lead. It is important to recognise that developing countries are faced with socio-economic challenges and as such environmental issues are unfortunately not lower priority, and the government's primary issues of importance are on elevating poverty, creating employment opportunities and addressing health related epidemics (Ikhlayel, 2017). Therefore, environmental awareness strategies are necessary to create the required high level of awareness on health and environmental impacts associated with ineffective e-waste management.

Lastly, implementing an effective waste recovery system requires an integration of informal waste collectors and recyclers in the formal process. This type of effective e-waste management can be achieved by integrating e-waste solutions within the existing municipal, informal sector and private public partnerships (Ikhlayel, 2017).

As a long-term solution, control and avoidance of use of toxic raw materials in the manufacturing process is key to resolving the issues of hazardous waste that cannot be recycled and causes health and environmental impacts (Ikhlayel, 2017). The current business as usual approach must change, and this requires substitution of hazardous materials with safer and environmentally friendly materials and where not possible reduction of use.

Solutions to e-waste challenges need to focus on both upstream and downstream solutions (Bakhiyi, Gravel, Ceballo, Flynn, and Zayed 2018). Upstream solutions need to consider the role of producers and how they can influence selection of materials during the production phase to increase e-waste recyclability to meet set targets, increase eco-orientated consumer habits, and control the use of hazardous components in production of e-waste (Bakhiyi *et al.,* 2018). Downstream solutions need to focus on issues of illegal trade in hazardous waste, introduce stronger reverse logistics mechanisms to enhance recycling/ upcycling, and set product specific recycling target at consumer level to encourage recycling and place equal responsibility on consumers and manufactures (Bakhiyi *et al.,* 2018).

CHAPTER 3: STUDY AREA, RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter commences by providing specific information about the study area, particularly the geographical location and the demographics of the study areas such as population size and education profile. It further provides explains the research design and methodology applied for the selection of the study area, sampling methodology, data collection methods and subsequently data analysis.

3.2 Study Area

The study area is eThekwini Municipality (Figure 3.1) is the largest city in the KwaZulu-Natal province and the third largest city in the country of South Africa. EThekwini Municipality is home to approximately 3.81 million people (StatsSA, 2016). According to the 2019 annual report, the population size for eThekwini was forecasted to be 3.85 million people in year 2020 (eThekwini Municipality, 2019).

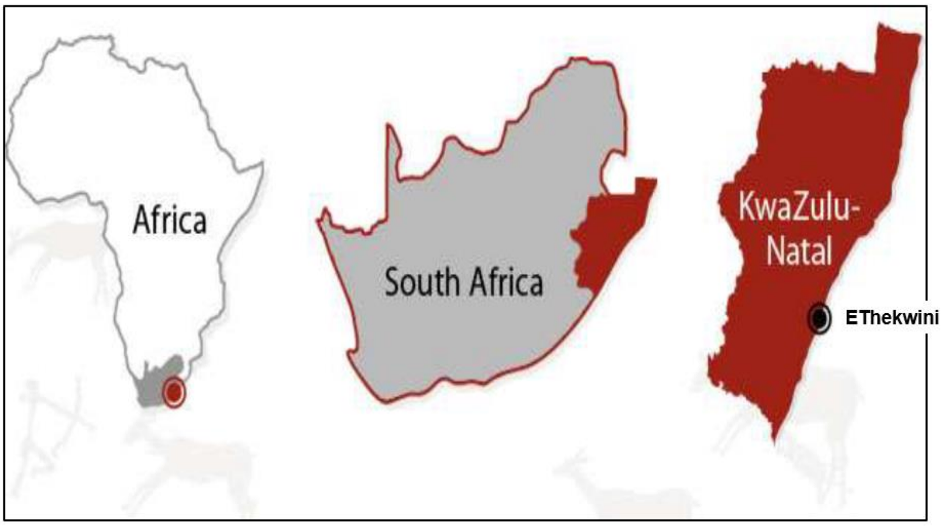

Figure 3.1: Maps of Africa, South Africa, KwaZulu Natal province and eThekwini Municipality (Source: Tourism KwaZulu-Natal, 2014).

EThekwini Municipality is bordered in the north by iLembe District Municipality, to the east by the Indian Ocean, to the south by uGu District Municipality and to the west by the uMgungundlovu District Municipalities (StatsSA, 2016). EThekwini Municipality comprises of industries, residential area recyclers and landfill sites, hence its selection as the study area.

KwaMashu and Hillcrest areas were selected as a representative site for residential areas within eThekwini Municipality. KwaMashu represents the township setting and Hillcrest represents the suburb setting within the Municipality. The reasons for selecting the two locations was to cover both township and suburban settings.

Kwamashu has a population size of 175 663 people and 50 683 households (StatsSA, 2016). It is in the northern area of eThekwini (Figure 3.2). Hillcrest has a population of 13 329 people and 5 231 households (StatsSA, 2016) and is in the western area of eThekwini (Figure 3.3).

Figure 3.2: Map showing the geographical location of the KwaMashu residential study area
Source: http:// wwww.google.co.za (accessed10/10/2016)

Figure 3.3: Map showing the geographical location of the Hillcrest residential study area
Source: http:// wwww.google.co.za (accessed12/13/2016)

3.3 Research Design

Both qualitative and quantitative research methods were used to acquire data from eThekwini Municipality. This research method is known as mixed methods and involves the collection and analysis of data as a result of both quantitative and qualitative methods (Hammack-Brown, B.R. and Nimon, 2016). The quantitative research method is used to evaluate a problem by making use of numerical data and then transforming it into statistics for easy analysis and understanding of concepts and relationships. Qualitative research on the other hand is descriptive and aims to understand complex human problems and behaviours (Sullivan and Sargeant, 2011). The qualitative method is mostly used when certain answers to the research question require an explanation (Sullivan and Sargeant, 2011).

The mixed methods approach was most appropriate for the study as it enabled the researcher to obtain greater understanding of the topic under consideration. Benefits of applying the mixed methods approach is that the researcher can apply both methods and is therefore not restricted to one approach.

Table 3.1: Research design, research methods, sampling methods and data collection methods

Research Objective	Research Method Used	Sampling Method	Data Collection Method	Analysis Method
• To identify types and sources of e-waste in eThekwini Municipality.	Quantitative Method	**Random Sampling:** Households (x350) **Purposeful Sampling:** Industries (x3) **Convenience Sampling**: Formal recycling facilities (x3) Informal recyclers (x3)	**Questionnaires:** Households; industry environmental managers; landfill site manager; recycling industry. Waste reports for all waste generated and either disposed or recycled.	Excel Sheet Graphs Statistical Package for Social Sciences
• To establish e-waste management practices such during collection, storage, transportation, disposal and recycling in eThekwini Municipality.	Quantitative Method	**Random Sampling:** Households (x350) **Purposeful Sampling:** Industries (x3) **Convenience Sampling**: Formal recycling facilities (x 3) Landfill site (x1)	**Interviews:** Industry environmental managers; landfill site manager; environmental health practitioner, **Observation:** Industries, and recycling facilities.	Excel Sheet Graphs Statistical Package for Social Sciences
• To determine the role of informal recyclers regarding e-waste management in eThekwini Municipality.	Qualitative Method	**Random Sampling:** Households (x350) **Convenience Sampling**: Informal recyclers (x3).	**Interviews**: Industry environmental manager, recyclers, landfill site manager. Waste records showing waste quantities and type.	Excel Sheet Graphs Statistical Package for Social Sciences
• To determine eThekwini Municipality policies and compliance with current and future legislation relating to E-WASTE.	Qualitative Method	**Purposeful Sampling:** EThekwini Waste Management	**Interview:** Durban Solid Waste (DSW) Waste management representative. Review of bylaws and regulations.	Excel Sheet Graphs Statistical Package for Social Sciences
• To evaluate the level of awareness of stakeholders on risks of E-WASTE	Quantitative Method	**Random Sampling:** Households (x300) **Purposeful Sampling:** Industries (x3) **Convenience Sampling**: Formal recycling facilities (x 3) Informal recyclers (x3)	**Questionnaire:** Household **Interviews:** Recyclers, industry	Excel Sheet Graphs Statistical Package for Social Sciences

3.4 Research Methods

3.4.1 Sampling methods

For the selection of a study area, purposeful sampling method was selected. Purposeful sampling is widely used for the data sample identification and selection purposes and requires the researcher to select the preferred area from where the data will be collected (Palinkas, Horwitz, Green, Wisdom, Duan, and Hoagwood, 2015). The sampling approach provides flexibility to the researcher and is very simple to use. EThekwini Municipality is the largest city in KwaZulu-Natal province, the third largest in the country and provides a very a good benchmark of waste management practises within the province.

A random sampling method was applied to select households for questionnaire administration. Random sampling is a type of sampling technique where samples from a larger population are selected randomly without following any specific pattern or periodic interval. The advantage of using the random sample method is the convenience and ease of use, particularly in the selection of individuals (households). As a result, the random sampling method provides a good representative sample with minimal challenges as represented for example by the random systematic sampling method where in some cases the selected sample may not want to participate. The total number of households in both Kwamashu and Hillcrest is 18 560 (StatsSA, 2016). Three hundred and fifty questionnaires were distributed in the households. In the event where the randomly selected household could not participate, the researcher skipped that household and move on to the next available household.

For selection of the industry sample, the researcher applied the convenience sampling method. The researcher identified and approached five industries within eThekwini Municipality. Three industries approved participation in the study and were then selected as study sites. The industries that approved participation in the research were from the mining sector, the manufacturing sector and the chemical industry. A similar convenience sampling approach was applied for sample section of recyclers, and landfill site. The researcher contacted eWASA to obtain a list of formal e-waste recyclers that operate within the eThekwini Municipality area. Approval was only obtained from three formal recyclers. Informal recyclers were approached directly, and a sample site was selected based on willingness to participate. The target for informal recyclers was a total of three and was achieved. None of the landfill sites approached approved site visit.

3.4.2 Data collection methods

Primary data were collected through observations, questionnaires, interviews and records obtained from participants. The target population was comprised of industries, formal recyclers, informal recyclers and household representatives. Secondary data such as records were obtained from previous research, journals, articles, books, company reports and records. Interviews were held with the eThekwini City Health representatives responsible for responding to complaints from the residents. The aim was to ascertain the issues surrounding illegal disposal of e-waste in eThekwini. This however did not take place as the eThekwini representative advised that they don't deal with waste related complaints but rather health related complaints such as nuisance, smell odours etc.

3.4.2.1 Primary data collection

3.4.2.2 Questionnaires

Three hundred and fifty questionnaires were administered in the residential areas of Hillcrest and KwaMashu – households were selected randomly. Questionnaires focused on awareness, sources, quantification, storage, transportation and disposal of e-waste. The questionnaires were made specifically for the different categories of respondent (Appendices 1 to 5). The questionnaire consisted of 18 close-ended questions and 1 open-ended question.

The household questionnaire was administered and collected at the same time from households to prevent loss of data. In the event where there were no adults, the researcher moved on to the next household. The household questionnaire comprised the following four sections:

Section A: Demographics: This section covered information on demographics of the participants and was important to understand the respondent's age, gender, geographical location etc.

Section B: Waste Generation: Section B sought to identify sources and types of e-waste generated.

Section C: **Storage, Transportation, Disposal and Recycling**: The questions in this section sought data on e-waste management practices employed in households and the identification of associated potential affects and risks.

Section D: e-waste Awareness: The questions in this section of the survey were designed to establish the level of awareness and general knowledge on e-waste including the risk and hazards associated with e-waste.

3.4.2.3 Field observation

Observation involves the examination of research subjects in a natural social environment with attention paid to the subject matter (Polit and Beck, 2008). Observation was an important research technique to use for data collection at the landfill and recycling facilities. Researcher observations are used to validate what is presented during the interviews or present new information that is otherwise construed or not disclosed during interviews or questionnaires.

Observations were not conducted at the landfill site due to the researcher not being granted access, the recycling facilities (formal and informal), and at the three industries, observations were undertaken over a period of one hour a day over a period of three non-consecutive days and a pre-developed checklist (Appendix 2) was used to records observations made. The advantage of keeping a pre-developed checklist is that all vital aspects are evaluated during the observation. Photographs were taken for record purposes after approval was obtained.

3.4.2.4 Structured interviews

The following interviews were held:

- One interview was conducted with eThekwini Municipality Durban Solid Waste (DWS) compliance department to acquire an understanding on the Municipality's e-waste management policies and services available to households for transportation, storage, and recycling of e-waste. The interview also covered some questions relating to the Municipality's processes to assess and enforce correct management of e-waste as per waste management legislation. The interview also focused on determining plans to effectively manage e-waste in line with the upcoming e-waste restrictions and bans.

- Three interviews were conducted with informal recyclers.
- One interview was conducted with a landfill site manager.
- Three interviews were held with industry representatives.
- Three interviews were conducted with formal recyclers to acquire information particularly regarding e-waste generation and management options applied within eThekwini Municipality.

3.4.2.5 Secondary data

Secondary data involves the review of already existing information. Some records were obtained on waste generated, services available and number of facilities available and their location. This information and records provided background on current e-waste management practices, generation trends etc.

The following records were obtained from the research participants:

- Formal recycler – Waste collection/recycling records.
- Industry – Waste disposal records.
- South African Waste System (SAWIC) - eThekwini Municipality Waste records.

3.4.2.6 Types of data collected and their necessity

3.4.2.7 Data on types of electronic waste generation

Data on the types and sources of e-waste generated in residential areas and industries was important to quantify as well as to identify types and sources of e-waste that are generated within eThekwini Municipality. The data were collected through research questionnaires and interviews that were carried out at households and industries (see Appendix 1 and Appendix 2).

3.4.2.8 Data on level of community awareness of electronic waste

Information on the level of community awareness on e-waste is essential to evaluate the community’s understanding and knowledge as it plays a role on how waste is handled. Both industry and household questionnaires had sections which assessed e-waste awareness amongst participants (See Appendix 1 and Appendix 2).

3.4.2.9 Data on management practices for collection, transportation, storage, disposal and recycling of e-waste

Information on management practices was acquired through interviews and questionnaires with the following stakeholder:

- EThekwini Municipality Durban Solid Waste Management (DSW).
- Household representatives.
- Industry representatives.
- Recycling representatives (formal and informal).
- Landfill site representatives.

3.4.2.10 Data on the role of informal recyclers

At least three informal recyclers were interviewed to determine their role in the management of E-waste. Data was collected through interviews also with formal recyclers to evaluate the role of informal e-waste recycling in managing e-waste. Three formal recyclers were interviewed using the questionnaires in Appendix 4. Observations were conducted to learn and understand the processes applied by recyclers during collection, storage and recovery of e-waste (see Appendix 5).

3.4.2.11 Data on policies and plans to comply with current and future e-waste legal requirements

Interviews were conducted with a representative from eThekwini Municipality Durban Solid Waste department to determine plans that are in place to ensure alignment with current and future legal requirements on e-waste (See Appendix 3). Table 3.1 shows the overall research design followed.

3.5 Data Analysis

Data collected during a research can be enormous, as such, data analysis enables the researcher to reduce information to a manageable size for better examination (Hesse-Biber and Johnson, 2015). Both descriptive and quantitative analytical approaches were applied in the study. Descriptive data obtained from interviews, questionnaires, records and observations were well organised, and checked for completeness, quality, and correctness. To process descriptive data, results were processed in one of the following ways as recommended by Laerd Statistics (2013):

- Tabular explanation, to explain frequency and percentages of trends.
- Graphical illustration, (pie graph, bar graphs and line graphs), and
- Statistical annotation through explanation of results.

Quantitative data was required essentially to quantify waste generated in the study area. Data obtained from questionnaires was first coded. Coding involves grouping of responses and assigning code to specific responses (Joanna Briggs Institute 2014). Invalid responses were omitted from the analysis. Data was processed with the assistance of Package for Social Sciences (IBM SPSS statistics version 21.0), Microsoft Excel, to calculate the mean, the mode, median, standard deviation.

3.5.1 Questionnaires

A list of electronic equipment was provided in the questionnaire and respondents selected appliances in their household / industry and indicated quantities / number of units. The appliances were grouped by type of e-waste (small, large, ICT, entertainment and lighting equipment). Data was then analysed to ascertain types of appliances and quantities of e-waste that can be generated annually from each waste stream. To quantify e-waste researched statistical data on average e-waste mean lifespan and mass was applied to estimate e-waste generated in the study area. Once average mass (weight) and average lifespan (years) of each stream was established, a simple calculation using the formular below developed by Robinson (2009) was applied to estimate quantities of e-waste per annum in the study area.

$$\text{waste (kg/inhabitant/yr)} = \frac{\text{number of pieces of equipment x average weight (kg)}}{\text{Average lifespan}} \div \frac{\text{household with waste}}{\text{average No. of people per household}}$$

Using the above formular, the total number of units of electronic and electrical equipment was multiplied by mean weight (kg) of each waste type of e-waste, divided by average lifespan of each waste type (years) based on researched data research. This calculation estimates the expected quantities of e-waste (kg/year). To calculate waste generated per capita per year, total waste (kg/year) was divided by mean number of households in the study area with the waste type and average number of persons per household (based on StatsSA, 2018). The formula was applied across all types of e-waste to estimate quantities generated per type of e-waste in the study area.

3.5.2 Observations and interviews

Quantitative data collected from observations and interviews was sorted, grouped and captured on Excel. Thereafter, results were analysed and interpreted descriptively using statistical information such as standard deviation, mean, highest value, lowest values to explain patterns and certain relationships.

3.5.3 Records

Records received included policies, annual reports and waste generation records from recyclers, eThekwini Municipality and industries. The records were analysed to ascertain management practices as well as to determine types of e-waste generated and managed in the study area. Information collected s presented as discussion in the results.

3.5.4 Ethical Procedures

The researcher obtained approval and clearance through the University of South Africa's ethical clearance procedure, clearance number 2017/CAES/049. This involved endorsement of the research proposal by the University's ethics committee. Permission to conduct research was attained in 2016. The researcher also received approval from eThekwini Municipality Manager to undertake the study (Appendix 6). Participants from household, industries, landfill site and recycling facilities were informed that participation was entirely voluntary. An information letter was issued to all participants involved in the study. The letter advised the participants that participation is completely voluntary, and they also provide consent by signing the form to participate in the study. Furthermore, the information letter provides assurance that information provided remains confidential and advises that participants are free to withdraw from participating at any point. There was no harm to the environment, person's health or violation of one's privacy during the research.

3.6 Limitations of the Study

The following limitations pertaining to the study are acknowledged:

The research was meant to include interviews and site visits with representatives from residential, industrial, landfill, and Municipality, formal and informal recyclers. However, the research did not include a site visit at the landfill site as permission was not granted however a telephonic interview was conducted

Some participants expected payment to participate in the study while others were illiterate or not interested in participating in the study. These were omitted from participating.

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter provides an analysis of results from the research conducted in the study area with participants from household, industry, recyclers, and the Municipality Solid waste Management Unit. The demographics of the study and quantities of e-waste generated in the study area are presented on sections 4.1 and 4.2 respectively. This provides an overview on which electronic wase is mostly consumed. Sections 4.3 and 4.4 illustrate the contributions of informal recyclers in management of waste as well as compliance to waste policies. Lastly the results on public's awareness on e-waste related issues is explained on 4.5 of this chapter.

4.1.1 Background of respondents in the study area

A total of 350 questionnaires were distributed to households within Hillcrest and KwaMashu as representatives of eThekwini Municipality households, and about 322 questionnaires were completed satisfactorily. This translates to a response rate of 92% of the total sample and was adequate to draw conclusions. Additional responses received from three industries, three formal recyclers, three informal recyclers, one landfill site Manager, and eThekwini Municipality Cleansing and Solid Waste representative were analysed. All respondents who participated in the study reside within the study area and were over the age of 18. The respondents were comprised of men and women in the following proportions - 51% and 49%, respectively. This is similar with the 2016 statistical survey results where both KwaMashu and Hillcrest gender distribution averaged at 49% female and 51% males (StatsSA, 2016).

4.1.2 Highest qualification distribution of respondents in the study area

The results on educational achievements of participants in study area are shown in Figure 4.1. Those who have either completed high school or tertiary education amounted to 74% of the total whereas those without any formal education constituted less than 10% of the total sample.

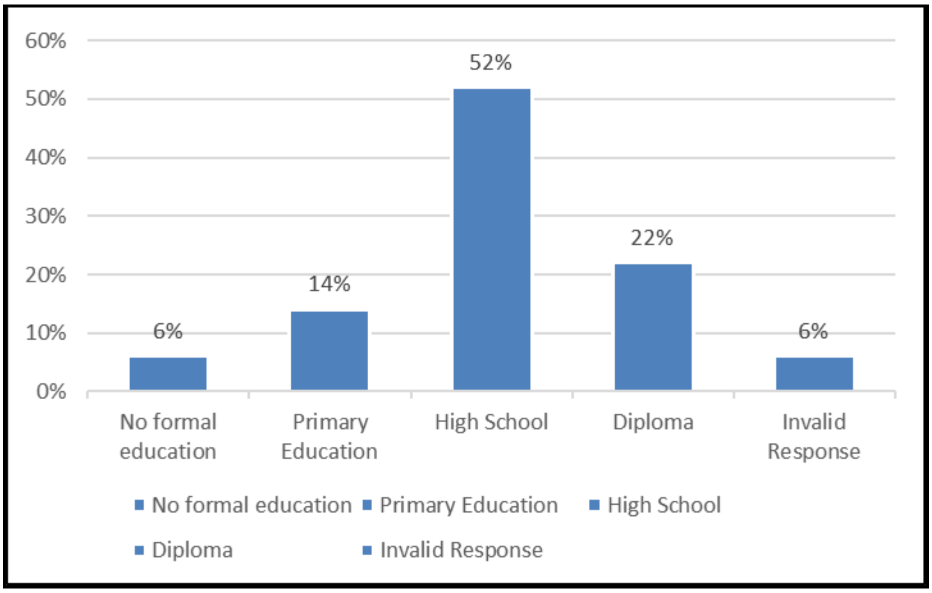

Figure 4.1: The educational profile of participants in the study area

4.1.3 Geographic location of respondents in the study area

KwaMashu had the highest proportions (i.e. 57.7%) of participants as compared to Hillcrest, which comprised 40% of participants. On the other hand, nearly 2.7% of participants did not provide the data on this question. Be that as it may, the point that KwaMashu exhibited the largest proportion of participants seem to follow the population distribution trends as this area has 90% more residents than Hillcrest (StatsSA, 2016).

4.2 Types of e-waste generated in the study area

4.2.1 Introduction

The study was based on electronic equipment in use as and obsolete at the time of the research. The study focused on five groups of e-waste, namely waste from small equipment, large equipment, lighting equipment, entertainment equipment, and information technology and communication (ICT).

According to Figure 4.2, 43% of participants mentioned electronic waste derived from ITC equipment. This waste category comprised items such as old unwanted or broken laptop and desktop computers, computer screens, photocopier machines, printers, tablets, telephones, cell phones and smartphones. The second most prevalent waste type after ICT waste was waste from entertainment equipment such as obsolete TV’s, LCD screens, audio systems, stereo systems, etc, which were mentioned by 28% of participants. The new LCD TV screens, old TV sets and headphones were the most dominant type of entertainment equipment, comprising over 50% of entertainment waste. By contrast, waste categories derived from large equipment as well as electronics used for lighting purposes represented lower percentages, 15% and 14%, respectively.

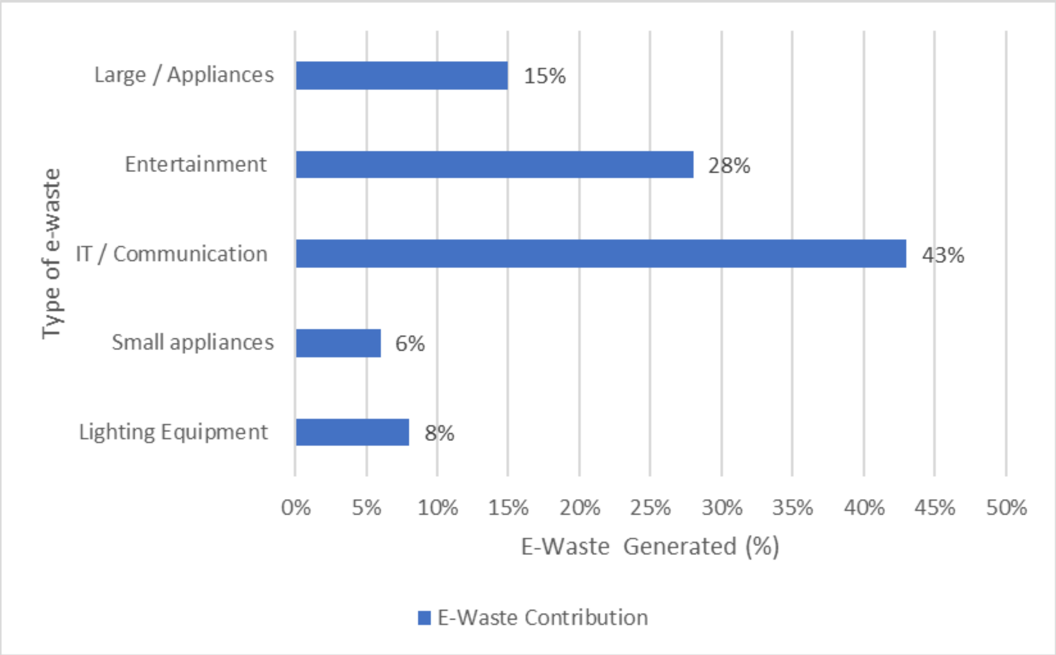

Figure 4.2: Overview of e-waste generation in the study area

4.2.2 Quantities and types of e-waste generated in the study area

Using Robison's formular, as explained in section 3.5.1, estimated quantities of e-waste was computed for the study area. Actual collected data from respondents that were surveyed was used. The formular for the computation of e-waste quantities required researched average lifespan, average mass and number of units from all participants in order to calculate the estimated waste per year. Table 4.1 illustrates the average e-waste generated in the study area, 6.77 kg /inhabitant/year. The results were within the range of developing countries such as Brazil, Mexico and Thailand that are reported to have a rate of 7 kg/inhabitant/year, 8 kg inhabitant/year, and 6 kg/ inhabitant/ year respectively (Borthakur and Govind, 2017). It is also similar to the e-waste rate that was recently announced by eWASA, 6.2 kg /inhabitant /year (APWC, 2020).

Table 4.1: Types and quantities of e-waste generated in the study area

E-waste Type	Number of items of equipment in the study area	Average weight of waste type (kg)	Mean lifespan	No. of households (out of 322)	Estimated waste (kg/year)	Inhabitants per household	Waste generated (kg/inhabitant/year)
Entertainment equipment	1140	14.00	6	66	2660	3	13.43
Large equipment	720	20.00	10	47	1440	3	10.21
IT communication	781	24.00	4.5	188	4165	3	7.38
Small equipment	1151	1.50	3	101	575	3	1.89
Lighting equipment	6000	0.13	1	288	780	3	0.90
Estimated waste generated per (kg/inhabitant/year) in the study area = 6.77							

4.2.3 E-waste generated from ICT equipment in the study area

The frequency and distribution of responses relating to the number of ICT equipment in use and obsolete / redundant is represented in Table 4.2. The average mass of ICT equipment was relatively high, (24 kg) compared to lighting equipment (0.13 kg). The higher average mass of ICT equipment together with low average lifespan influenced the total mass of e-waste generated. ICT waste generated in the study area amounted to 4165 kg/year, as shown in Table 4.2 and Figure 4.3. ICT was the most prevalent waste stream in the study area. The use of ICT equipment has drastically increased as the world embraced the various online platforms such as online shopping, schooling, training and online careers.

Table 4.2: E-waste generated from ICT equipment in the study area

Indicator	Household and Industry
No. of units generated	1509
No. of households	188
Average lifespan (years)	4.5
Average mass (kg)	24
E-waste generated (kg/ year)	4165
E-waste generated per (kg/inhabitant)	7.38

Figure 4.3 provides an overview of the composition of ICT equipment. The number of smartphones in use and obsolete were the highest contributed 35% of the total ICT waste. The least frequent ICT equipment was printers, which constituted only 5% of total ICT waste. Unlike smartphones, printers and photocopiers are shared in offices and homes hence the very low numbers. The calculated standard deviation for the number of ICT equipment per household was relatively high (4.87). Thus, the number of ICT appliances varied significantly between households. This may possibly be due to the different socio-economic profiles of the participants involved in the study particularly in Hillcrest suburb and KwaMashu township. The prevalence of smartphones suggests that smart phones are the most frequently generated type of ICT equipment. As such, for effective management of e-waste, it is recommended that more initiatives should be aimed at encouraging repair, recycling of smartphones.

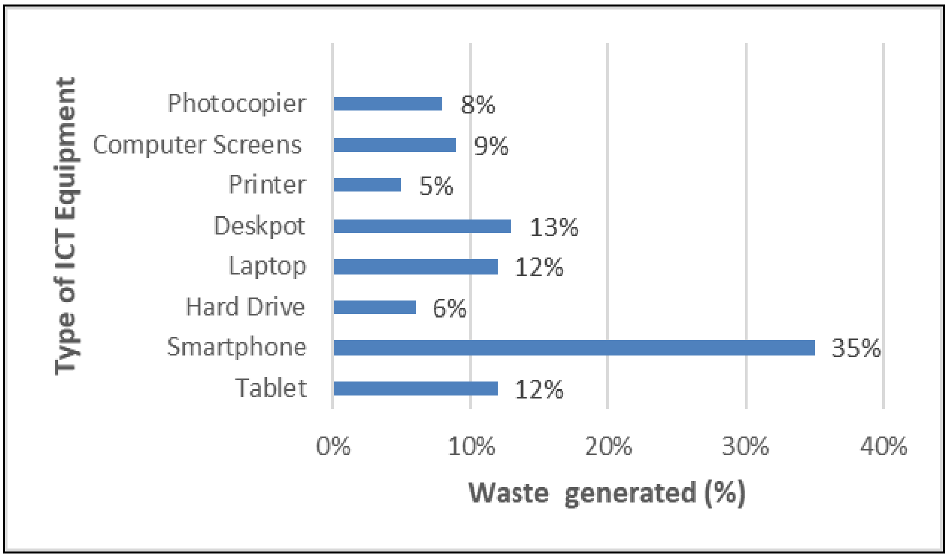

Figure 4.3: ICT equipment composition in the study area

4.2.4 E-waste generated from entertainment equipment in the study area

Table 4.3 provides a summary of the frequency and distribution of responses relating to the number of entertainment equipment in use and the number that were obsolete/redundant is represented. According to respondents, there were 1140 units of entertainment equipment in the study area. Estimated e-waste from entertainment equipment was 2 660 kg per/annum and estimated e-waste generated per capita was a high 13.43 kg per inhabitant per year.

Table 4.3: Entertainment waste in the study area

Indicator	Study Area
No. of units in sampled area (mean)	1 140
Mean lifespan (years)	6
Mean mass (kg)	14
E-waste generated (kg/ year) in 322 households	2 660
E-waste generated (kg per inhabitant per year)	13.43

According to Figure 4.4, television (old and new), contributed 50% of total entertainment equipment. Over the last decade, there has been a constant increase in TV sales due to the advancement of TV technology. Initially it was the introduction of the high definition TVs in early 2000, the in the last three years, 3D TVs and smart TVs entered the market, thus influencing replacement of older TV's before end-of-life (Aggarwal *et al*., 2016).

Furthermore, unlike the old durable "box" TV's, the new LCD and flat screens TV's break easier, yet they are very expensive to repair, and when broken, the whole TV must be replaced. This also contributes to the generation of entertainment e-waste, as shown in Figure 4.4. The introduction of strict laws around product design and can eliminate the current challenge of irreplaceable screens.

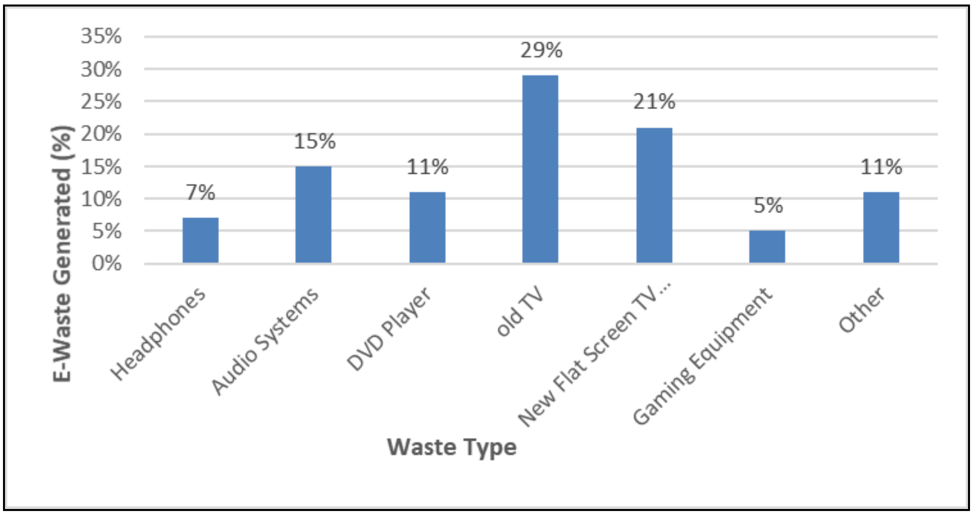

Figure 4.4: Characterisation of waste from entertainment equipment in the study area

4.2.5 E-waste generated from large equipment in the study area

Table 4.4 illustrates the frequency and distribution of responses relating to the number of large equipment in use and the number that were obsolete/redundant. Electrical appliances from large equipment amounted to 1440 kg/year and was the third largest contributor in e-waste in the study area. E-waste from large equipment amounted to 10.21 kg/ inhabitant/year. Large appliances are relatively heavy by mass, hence a very high per capita rate.

Table 4.4: E-waste Generated from large equipment

Indicator	**Household**	**Industry**
No. of units generated	706	14
% Contribution	98%	2%
Average lifespan (years)	10	
Average mass (kg)	20	

E-waste generated from large equipment (kg/ year)	1440
Estimated e-waste generated kg/inhabitant	10.21

The majority of the respondents had high number of refrigerators (32%), and less frequent equipment was dishwasher and vacuum (2% respectively).

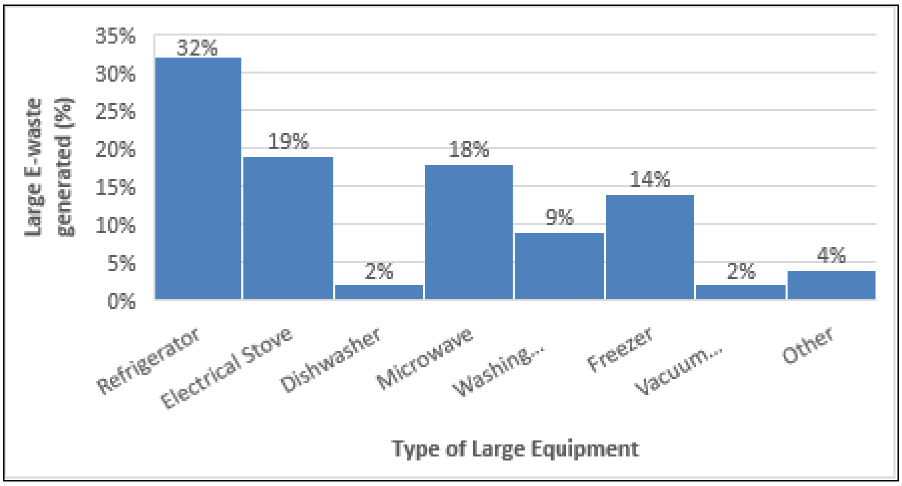

Figure 4.5: Type of waste generated from large equipment in the study area

The calculated average number of large equipment per household was 2.5 appliances per household and the calculated standard deviation for the number of large equipment per household was low, (0.87). Thus, the number of large appliances did not vary significantly across the participants from various households. The common types of equipment were refrigerators (32%), microwaves (18%) and electrical stove (19%). The least common large appliances were vacuum and dishwasher (2%).

4.2.6 E-waste generated from lighting equipment in the study area

The frequency and distribution of responses relating to the number of lighting equipment in use and the number that were obsolete/redundant is represented in Table 4.5. Waste from lighting equipment entails waste from fluorescent lamps, light bulbs, heavy duty lamps and other (torches, fluorescent lights, industrial lighting equipment). According to respondents, there were over 5000 units of lighting equipment in the study area.

E-waste generated from lighting equipment was 780 kg/year. While there was a significantly high number of units of lighting equipment, the quantities of e-waste generated, by mass were very low due to significantly low average weight of lighting equipment (0.13kg) and a short lifespan (1year). Consequently, lighting only contributed 7% of total e-waste generated in the study area and had a capita rate of 0.90 kg/inhabitant/year.

Table 4.5: Potential lighting e-waste generation in the study area

Indicator	Household	Industry
No of units generated	5400	600
% Contribution	90%	10%
Average lifespan (years)	1	
Average mass (kg)	0.13	
E-waste generated from lighting equipment (kg/ year)	780	
E-waste generated per (kg/inhabitant)/year.	0.90	

Figure 4.6 depicts results of the respondent’s responses on types and number of lighting equipment in the study area. Light bulbs were the most frequent, (64%), followed by fluorescent lamps (24%) and other lighting equipment such as torches and industrial lighting only contributed 14% collectively. Fluorescent lamps are classified as hazardous waste, as per waste norms and standards for disposal of waste cannot be discarded in landfill but must recycled. Though fluorescent lamps are small by average weight (0.13 kg), this waste stream contains mercury and should be disposed currently. However, respondents indicated that 92% was disposed together with general waste. Respondents in the study area were unaware that disposal of fluorescent lamps as part of domestic waste was a violation of the waste laws. Initiatives to enhance public awareness amongst on correct disposal methods should be explored urgently.

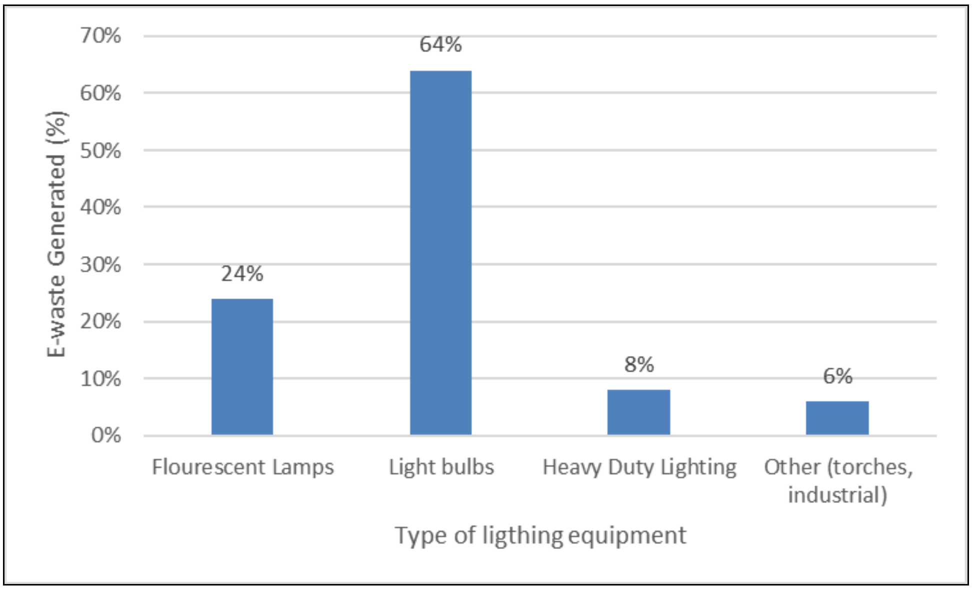

Figure 4.6: Lighting equipment generated in the study area

According to table 4.6, calculated e-waste from lighting equipment was 780 kg/year. The per capita rate was 0.90 kg/ inhabitant/year, making it the second lowest of the five streams.

4.2.7 E-waste generated from small appliances in the study area

The frequency and distribution of responses relating to the number of small equipment in use and the number that were obsolete/redundant is represented in Table 4.6. Quantification of each group of waste groups was completed, with small appliances recording the least quantities of waste. Figure 4.7 shows sources of waste from small equipment. As displayed, the most common waste from small appliances was kettles and irons (60%); other equipment such as toaster, electric frying pan, coffee machine etc. contributed the remaining (40%).

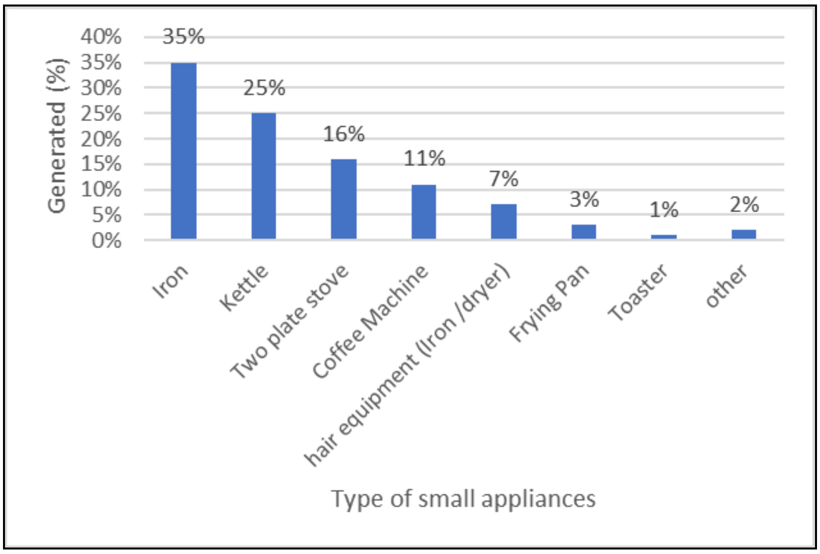

Figure 4.7: Waste from small equipment in the study area

Table 4.6 demonstrates the quantities of e-waste generated (kg/year) from small equipment. It is estimated that 575 kg was generated annually. Small electronic equipment contributed the smallest in mass amongst the five types of e-waste evaluated. E-waste generated per inhabitant from small appliances as shown in Table 4.6 is 0.89 kg/ inhabitant per year, the lowest contributor of all the e-waste streams. This is expected mainly due to the short lifespan and very low average weight of lighting equipment. However, the observed inappropriate disposal of some lighting equipment renders this waste stream the greatest concerning waste stream and requires urgent recycling solutions for the general public.

Table 4.6: E-Waste generated from small appliances in the study area

Indicator	**Industry**	**Household**
No of units generated (median)	16	1 135
% Contribution	1.4%	98%
Average lifespan (years)	3	
Average mass (kg)	1.5	
E-waste generated from small equipment (kg/ year)	575	
Estimated e-waste generated kg per inhabitant per year	0.89	

In conclusion, waste from ICT was found to be the highest contributor (43%), followed by waste generated from entertainment equipment (28%), large equipment (15%), lighting equipment and small equipment contributed 8% and 6% respectively. The results were compared with international results and developing countries such as Brazil, Mexico and Thailand had relatively low rates of 7 kg/inhabitant/year, 8 kg/inhabitant/year, and 6 kg/inhabitant/year respectively (Borthakur and Govind, 2017). Management practices including storage, transportation, recycling and disposal of e-waste are discussed next.

4.2.8 Storage of e-waste

Storage is an important aspect of waste management, particularly to prevent harm to the nearby environment. Inadequately stored e-waste poses a risk to the environment. Once e-waste is dismantled, there is great potential for toxic elements to leach into the surface water or soil, thus resulting in soil and or groundwater contamination. Research conducted in India on a recycling facility confirms that leaching of contaminants from poor storage and handling practices is eminent (Ackah, 2017). The type of pollutants released into the environment depends on the composition, age, type of e-waste handling and processing processes (Bakhiyi *et al.*, 2018). Processing of e-waste in some cases requires use of toxic acids such as nitric acid and cyanide, which produces large amounts of wastewater containing acids which may cause harm to people and the environment when leached into the ground (Ackah, 2017).To understand the potential release of contaminants into the environment, responses and observation of practices being applied at storage areas by recyclers (formal and informal), household and industry were documented and the results are disclosed on Figure 4.8.

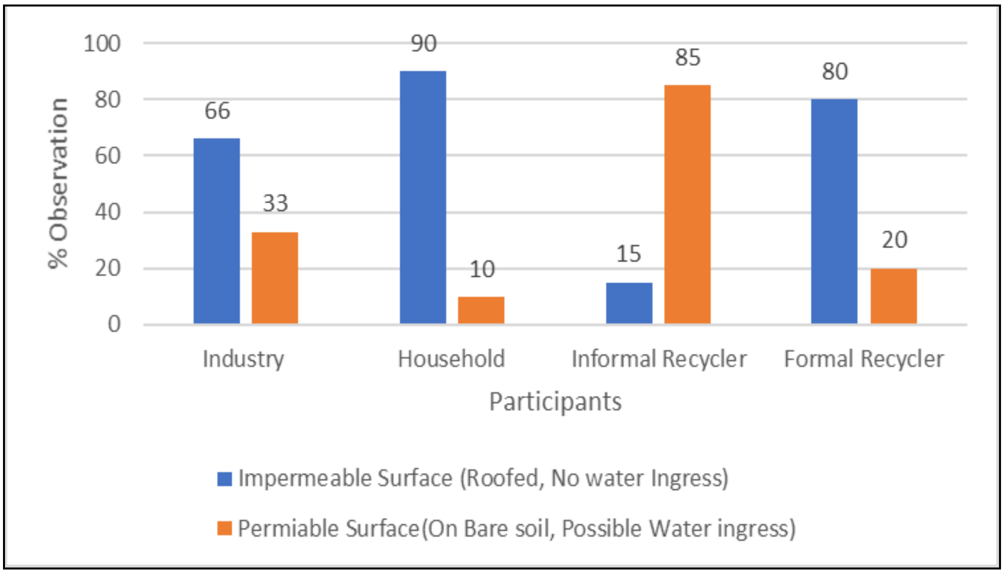

Figure 4.8: E-waste storage Practise in the study area

From observations and responses received, majority (90%) of unused electronic equipment were stored inside the house. On average 66% of industry participants stored their e-waste such that it posed no risk to soil contamination or surface water.

Electrical equipment in most households was also kept in its original state and had not been stripped or interfered with or dismantled. This significantly reduced the risk of any chemicals from leaching into the ground. This practice of retaining and old or broken appliances is also common in Vietnam where citizens prefer to retain their old equipment for sentimental value (Yokoo *et al.,* 2018).

Results of the study showed that 80% of formal recyclers stripped their waste but kept it inside their warehouse and where there is no possibility of water ingress. Figure 4.9 shows that industry stored waste similarly to household, indoors. Formal recyclers stored more than 50% of the e-waste in its inert form and on an impermeable surface prior to stripping. Informal recyclers on the other hand only stored 15% of their e-waste under an impermeable structure which protects the soil, and the majority (85%) was stripped and stored on the ground, likely to cause groundwater contamination.

Figure 4.9: Industry storage practices in the offices and formal recyclers. (Source: Mkhwanazi, 2018)

As shown in Figure 4.9, most of e-waste at formal recycling facilities and industries was properly segregated by type and kept in roofed structure with very limited risk of contaminating surface water or the soil.

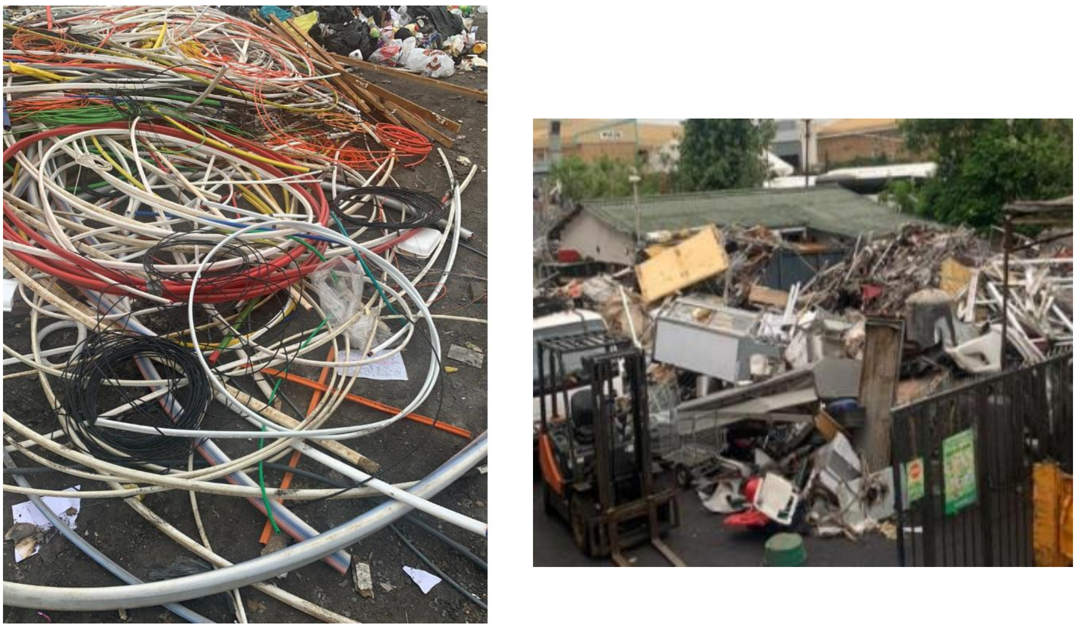

Figure 4.10: Poor e-waste storage practises by informal recyclers in the study area
(Source: Mkhwanazi, 2018)

4.2.9 Transportations and collection of e-waste

As illustrated graphically in Figure 4.11, the common mode of transporting e-waste is the municipal collection system (20%), and the least common mode of transport is private vehicles (3%). As the most common mode of transport was the municipal trucks, collecting general waste, it is not possible to dispose of large pieces of equipment through this method as they will not fit into truck. What is important to note though is that municipal waste trucks are not intended for collection of e-waste but for collection of domestic or, garden waste. E-waste transported as part of domestic waste is discarded incorrectly as it ends up being managed at landfill sites without any pre-treatment. Formal recyclers transport about 22% of e-waste from households. There are no free public services for transportation of e-waste from households. Lack of access to transport, contributes to exponential growth of informal recyclers (Godfrey and Oelofse, 2017).

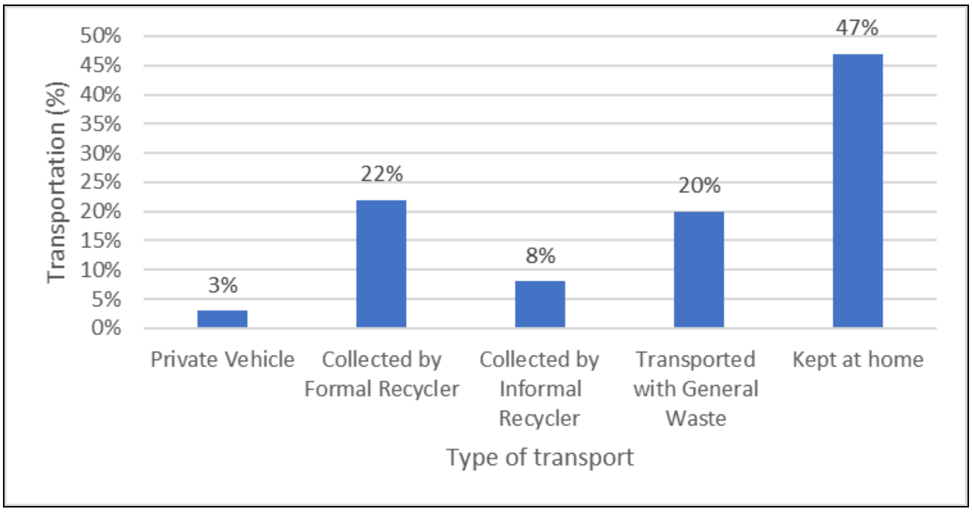

Figure 4.11: Practices of transportation and collection of e-waste

Figure 4.12: Transportation methods used by formal recyclers vs waste pickers
(Source: Mkhwanazi, 2019).

As demonstrated in Figure 4.12 (right), informal recyclers normally use home-made trolleys to transport waste, though it is in smaller quantities. When compared to formal recyclers, their mode of transport is manually intensive, however when it comes to access to waste the researcher observed that informal recyclers are also effective as they are able to recover unwanted equipment waste from households, illegal dump sites and in some cases landfill facilities. This type of transport generally limits the recycler in terms of quantities that can be transported and ultimately recovered. It is thus not very effective for larger commercial recycling initiatives.

4.2.10 Recycling of e-waste in the study area

The results highlighted that stakeholder recycling behaviours vary significantly amongst various participants. According to Figure 4.13, 69% of private industry respondents participate in recycling, however when it comes to household respondents, only 7% of household actively participate in recycling. The low recycling rate is also reported in reviewed literature. According to Andeobu *et al.,* (2021) the e-waste recycling rate in South Africa is below 10%.

Despite having robust legislation and waste prevention strategies, the reuse, recovery and recycling of waste remains relatively low. Recovery and recycling remain more burdensome and costly, compared to disposal option. One of the e-waste recyclers in Hillcrest area indicated that their focus is mainly on refurbishing goods such as laptops as there is not sustainable revenue generation from recycling due to high logistical costs and they also struggle with access to e-waste locally. It is envisaged that schemes developed through the EPR will improve small recycling rates, possibly even beyond the set targets.

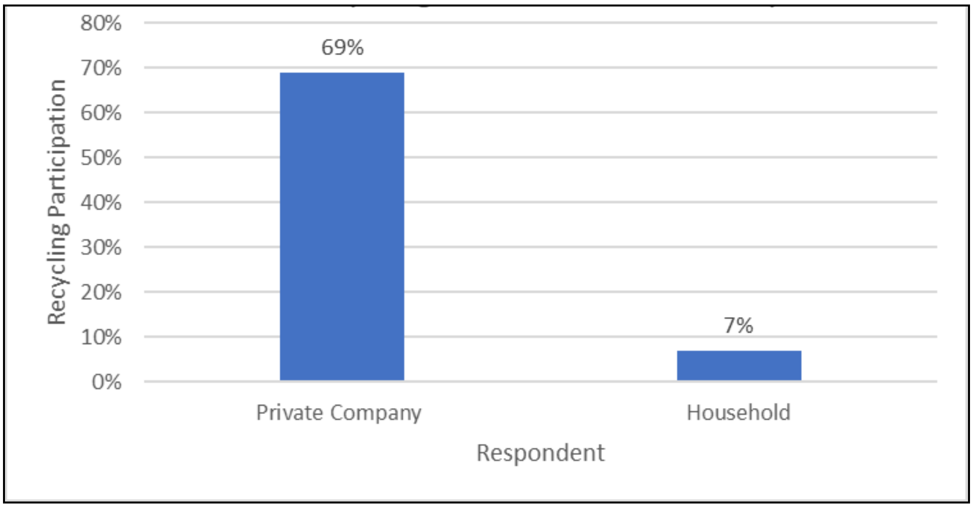

Figure 4.13: Recycling participation in the study area

Whilst the majority of participants prefer to landfill waste, recyclers have no access to waste discarded at landfill sites. The low supply of e-waste for recycling presents a challenge. To enhance recycling behaviour, informal recyclers must be empowered with resources and the intergrated waste management approach must be accelerated.

Figure 4.14 demonstrates how plastic from electoral cables is recovered in one of the recycling facilities. Plastic from cables was stripped, shredded and ground for reuse in the plastic manufacturing process as shown in Figure 4.14.

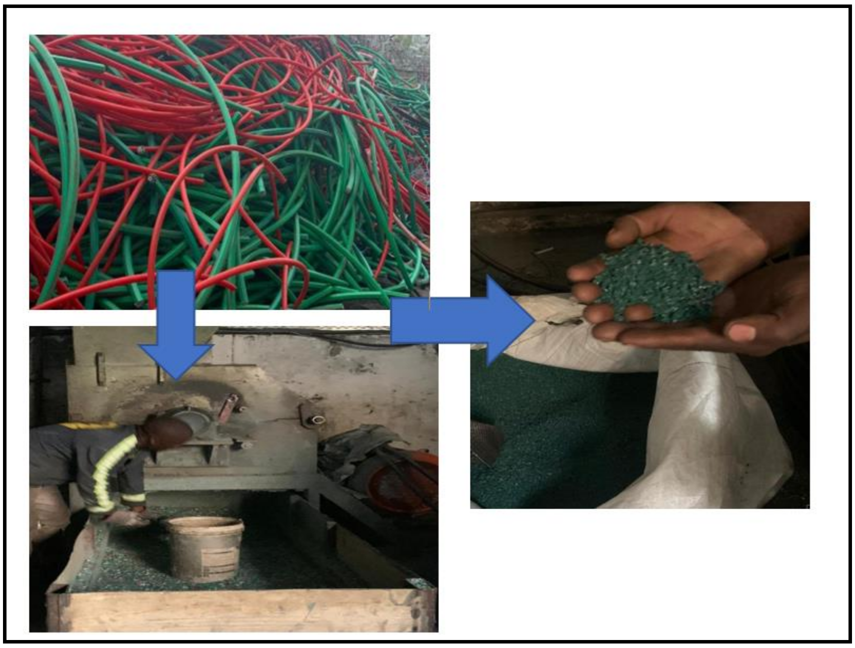

Figure 4.14: Plastic recovery process
(Source: Mkhwanazi, 2019)

Challenges related with recycling/recovery are low revenue from the recycling business as well as high transport / logistical costs associated with collection of e-waste. For this reason, most recycling facilities conduct secondary refurbishment business where they can generate more revenue through selling of second-hand electronic appliances/equipment such as laptops. Figure 4.15 shows some of the fabricated laptops in the Hillcrest recycling facility that participated in the study. Once fabricated, the laptops are sold as second-hand goods.

Figure 4.15: Computers and laptops refurbished in one of the e-waste recycling centres in Hillcrest.
(Source: Mkhwanazi, 2019)

Figure 4.16 is a summary of the data from the 2018 SAWIC report showing the type of e-waste recycled for the period of 2017. Mixed and ICT equipment was the most recycled. This also correlated with the results in the study were ICT is widely recycled.

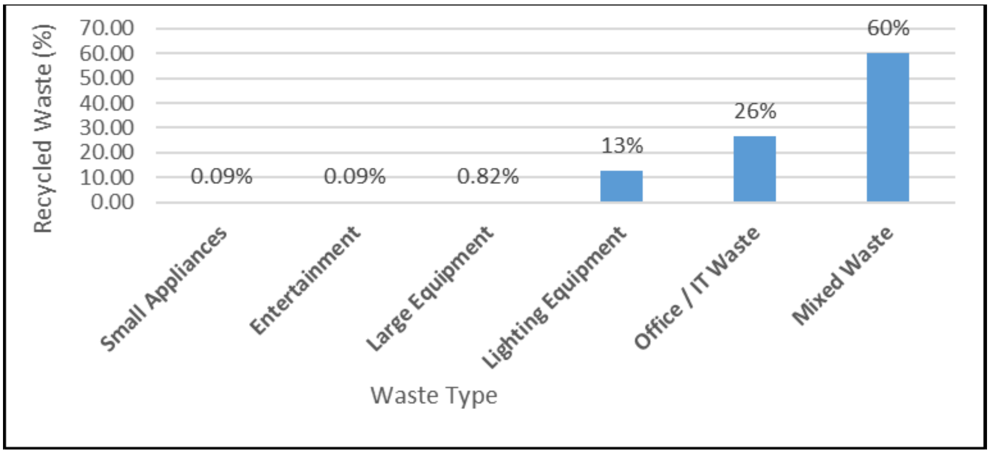

Figure 4.16: Recycling Material
(Source: The South African Waste Report, 2018)

Woolworths, Pick n Pay, Incredible Connection, and Makro are some of the well-known retail shops that provide a convenient service to their customers to drop off their unwanted electronic waste for proper treatment and recycling. However, the low recycling rates highlights the low level of awareness regarding these services.

Figure 4.17: E-waste collection at retail and commercial sites.
(Source: Mkhwanazi, 2019)

Figure 4.17 shows examples of the drop off containers outside some of the retail shops in eThekwini Municipality. Once full, containers are collected by recyclers for further treatment and recycling. Pick n Pay generally collects ink cartridges, light bulbs, plastic containers and used batteries. eWASA also has over 100 reputable companies across the country that provide services of e-waste recycling. Within the study area there is, however, a shortage of these companies, with only five known sites, and the majority of the recyclers are located in the main centre of e-waste recycling, in Gauteng province.

Informal recyclers highlighted that there is no single source of e-waste as such they spend time searching for e-waste to recover. It can be found anywhere where there is waste including households, landfill sites and illegal dump areas. Other equipment of interest to the recyclers are printed circuit boards, cables, copper as shown in Figure 4.18.

Figure 4.18: Recovery of valuable materials from e-waste
(Source: Mkhwanazi, 2019)

For informal recyclers, waste is collected and transported then dismantled to recover precious metals. The recovery method could be acid usage or open burning depending on the waste being handled. Figure 4.19 demonstrates the cables that were being burnt to recover copper using open fire burning, resulting in release of toxic emission and possible residue contamination in the area.

Figure 4.19: Open fire burning of cables at informal recycling centre in Umgeni Road, eThekwini
(Source: Mkhwanazi, 2019)

4.2.11 Disposal of e-waste in the study area

The largest percentage (41.2%) of household participants dispose of e-waste together with other general waste and less only 20% of them directed their e-waste for recycling (formally or informally) purposes. On the other hand, nearly 22% of respondents do not discard of their broken appliances, while about 12% dump it illegally in open areas. Nearly 4% of respondents did not respond to this question. The high percentage of households that dispose of e-waste together with general waste suggests they were either unaware of the prohibition or they have no alternative options but to dispose of e-waste as part of domestic waste.

Figure 4.20 illustrates a comparison between industry and households on e-waste management practises. The majority of industries (67%) recycle e-waste whereas the common practise for household participants was disposal or storage (65%). Industries were more aware of legal requirements and actually comply. High recycling rates by industry may be influenced by strict governance and due diligence procedures. The results were comparable to the awareness issues which illustrates that household generally do not know enough about correct e-waste disposal nor about the risk of poorly managed waste.

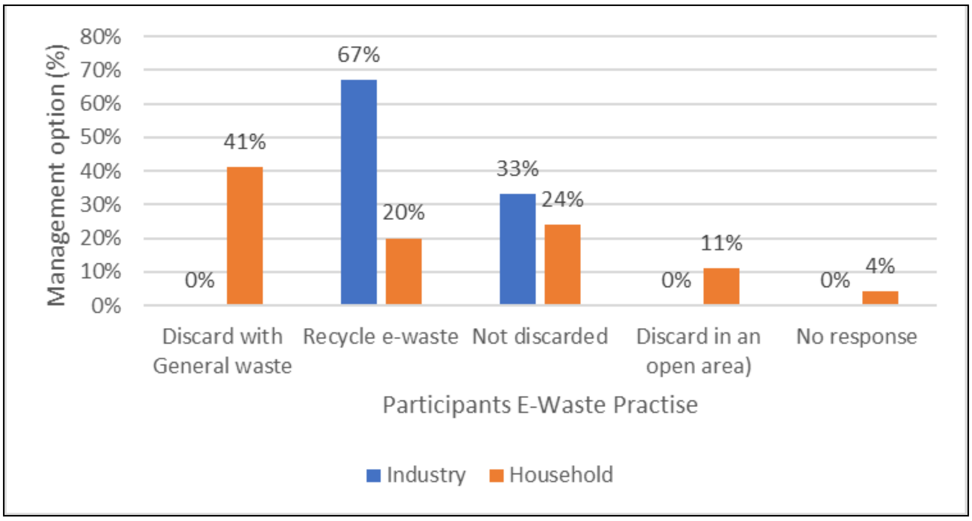

Figure 4.20: E-waste disposal practises in the study area

The 2013 norms and standards for disposal of waste to landfill prohibits landfil disposal of flourescent lamps. Industry complied with the stautory requirements and only recycle their flourescent. However, only 1% of household respondents recycle their flourescent lamps and the majority (99%) dispose of waste in a way that it is then directed to landfill sites for disposal, as shown in Figure 4.21.

Figure 4.21 E-Waste disposal practises by residents in the study area
(Source: Mkhwanazi, 2019)

Further analysis of the type of waste and management options showed that respondents generally disposed of their e-waste (36%), while 26% is repaired and only 4% is sold and invalid responses was 10%.

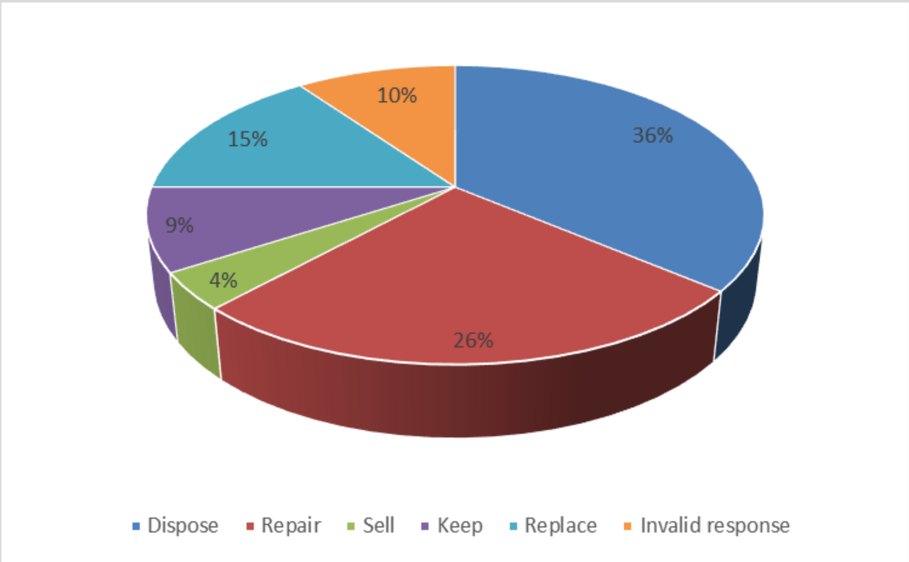

Figure 4.22: E-waste management practises in the study area

Average respondents prefer to dispose or replace broken and unwanted electronic appliances (51%), as shown in Figure 4.22. A lesser percentage of respondents actually conduct repairs (26%). A very small percentage sell their e-waste (4%). The results suggest that a behaviour of consume and discard is still dominant in the study area. This pattern of consume and discard is not sound environmental practise and is unsustainable especially as most waste ends up in landfill sites or discarded in illegal dump sites. More education and awareness around the environmental and health risks of such practises may influence consumers to practise safe disposal and consider recycling.

4.3 Role of informal recyclers in e-waste management

Research showed that informal recyclers, to a certain degree act as a source of e-waste for formal recyclers, though at a very small scale (<10%). Formal recyclers perceptions of the role of informal recyclers indicate that over 60% of formal recycler recognised informal recyclers as positive contributors to the management of e-waste. The perception of the remaining 40% is not known, perhaps it may be owing to concerns over known poor practises applied by the informal recyclers such as improper disposal of waste after recovering precious materials. Nonetheless, extensive research has shown that waste recycling is a profitable business with less expertise required than in other businesses, so many have found a livelihood in this work (Umair, Bjorklund, Petersen, 2015; Dias *et al.,* 2018; Rodseth *et al.,* 2018).

One of the informal recyclers reported that, in their experience, the public does not want to discard old and unused electrical appliances due to perceived value; plans to repair and in most cases prefers to keep a spare appliance (D. Khumalo, personal communication, September 16, 2019). As such the waste pickers close that gap as they move door to door seeking old equipment.

Informal recyclers collect, dismantle and recover most waste containing precious materials (J. Zulu, personal communication, September 16, 2020). The most sought after, was waste containing copper due to its high selling value. CRT boards, broken ICT equipment, and big electronic cables were most observed during the field visit at the informal recycler's facilities. At the time of the interview, informal recyclers, who were a small group of about eight young men, highlighted the financial benefit from recycling activities and confirmed that this as their formal employment (K. Zuma and R. Khumalo personal communication, September 16, 2020). Once waste is sold, monies are split amongst the group and at times they take turns to get paid. At the time of the interviews, informal waste collectors advised that the payment rates were approximately R85/kg for copper, R50/kg for steel, R11/kg for aluminium, R2.50/kg for plastic and R1.80/kg for subgrade metals. On a good day they are able to earn approximately R300 (J. Zulu, personal communication, September 16, 2020).

When one informal recycler was probed about challenges that they face, he revealed that not being allowed to operate freely was the biggest challenge. "This is because our activities are considered as illegal, so even when the public wants to bring their waste, it is unsafe as they may get penalties and fines from eThekwini Municipality Metro police for illegally dumping waste even if it's recyclables" (K. Mbatha personal communication, September 16, 2020). Secondary to legalising of the informal recycling was, access to land for sorting and storage. Sorting and storage areas are not allocated to informal recyclers. South Africa's old waste management system did not recognise informal recyclers and as such they are not yet integrated. Access to facilities such as land, transport, and equipment as well as a permit system for informal recyclers will greatly advance the recovery and recycling of waste. However, the waste new strategy acknowledges that both formal and informal waste sectors have defined roles and opportunities to accelerate and improve waste recycling in the study area.

4.4 Legislation and policies regarding e-waste management in eThekwini Municipality

To understand eThekwini Municipality's policies and plans in ensuring compliance with current and future legislation relating to e-waste, the researcher evaluated waste policies, eThekwini bylaws and conducted interviews with an eThekwini Municipality Solid Waste Management team. This section briefly explains the outcome of the discussions, particularly the legal frameworks that govern waste management within eThekwini Municipality.

E-waste is pre-classified as hazardous waste, in terms of waste classification regulation. As such its storage, disposal and recycling must comply with requirements of hazardous waste. Hazardous waste must be stored in an impermeable area. Holistically, households comply with this requirement (90%), but informal recyclers were a different case, as 85% were observed storing stripped waste on permeable surfaces. However, e-waste in its inert state does not pose risk to the environment. By pre classifying all e-waste as hazardous, the requirements of storage, recycling, and disposal kick in, though there may be no risk caused by inert electronic appliances. This should cause the legislation and policy makers to reconsider the definition and classification e-waste to accommodate inert e-waste, which is not hazardous and to avoid confusion.

Disposal of e-waste, mainly fluorescent lamps, has been prohibited since 2016 thereafter all other electronic waste will be prohibited from landfilling as from August 2021. The 2013 Waste Act regulations are aimed at diverting all e-waste from landfilling to alternative avenues. Households in the study area generally do not comply, as discussed in section 4.2.8, only 8% of household respondents indicated that they recycle their fluorescent lamps. The EPR has prescribed collection and recycling for lightbulbs is 50% of all used bulbs from consumers. The current 8% is significantly low and drastic measures are required for swift transition to a circular and sustainable waste management.

Industries participating in certain activities such as recovery and recycling of waste require a waste management license. In addition to the waste management license, facilities undertaking salvaging, collecting, sorting, storing, treating, processing or recycling/reclaiming of waste in eThekwini Municipality require a Schedule Activities Permit (SAP) (eThekwini Municipality, 2018). To ensure compliance with SAP, Health Department within eThekwini Municipality conducts regular audits and non-conforming facilities risk are identified. Research illustrates that compliance with waste management licenses is not within the jurisdiction of eThekwini Municipality.

DEFF may conduct compliance audits at any facility regarding whether it holds a waste management license or not, to ensure compliance to statutory requirements. When requested to expand about systems in place to ensure correct management of fluorescent lamps in line with the waste norms and standards, respondent indicated that eThekwini Municipality currently does not have its own facilities therefore the waste stream is managed by the generator. However, with introduction of the EPR, more solutions will be made available to the public which will include collection and recycling of waste such as fluorescent lamps from consumers. The inclusion of incentives as part of EPR will positively impact on the recycling behaviour. Literature reviewed also highlighted that economic incentives are key to the success of e-waste management and that an effective and practical waste management system (Zeng *et al.,* 2017)

Whilst there is reasonable legislation and standards to ensure environmentally sound management of e-waste, the researcher observed lack of supporting infrastructure and systems as a challenge. This is evidenced for example with the prohibition of fluorescent lamps at landfills, where the Waste Act requires the recycling yet there are no facilities available at local residential areas. The imbalances between legislation requirements and on the ground resources and infrastructure seemingly delays progress and must be prioritised for effective implementation of statutory requirements.

4.5 Awareness of e-waste issues amongst stakeholders in the study area

The participants' awareness and understanding of e-waste definition varied between household, industry and recycles. According to Figure 4.23, industry demonstrated sound knowledge and understanding of e-waste management as their responses were 100% accurate. In contrary, only an average of 40% of household respondents answered the question correctly, meaning that the majority of the public has limited awareness of what constitute e-waste. The lowest correct responses were from informal recyclers, with only 30% of the respondents who answered the question on e-waste definition correctly. The high percentage of respondents that lacked e-waste understanding correlates with the high level of non-compliance (90%) recorded in households. The results suggest that the incorrect behaviour may be associated with lack of information.

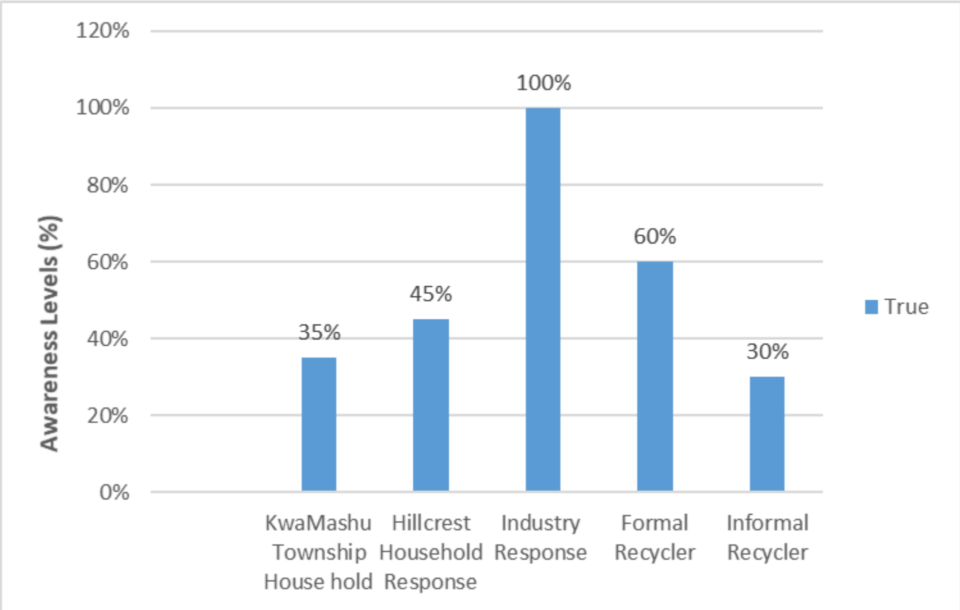

Figure 4.23: Awareness of e-waste issues amongst stakeholders in the study area

Additionally, when evaluating respondents' perceptions of environmental risks, the largest percentage of respondents (63.1%) indicated that there was no risk posed by poor management of e-waste, and a smaller percentage, 33% perceived it to pose environmental risks. The respondents' perceptions of e-waste risk explain the inappropriate and unsafe disposal practises that were observed during the research. Mercury containing waste, fluorescent lamps were observed discarded together with domestic waste. To encourage responsible management of e-waste, eThekwini Municipality needs to educate the public about responsible e-waste management and highlight environmental impacts of disposing hazardous waste in landfill sites that are not designed to manage hazardous waste.

4.6 Comparison with Literature

The overall quantities of waste generated per inhabitant in the study area is 6.77, kg per inhabitant per year. This is comparable to the waste generation rate for other developing countries such as Brazil, Mexico and Thailand of 7 kg per inhabitant, 8 kg/inhabitant, and 6 kg per inhabitant respectively (Borthakur and Govind*,* 2017). The highest waste generation per inhabitant per year based on research assessments was observed in Europe (15.6 kg per inhabitant), followed by Oceania (15.2 kg per inhabitant) based on a research conducted in 2015 and has most likely increased by now (Dias *et al.,* 2018)

CHAPTER 5: REVIEW, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter provides a conclusion of the study and outlines the extent to which the study objectives were met. The aims of this research were to evaluate e-waste management in eThekwini Municipality; provide an estimation of quantities of e-waste generated; highlight the stakeholder awareness of-waste issues; evaluate role of informal recyclers and evaluate compliance with relevant e-waste legislation. Results of the study may be applied to inform decision makers of current status and ensure appropriate interventions to achieve effective management of e-waste from storage, transportation, disposal, treatment and recycling.

5.2 Summary of findings

5.2.1 Type and sources of e-waste generated in eThekwini Municipality.

The study was limited to five types of electronic waste, namely small, large, entertainment, ICT and lighting equipment and excluded other types of e-waste such as electronic tools, toys, leisure and sports equipment, medical equipment, monitoring and control instruments, and automatic dispensers. It was found that waste from ICT was the highest generated waste stream (43%) followed by entertainment waste (28%), large equipment (15%), lighting and small appliances (14%) collectively. The results are comparable with international reports which show an upward trend on waste of Information Telecommunications and Technology.

5.2.2 Management of e-waste

EThekwini Municipality is mandated under the constitution of South Africa to manage waste, however there is currently no services provided to the public by eThekwini Municipality for collection, transportation, treatment or recycling of e-waste.

Waste management services provided to the public includes collection, transportation, treatment and recycling of for the public is in place, however, does not include e-waste.

Currently it is mainly for domestic waste, plastic, paper, cardboard, garden waste etc. Whilst there are a few drop off centres (Makro, Pick ‘n Pay, Woolworths, Incredible Connection, Apple Stores), these are often in remote areas, far from residential areas.

Research showed that most of the e-waste in household areas was stored in its inert state, indoors and posed no risk to the environment. However, the opposite was true when it comes to informal recyclers and waste scavengers who religiously dismantle e-waste to recover the precious materials. Most of the e-waste was stored outdoors, on permeable surfaces with the potential to contaminate surface water, soil and groundwater.

Informal waste recyclers main challenges emanate from poor storing, disposal practises and the subsequent ground contamination. Due to high waste disposal costs, waste generated during the recovery processes accumulates on land, and once full, the site is abandoned with heaps of waste. Once the area is used up, the cycle begins again when new space is found and continues in the same pattern, resulting in multiple dilapidated sites. This is the reason why eThekwini Metropolitan and informal recyclers are in conflict. Apart from the challenges, the informal sector plays a very critical role in the circular economy. There is an urgent need for a holistic and integrated waste management system that acknowledges informal recyclers to enhance collection and recycling. With the promulgation of the EPR, the Waste Pickers Integration Guidelines and the National Waste Strategy in 2020, it is envisaged that management of waste will gradually transition completely to integrate the informal sector and to move away from disposal towards a circular economy. Implementation of EPR regulations will accelerate eThekwini Municipality’s sustainability target of diverting 95% of its waste from landfill by 2050.

5.2.3 The role of informal recyclers in e-waste management at eThekwini Municipality

Informal recycling plays a pivotal role in diversion of waste from landfill. It provides employment opportunities, improves the quality of life for the unemployed youth and contributes to conservation of natural resources. The participants perception strongly acknowledges the role of informal recyclers. With support from the government and formal sector, this multibillion sector could create and sustain more formal and informal jobs whilst also protecting the environment. Majority of waste is still being disposed, and its diversion to alternative avenues is pertinent to unearth the great capital from waste.

5.2.4 eThekwini Municipality's policies and plans to ensure compliance with current and future legislation relating to e-waste

Part of the study was to examine compliance with the obligatory requirements for electronic waste. Monitoring and enforcement of compliance was very evident, largely directed towards industries. However, amongst the wider public it remains a challenge. One of the challenges with enforcing legislation is the lack of infrastructure and facilities. It is difficult for eThekwini Municipality to enforce compliance since there are no solutions provided to enable compliance.

5.2.5 Awareness of stakeholders of risks of e-waste

Industry and formal recycler representatives displayed sound knowledge and understanding of electronic waste and its associated risks. Similarly, their participation in recycling is relatively higher compared to households as 69 of industries participated in recycling. However, household respondents demonstrated very limited knowledge. This correlates with the established low recycling rate by household respondents (7%). The high costs associated with appropriate management of waste continue to be a factor, hence a need for more partnership to minimise the costs.

5.3 Conclusion

Radical change in technology together with increasing demand for electronical appliances has contributed to the increase in e-waste generation. Despite the confirmed growth of electronic waste, results of the study reveal that there is a lack of awareness on e-waste and its associated risks on the part of the public. eThekwini Municipality Cleansing and Solid Waste Unit offers waste education programmes to communities on topics such as littering and proper waste management, however, there is evidence of illegal disposal of e-waste. Currently, none of the programmes focus on e-waste management. This is mainly due the current gap. The informal sector is very active in the removal and recovery of electronic waste in the study area. The informal recycling sector should not operate in isolation. It must be integrated into the existing system, supported through freedom to trade and incentivized.

Regarding compliance with legislation, there is still a relatively high non-compliance associated with disposal of waste, particularly the banned fluorescent waste lamps.

With the introduction of EPR regulations, eThekwini Municipality compliance will improve because EPR places responsibility on the manufacturers and sets strict targets for waste collection, recycling, take back mechanisms. However, COVID-19 has also affected most businesses, and this may impact their capability to fund the establishments of schemes. The government may need to intervene and provide funding to promptly set up infrastructure or extend the transition period thus enabling industry to recover and fund the schemes in line with the EPR requirements.

5.4 Recommendations

The very first recommendation is for eThekwini Municipality to update the 2016 eThekwini Municipality Intergrated Waste Management. The updated Intergrated waste management plan must provide strategies, plans and systems to be established for effective management of e-waste. In the interim, the following additional initiatives are recommended:

- Prioritise education campaigns for the public, recyclers and manufactures to raise awareness on e-waste mismanagement challenges and to build partnerships to eliminate the challenges and risks contributing to mismanagement of e-waste.
- Consider dedicating at least one day a month for collection of e-waste only.
- Partner with waste producers and recyclers for the provision of e-waste collection containers in all public areas such as libraries to act as drop off centres for larger waste equipment.
- Set clear recycling and collection targets for known high risk products, particularly the ones that have not been listed under the 2020 EPR.
- Simplify the environmental permit / license application processes (national and local) to encourage more entrepreneurs in the waste economy sector. Consider having an intergrated waste license application as well as exemption.

- Lastly, enforce compliance among the public to transform the consumer behaviour. Rules on correct management of household e-waste should be incorporated into eThekwini Municipality's bylaws.

5.5 Recommendation for further studies

The research evaluated the role of informal recyclers, level of awareness and e-waste management practices during transportation, collection, recycling and disposal of e-waste at eThekwini Municipality, in KwaZulu-Natal. However, the study focused on only five categories of e-waste. Further studies could be extended to e-waste that was excluded in this research study, such as electric tools (drill, saws, sewing machine, gardening tools); toys and leisure equipment (treadmill, sports equipment); medical devices (cardiology equipment, dialysis equipment) and monitoring equipment (thermostat, smoke detector, heating regulators etc.).

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APPENDICES

Appendix 1: Research questionnaire for households

Questionnaire to be completed by representatives of eThekwini Municipality household only.

QUESTIONNAIRE NUMBER

Please mark with an X where appropriate in the box

A. DEMOGRAPHICS

1. Gender

Male	☐	Female	☐

2. Age

0 - 18	☐	18 - 65	☐	Over 65	☐

3. Number of people living in this household.

0 – 4	5 - 6	06 - 08	08 - 12	13 – 15	More than 18
☐	☐	☐	☐	☐	☐

4. Highest level of Education

No Formal Education	Primary School	High School / Grade 12	Diploma, Degree
☐	☐	☐	☐

5. Location

KwaMashu Area / Township Area	Hillcrest Area /	Other
☐	☐	☐

B. WASTE OF ELECTRICAL and ELECTRONIC EQUIPMENT- GENERATION

Please indicate number of appliances in your household (both those in use and those that broke within the space of 1 year from.

1. Small Appliances	**1 .Iron**	**1.2. Kettle**	**1.3. Stove**	**1.3 Electric pan /**	**1.4 Coffee Machine**	**1.5 Toaster**		**1.6 Hair Dryer / Hair Iron/**
Total No of appliance in use								
No of appliances broken within 1 year								
2.Entertainment Equipment	**2.1 DVD Player**	**2.2 Speaker system, /Sound bar**	**2.3 Audio System**	**2.4 TV**	**2.5 Game PlayStation**	**2.6 Earphones/Headphones**	**2.7 Remote Control**	**2.8 Projector/ Monitor**
Total No of appliance in use								
No of appliances broken within 1 year								
3. Large Equipment	**3.1 Refrigerator**	**3.2 Deep Freezer**	**3.3 Washing Machine**	**3.4 Dish Washer**	**3.5. Tumble Dryer**	**3.6 Micro-wave**	**3.7 Electrical Stove (4 Plate)**	**3.8 Air Conditioner System / Vacuum.**

Total No of appliance in use								
No of appliances broken within 1 year								
4. Lighting Equipment	**4.1 Florescent Lights**	**4.2 Light Bulb**	**4.3 Side Lamp**	**4.4 Heavy Duty Lighting Equipment**	**4.5 Other Lighting equipment**			
Total No of appliance in use								
No of appliances broken within 1 year								
Information /Telecommunications	**5.1 Printer**	**5.2. Photocopier**	**5.3. Desktop**	**5.4 . Laptop**	**5.4 . Hard drive**	**5.5. Smart Phone**	**5.6 Tablet / iPad**	**5.7. Screens**
Total No of appliance in use								
No of appliances broken within 1 year								

List others not mentioned above

a) ………………………………………….

b) ………………………………………….

c) ………………………………………….

d) ………………………………………….

1. In total, how many electronic appliances are in your entire household?

No of appliance	Select
0-5	
6-10	
11-15	
16-20	
More than 20	

2. **What do you understand by electronic waste (WEEE)? Is it any waste of electronic and electrical equipment that has no further use by the owner Choose correct answer below?**

a) True	b) False	c) Not sure

C. STORAGE DISPOSAL and TRANSPORTATION

1. **Where do you store any broken or waste electronic equipment?**

a) Inside the house (Impermeable Area)

b) Outside, on bare ground (Impermeable Area)

2. **Do you store e-waste separate from general waste?**

a) Yes	b) No

3. **How do you dispose of any of your broken electronic appliances?**

   a) With other general waste

   b) Through recycling company

   c) In an open area

   d) I don't know what to do with broken appliances

4. **How do you dispose of broken fluorescent lamps?**

   a) Open Area

   b) Together with all general waste

   c) At a drop off centre like pick 'n pay (Recycling Facility)

   d) At a central waste collection facility

   e) Not Discarded

5. **Did you know that it is illegal to dispose of fluorescent tube in the landfill as from 23 August 2016?**

1. Yes	No

6. **Select any broken appliance that you have but are struggling to dispose of**

Printer	**telephone**	**laptop**	**Desktop**	**fridge,**	**vacuum**	**washing machine**
dishwasher	**Photocopier**	**TV**	**Hair dryer**	**Hi-fi**	**coffee machine**	**iron,**
air conditioner	**plate stove**	**tumble dryer**	**video camera,**	**Cellular phone**	**Kettle**	**Video Game**

Other

1. ………………………………………….

2. ………………………………………….

6. **How is your broken and old electronic waste transported for disposal?**
   a) Private transport
   b) Formal recycling
   c) Informal recyclers
   d) Together with Municipality General Waste
   e) Kept at home

D. Awareness and Understanding of e-waste

1. **Do you think waste of electronic and electrical equipment is hazardous?**

a) Yes	**b) No**

2. **Do you think e-waste can be harmful to human health?**

a) Yes	**b) No**

3. **Do you think e-waste can be harmful to the environment if handled incorrectly?**

a) Yes	**b) No**

E. RECOMENDATIONS

1. **What are the challenges that you have with disposing the broken electronic e appliances?**
   a) I don’t know where to dispose of electronic appliances
   b) I don’t have transport to dispose of electronic appliances
   c) I would like to repair the broken appliance.

d) I don’t have any challenges.

2. How can the above challenges be overcome?

………

Appendix 2: Questionnaire for Industries

Assessment of Electronic Waste (e-waste) Management in eThekwini Municipality, Kwazulu-Natal Province, South Africa ***Questionnaire to be completed by industry representatives only***

QUESTIONNAIRE NUMBER

0	1			

A. DEMOGRAPHICS

Name	**Geographical Location:**

1. Industry Type

Manufacturing	Mining	Electrical	Marketing	Chemical	FMCG

2. Date

Number of people employed by the company.

0 – 50	51 – 100	101 – 150	151 - 200	200 – 300	More than 300

Select available equipment below and indicate total number of appliances for each one Please indicate number of appliances in your household (both those in use and those that broke within the space of 1 year from.

1. Small Appliances	1 Iron	1.2. Kettle	1.3. Stove	1.3 Electric pan /	1.4 Coffee Machine	1.5 Toaster		1.6 Hair Dryer / Hair Iron/
Total No of appliance in use								
No of appliances broken within 1 year								
2.Entertainment Equipment	2.1 DVD Player	2.2 Speaker system, /Sound bar	2.3 Audio System	2.4 TV	2.5 Game PlayStation	2.6 Earphones/ Headphones	2.7 Remote Control	2.8 Projector/ Monitor
Total No of appliance in use								
No of appliances broken within 1 year								
3. Large Equipment	3.1 Refrigerator	3.2 Deep Freezer	3.3 Washing Machine	3.4 Dish Washer	3.5. Tumble Dryer	3.6 Micro-wave	3.7 Electrical Stove (4 Plate)	3.8 Air Con-ditioner System / Vacuum.
Total No of appliance in use								
No of appliances broken within 1 year								
4. Lighting Equipment	4.1 Florescent Lights	4.2 Light Bulb	4.3 Side Lamp	4.4 Heavy Duty Lighting Equipment	4.5 Other Lighting equipment			
Total No of appliance in use								

No of appliances broken within 1 year								
Information /Telecommunications	**5.1 Printer**	**5.2. Photocopier**	**5.3. Desktop**	**5.4 . Laptop**	**5.4 . Hard drive**	**5.5. Smart Phone**	**5.6 Tablet / iPad**	**5.7. Screens**
Total No of appliance in use								
No of appliances broken within 1 year								

Indicate others not listed above.

a)

b)

c)

How do you store e-waste ?	
Inside the house (Impermeable Area)	
Outside, on bare ground (Impermeable Area)	

1. **How does the company dispose of your electronic appliances such as old telephones, copier machines, laptops, desktops?**

a) All e-waste is collected by a licenced recycling company

b) All e-waste is collected by informal recycling company

c) Has never been disposed before.

d) Disposed with general waste

1. Other………………………………………………

2. **Has the company considered any mechanisms to help reduce e-waste generation? Examples include take back mechanism, Recovery of e-waste for reprocessing, Re-use or recycling of e-waste . If yes, please explain.**

Yes	No

--

3. **What are the challenges that you have experienced with either collection, storage, transportation, recycling or disposal of e-waste within the organization?**

4. **What do you understand by electronic waste (E-WASTE)? Is it any waste of electronic and electrical equipment that has no further use by the owner Choose correct answer below?**

Yes	**No**	**Not sure**

5. **Are you aware of any health or environmental and health risks associated with poor storage, treatment or disposal of e-waste ?**

Yes	No

6. **By estimation, how many electronic appliances has the organization disposed of in the last 12 months (in Tonnes)?**

0-1	2-5	6-10	11-20	20-30	Above 50	Unknown

7. How does your organization dispose of fluorescent lamps?

1. Recycled
2. Disposed at Landfill Site
3. Not disposed

8. Is your organization aware of recycling companies that can manage e-waste within the EThekwini area?

Yes	No

9. Is your organization aware that disposal of all electronic appliances at landfill is banned as from August 2021?

Yes	No

Appendix 3: Questionnaire for eThekwini Cleansing and Solid Waste

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APPENDIX 04 QUESTIONNAIRE FOR ETHEKWINI WASTE MANAGEMENT REPRESENTATIVE

An assessment into effectiveness of WEEE management practices: A case study of EThekwini Municipality, KwaZulu-Natal

Questionnaire to be completed by EThekwini Municipality Representative

QUESTIONNAIRE NUMBER

1. **What do you understand by electronic waste (WEEE)? Is it the ff:**

Anything that is rejected that requires power or electrical connection to function.

a) True	b) False	c) Not Sure

2. **Does the municipality have a policy on WEEE?**

Yes	No

3. **What services does the municipality offer to residential areas to manage WEEE? E.g. collection, transportation.**
   a. Collection of WEEE
   b. Transportation of WEEE
   c. Recovery of WEEE
   d. None

4. **Are there any municipality facilities for managing (transport, collection or recycling) of WEEE ?**
   a) Yes
   b) No

5. **List a few municipality landfills within EThekwini municipality can accept WEEE?**
   a)
   b)
   c)
   d)
   e)

1

Appendix 4: Questionnaire for recyclers

Aspect	Response
Formal Recycler /Informal	
What is your role in terms of e-waste management? Select all that is applicable	a) Collection b) Dismantle c)Transportation d) Storage e) Recovery f) Disposal g) Treatment
Which locations does the company cover within EThekwini Municipality? Select all that is applicable	a) CBD b) Certain geographical areas c) All Areas d) Other________________________
Where is majority waste collected from?	a) Industries b) Household c) Landfill d) Informal Recyclers / e) Academic Areas/ Institution e) Other, specify
What are different types of electronic equipment noted List	a) IT and Telecommunications (Photocopier, PC, Printer, Telephone) b) Large Household equipment (Washing Machine, Microwave, TV, etc.) c) Small Household Equipment (Toaster, Iron, frying pan, vacuum

Aspect	Response
	cleaner) d) Lighting Equipment e) Electric Tools (Drill, Saws, Sewing Machine, gardening tools f) Consumer Equipment (Camera, TV, Radio Set, DVD) g) Toys and Leisure Equipment (Treadmill, sports equipment) h) Medical Devices (Cardiology equipment, Dialysis equipment, etc.) i) Monitoring Equipment (Thermostat, smoke detector, Heating regulators etc.)
Mode of transporting waste?	a) Van b) Truck c) Small car d) No transport e) Other (specify)
How much electronic waste is collected on average per year	a) 1-10 (t) b)10-100 (t) c) 100-500 (t) a) 500- 900 (t) b) Specific---------------
Are you aware of health / environmental risks of e-waste ?	a) Yes b) No
Is protective clothing worn when necessary by employees?	a) Yes b) No
Where is waste stored	a) Designated area, impermeable

Aspect	Response
	b) Designated, permeable c) Open area
Any relationship with landfill or waste generators	a) Yes b) No
In your opinion, how do informal recyclers contribute towards e-waste management	a) Positively b) Negatively Provide Details:
What are the main challenges in terms of e-waste management (Collection, storage, transportation, treatment, or disposal)	
What policies are in place to ensure EThekwini citizens can comply with current future legislation such as current ban of disposal of fluorescent lamps and future total ban of disposal of e-waste by 2021?	
Whilst audits are undertaken at Industries, against Waste license and Scheduled activity permit, how do you ensure compliance at household level? Explain.	

Observation for Recyclers / Landfill/ Industry

Aspect	Yes	No	Comments
Is there access control to the landfill/ Recycling facility?			

Aspect	Yes	No	Comments
Is there appropriate signage at entrance			
Is e-waste separated from all other waste?			
Is waste stored in labelled bins/receptors?			
Are there any waste pickers collecting e-waste from landfill?			
Any excessive odours noted?			
Any excessive noise Observed?			
Are workers wearing protective clothing			
Is e-waste landfilled?			
Are waste pickers allowed to scavenge for waste?			
Is Storm water managed adequately?			

Appendix 5: Interview and Observation Checklist for Landfill / Recycler (Formal and Informal)

Researcher	
Landfill Site / Recycler	**a) Recycler: Formal / Informal Recycler** **b) Landfill:**
Date of Interview / Observation	

Aspect	**Response**
Formal Recycler /Informal	
What is the company's role in terms of e-waste management? Select all that is applicable	a) Collection b) Transportation c) Storage d) Recovery e) Disposal
Which locations does the company cover within EThekwini Municipality? Select all that is applicable	a) CBD b) Certain geographical areas c) All Areas
Where is majority waste collected from? Select 1 only.	a) Industries b) Household

	c) Landfill d) Dumped
What are different types of electronic equipment noted List	a) IT and Telecommunications (Photocopier, PC, Printer, Telephone) b) Large Household equipment (Washing Machine, Microwave, TV, etc.) c) Small Household Equipment (Toaster, Iron, frying pan, vacuum cleaner) d) Lighting Equipment e) Electric Tools (Drill, Saws, Sewing Machine, gardening tools f) Consumer Equipment (Camera, TV, Radio Set, DVD) g) Toys and Leisure Equipment (Treadmill, sports equipment) h) Medical Devices (Cardiology equipment, Dialysis equipment, etc.) i) Monitoring Equipment (Thermostat, smoke detector, Heating regulators etc.)
Mode of transporting waste?	a) Van b) Truck c) Small car

	d) No transport e) Other (specify)
How much electronic waste is collected on average per month	a) 1-10 kg b)10-50 kg c) 50-100 kg e) Over 100 kg
Are you aware of health / environmental risks of e-waste ?	a) Yes b) No
Is protective clothing worn when necessary?	a) Yes b) No
Where is waste stored	a) Designated area, impermeable b) Designated, permeable c) Open area
Any relationship with landfill or waste generators	a) Yes b) No

In your opinion, how do informal recyclers contribute towards e-waste management	a) Positively b) Negatively Provide Details:
What are the main challenges in terms of e-waste management (Collection, storage, transportation, treatment, or disposal)	

b) Landfill / recycler Observation Checklist

Aspect	**Yes**	**No**	**Comments**
Is there access control to the landfill?			
Is there appropriate signage at entrance			
Is e-waste separated from all other waste?			

Is waste stored in labelled bins/receptors?			
Is there a dedicated area for sorting of electronic waste?			
Are there any people collecting e-waste from landfill?			
Any excessive odours noted?			
Any excessive noise Observed?			
Are workers wearing protective clothing			
Is e-waste landfilled?			
Is e-waste treated separately?			
Is Storm water managed adequately?			

Types of e-waste Observed and Quantities/ On Records for year 2017.

No	Description of E-WASTE	Quantities
1		
2		
3		
4		

5		
6		
7		
8		
9		
10		

Appendix 6: Approval of Research by eThekwini Municipality

Pod 1, Second Floor, Intuthuko Junction, 750 Mary Thiphe Street, Umkhumbane, Cato Manor, Durban 4001.
Tel: 031 322 4513, Fax: 031 261 3405, Fax to email: 086 265 7160, Email: mile@durban.gov.za, Website: www.mile.org.za

For attention:
Chair: Research Ethics Committee
Department of Environmental Science
University of South Africa
Sunnyside
0002

25 October 2016

RE: LETTER OF SUPPORT TO MRS B MKHWANAZI, REGISTRATION NUMBER 4390-456-4 - GRANTING PERMISSION TO USE ETHEKWINI MUNICIPALITY AS A CASE STUDY

TITLE: "AN ASSESSMENT INTO THE EFFECTIVENESS OF E-WASTE MANAGEMENT PRACTICES: A CASE STUDY OF ETHEKWINI MUNICIPALITY, KWAZULU-NATAL".

We are pleased to inform you that eThekwini Municipality's Deputy Head: Durban Solid Waste and the Head: eThekwini Municipal Academy (EMA), have considered the request by Ms Bongiwe Mkhwanazi to use eThekwini Municipality as a research study site leading to the awarding of a Master of Science degree in Environmental Management.

We also wish to inform you of the acceptance of this request and hereby assure Ms Mkhwanazi of our utmost co-operation towards achieving her academic goals; the outcome which we believe will help our municipality in the long run.

In return, we stipulate as conditional, that Ms Mkhwanazi contacts MILE to present the results and recommendations of this study on completion of the study to a select audience from the city.

Wishing the student all the best in her studies.

Mr R. Abbu
Dep. Head : Durban Solid Waste
eThekwini Municipality

Dr M. Ngubane
Head: EMA
eThekwini Municipality

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Appendix 7: Editing Certificate

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EDITING CERTIFICATE

Re: **BONGIWE MKHWANAZI**
Master's dissertation: **ASSESSMENT OF ELECTRICAL WASTE (E-WASTE) MANAGEMENT IN ETHEKWINI MUNICIPALITY, KWAZULU-NATAL PROVINCE, SOUTH AFRICA**

I confirm that I have edited this dissertation and the references for clarity, language and layout. I did not edit the references. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years and supervised many master's degree dissertations during that period.

Dr Richard Steele
24 July 2021
per email

Appendix 8: Consent Letter

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CONSENT FORM

TITLE OF RESEARCH PROJECT: An assessment into management of electrical and electronic equipment waste (WEEE): A case study of EThekwini Municipality, KwaZulu-Natal.

Dear Mr/Mrs/Miss/Ms ______________________________ Date……/……./20……

NATURE AND PURPOSE OF THE STUDY

The study is focused on management of waste. The type of waste evaluated is electric and electronic equipment (WEEE) also known as e-wase. The purpose of the study is to evaluate WEEE management practices employed at EThekwini for collection, storage, transportation, disposal and recycling of WEEE. This research will focus on both industries and households.

POTENTIAL BENEFITS OF THE STUDY

- This research will assist EThekwini Municipality's Waste Management department to understand potential WEEE quantities generated.
- The reseasrch will identify challenges faced by industry, residents and recyclers when managing WEEE during collection, storage, transportation and disposal.
- It will also highlight levels of environmental awareness amongst communities on WEEE. This will guide Ethekwini Municipality on areas which require campaigns or education on WEEE.
- The research will assist the Municipality to identify levels of readiness to comply with latest and future legal WEEE management requirements.

RESEARCH PROCESSESS

Questionnaires and interview

1. The potential respondent would be introduced to the researcher (student) and assistants and brief background information on UNISA would be provided.
2. The potential respondent will be given a brief explanation on the purpose and the benefits of the study and will be informed of their rights to refuse to participate.
3. The potential respondent will be informed of the process of the survey.
4. The respondent will also be advised how data collected from the survey will be used.

5. Any potential respondent who agrees to participate in the survey would then be invited to go through the survey questionnaire with the help of the researcher (student)
6. The municipality waste manager, informal recycler and industry representative will each be interviewed by the researcher.
7. All respondents will be informed that they will remain anonymous and their information will be used only for the study.
8. After completion of the survey questionnaire, the respondent would be thanked for participating.

Observation

Where observations will take place, the following shall apply:

1. A checklist has been devised and will be utilized to make note of observations.
2. Observations will be undertaken at landfills, informal recycling facilities and at selected households.
3. The respondents (landfill workers, recyclers, and waste manager) will be introduced to the researcher (student).
4. The respondent will be given a brief explanation on the purpose and the benefits of the study.
5. During the observations, the researcher will not interfere or disturb the respondents.
6. For safety reasons, the researcher will adhere to all safety rules at landfill and industries, these include but not limited to use of personal protective equipment (PPE).
7. After the observation, the researcher will thank the municipality for the permission to access the landfill and collect data.

NOTIFICATION THAT PHOTOGRAPHIC MATERIAL WILL BE REQUIRED

The researcher hereby notifies survey participants that if deemed necessary, photographic evidence may be captured with camera.

CONFIDENTIALITY

All information received from participants will be used responsibly and treated with highest confidentiality. Names of industries or participants will not be disclosed or published.

STUDENT INFORMATION
Bongiwe Mkhwanazi
Department of Environmental Sciences
Cell: 0764822345
E-mail: bongiwe.zulu1@gmail.com

SUPERVISOR INFORMATION

Tshimbana, Tsakani
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CONSENT

I, the undersigned,…………………………………………………………………… (full name) have read the above information relating to the project and have also heard the verbal version, and declare that I understand it. I have been afforded the opportunity to discuss relevant aspects of the project with the project leader, and hereby declare that I agree voluntarily to participate in the project.

I indemnify the university and any employee or student of the university against any liability that I may incur during the course of the project.

I further undertake to make no claim against the university in respect of damages to my person or reputation that may be incurred as a result of the project/trial or through the fault of other participants, unless resulting from negligence on the part of the university, its employees or students.

I have received a signed copy of this consent form.

Signature of participant: ....

Signed at …………………………………… on ……………………………………

WITHNESSES

1 ....

2 ....