RECYCLING BIODEGRADABLE WASTE AS A WAY TO COMBAT POOR SOLID WASTE MANAGEMENT IN LUBUMBASHI, DEMOCRATIC REPUBLIC OF THE CONGO

by

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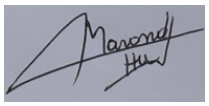
Declaration

I, Bukoko Pacy Marondji, declare that the contents of this dissertation represent my own unaided work, and that the dissertation has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed:  **Date: 20/11/2023**

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Abstract

Waste management is a social, economic and environmental problem faced by the world and all African countries. Poor waste management contributes to air pollution, climate change and directly affects many ecosystems and species, including human beings. Thus, this study sought to explore the potential of managing solid waste through composting to promote sustainable environmental management and agriculture in Lubumbashi, the Democratic Republic of the Congo (DRC). The intention was to apply the concept of circular economy which is underpinned by turning waste into other useful forms that provide solutions to human and environmental problems. For this study a mixed-method research design was adopted that included field observations, qualitative and quantitative research methods. Interviews, and waste weighing were used to collect the data where 162 households participated in the interviews and 15 participated in the waste-weighing exercise. Households were grouped into two categories depending on where they were located, whether it was a formal settlement (colonial) or informal settlement. The unit of analysis in this research was the household. Data analysis was done using the IBM Statistical Package for Social Sciences (IBM SPSS) and Microsoft Excel 2022, Version 16.

Results from the study showed that there is a need for attention and urgent action to address the poor waste management in Lubumbashi, DRC. When talking about the management of waste in the city, the practice is non-existent. The common mode of waste treatment around the city is burning and disposal of waste in open dumps. There are a few informal and formal waste pickers; they pick up and dump the waste on open dumps, which is not sustainable. Only a few of the respondents indicated that they used biodegradable waste as organic fertilizers, while the majority just wanted their waste to be taken away as it smelt bad, attracted flies and rodents. There was no attempt to raise awareness of sustainable waste management and most of the respondents were interested in attending such training. Furthermore, officials working in the department of environmental and waste management were from different backgrounds namely economists and lawyers. It was also observed that policies to regulate waste management in the city were not implemented and the population was not aware of any. With regard to the respondents' location, respondents in the formal settlements had access to many (formal and informal) waste pickers while those in informal settlements, had only few informal waste pickers. This was due to the socio-economic situation and road infrastructure.

It was found that the average household in Lubumbashi generates 6.797333333kg **(**0.006797333 ton) of compostable materials per week, which represents 141 840.55 tons of compostable waste that goes to the open dumps annually from 434 731.00 households in

Lubumbashi. This means that 9 219,6 tons of methane gas is released into the atmosphere from disposing compostable waste in open dumps in Lubumbashi, DRC annually. This could have a huge negative impact on human health and the environment if not managed sustainably.

Keywords*: Circular Economy, Compostable waste, Environmental Management, Green economy, Household, Waste Management**.***

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Dedication

This work is dedicated to my father Jean BUKOKO KATATA for his continuous support and believing in me.

Abbreviations and Acronyms

Abbreviation/Acronym	
ACEA	African Circular Economy Alliance
CE	Circular Economy
DRC	Democratic Republic of Congo
EM	Environmental Management
ISWM	Integrated Solid Waste Management
KPMG	A financial accounting firm whose individual letters stand for Klynveld, Peat, Marwick and Goerdele
MSMEs	Micro, small- and medium-sized enterprises
MSW	Municipal Solid Waste
ODs	Open dumpsters
3Rs	Reduce, Reuse and Recycle
SD	Sustainable Development
UN SDG	United Nations Sustainable Development Goal
WM	Waste Management

Glossary

Terms and concepts

Biodegradable Waste	Biodegradable waste is waste from once living organisms that can be broken down and recycled by decomposers or natural processes (Science World, 2022).
Composting	It is the natural process of recycling organic matter, such as leaves and food scraps, into a valuable fertiliser that can enrich soil and plants (Ayilara et al., 2020)
Compostable wastes/materials	Materials providing the earth with nutrients once the product has been completely broken down (Ivana, 2020).
Circular Economy	It is an alternative to a traditional linear economy (make, use, dispose) in which resources are kept in use as long as possible, extracts the maximum value from them while in use, then recovers and regenerates products and materials at the end of each service life/life cycle (Michelini et al*.,* 2017).
Environment	It is defined as the air, water and land in or on which people, animals and plants live (UNEP, 2021).
Environmental management	It is a discipline that focuses on finding solution to problems resulting from the interactions between humans and their environment (Alshuwaikhat & Abubakar, 2008).
Green business	It is a business which implements sustainable consumption and production practices to address environmental concerns (Mondal, Singh, & Gupta, 2023).
Household	It is defined as a social unit composed of those living together in the same dwelling (Merriam-Webster, 2021).

CHAPTER 1: INTRODUCTION

1.1. Background

Waste management (WM) remains a universal environmental issue that matters to everyone as waste-generation rates are rising throughout the world (Ijasz, 2018). Waste is a by-product of human activities that is discarded because it is deemed no longer to be useful (McDougall et al*.,* 2008).

The world generates 2.01 billion tons of municipal solid waste annually (Vu, 2019). Additionally, recent studies have revealed that the increase in municipal solid waste generation will rise by 70%, from 2.01 billion tons in 2016 to 3.40 billion tons in 2050, owing to the rapid population growth and urbanisation (Vu, 2019). Furthermore, residents in developing countries, especially in the poor urban areas, are more severely impacted by poor WM practices and over 90% of their waste is regularly discarded in unregulated dumps or openly burned (Vu, 2019). These practices have serious health, safety and environmental consequences, including serving as a breeding ground for disease vectors and contributing to global climate change through methane gas generation (Poddar, De, & Sarkar*,* 2020).

In Africa, including other developing regions in the world, waste-generation is driven by population growth, rapid urbanisation, a growing middle class, changing consumption habits and production patterns (Debrah, Teye, & Dinis*,* 2022; UN-Habitat, n.d. a). WM remains a big challenge worldwide including in Africa (Aluko et al*.,* 2022). Godfrey et al*.* (2019) presented the state of waste in Africa as follows: the available data show that in 2012, 125 million tonnes per annum of municipal solid waste (MSW) was produced in Africa, of which 81 million tonnes (65%) was from sub-Saharan Africa (Godfrey et al*.,* 2019). According to Godfrey et al*.* (2019), this is expected to almost double to 244 million tonnes per year by 2025. However, the Author continued, with an average waste-collection rate of only 55% (68 million tonnes), approximately half of all MSW produced in Africa remains within our cities and towns, dumped onto walkways, in open fields and in storm water drains and rivers (Godfrey et al*.,* 2019).

Previous studies by Mangenda et al*.* (2014), Mpinda, et al*.* (2017) and Jolie (2021) reveal that in the DRC, just as in other African countries, WM is still a challenge including in Lubumbashi. This is partly the result of a few factors such as poor local government capacity to deal with the waste problem (Mpinda et al*.,* 2017), the lack of awareness training, lack of collaboration between private and public sectors and a poor attitude towards WM. Therefore, as solid WM becomes a national concern, more research is needed to help us understand the dynamics of the waste problem with the aim of proffering recommendations to help solve the problem of WM in the city and the country.

Managing waste and adopting circular economy (CE) practices are in their infancy in Lubumbashi and the DRC generally. It is a common practice in Lubumbashi that private companies only collect waste and take it to dumping sites elsewhere around the city. At a national level, the DRC has shown interest

in joining the African Circular Economy Alliance (ACEA) that has five African countries as members (ACEA, 2021). This might be a step towards adopting and implementing CE in the country.

Poor environmental conditions result in public health problems (Aluko et al*.,* 2022; UN-Habitat, n.d. b). Therefore, better WM is a way of improving sanitation and environmental sustainability in the city. Promoting the concept of CE by turning organic waste into compost for use in agricultural production is one way of achieving this objective. This is what this study sought to explore.

1.2. Statement of research problem

WM is a big challenge in Lubumbashi, DRC (Mpinda et al*.,* 2016), the root causes of the WM problem in Lubumbashi can be traced to mining activities, population growth and the expansion of the city without basic public services, including a poor attitude towards WM (DRC (Mpinda et al*.,* 2016), Lubumbashi is an attractive city but because of mining activities, people have moved from the surrounding areas, even from other parts of the country, looking for opportunities. This has led to urbanisation and a rapid population growth. Furthermore, the increase in the population has made it difficult to keep up with the way in which the city was planned. This has resulted in the situation of formal (colonial) and informal settlements to accommodate the huge influx of people.

The poor WM in Lubumbashi is partly the result of the lack of local government capacity to deal with the waste problem (Mukemo et al*.,* 2020). As a result of this, households and businesses are left to manage the waste generated in their homes and businesses. Yet, one often finds heaps of domestic waste scattered almost everywhere around the city, presenting both poor environmental conditions and a potential public health menace. From the CE perspective, the biodegradable component of household waste could be recycled through composting to achieve two important goals. First, composting is a practical tool for organic WM to achieve a cleaner and safe environment. Second, the recycled nutrients (compost) could then be used to support agricultural production as a better substitute for inorganic fertilisers. In Africa, CE, as a concept, is still vague (Desmond & Asamba, 2019), even though the report of the Seventeenth Session of the African Ministerial Conference on the Environment (November 2019) suggests that elements of the concept can be found in a variety of programmes being implemented on the continent. However, a fundamental challenge is to align CE-thinking with national development plans and budget processes. For example: in many African countries in general and the DRC in particular, the legal and regulatory frameworks needed to nurture circularity are still in their early stage (Desmond & Asamba, 2019; ACEA, 2021). Therefore, the intention of this study was to explore the potential of managing biodegradable waste through composting, which connects waste with agricultural activities and thus leads to the conversion of waste to wealth, while improving the sanitation of the environment.

1.3. Assumptions and Objectives of the research

The main objective of the project is to explore the potential of managing solid waste through recycling of biodegradable wastes or composting to promote sustainable environmental management and agriculture in Lubumbashi. Table 1.1 presents the assumptions and specific objectives of the study.

Table 1.1: Assumptions and specific objectives of the study

Assumptions	Specific objectives
Composting of household biodegradable waste contributes to improving poor solid waste management	To explore composting of household biodegradable waste as an alternative approach to waste management
It is assumed that biodegradable waste constitutes a significant proportion of household waste in Lubumbashi	To assess the quantities of biodegradable waste generated by an average household in Lubumbashi
There is very little capacity to manage waste	To understand common modes of treatment or disposal of household waste,
There are environmental/waste policies in place to deal with waste problems, but there is little awareness about these, hence ineffective implementation	To assess the environmental policies for sustainable waste management

1.4. Research questions

The following two research questions will be addressed in this study:

Research Question 1: Is waste management a problem in Lubumbashi, DRC?

Research Question 2: Can composting biodegradable wastes contribute towards improving poor solid waste management in Lubumbashi?

1.5. Localisation of the study area

1.5.1. The study area

The research was conducted in Lubumbashi located at Latitude 11˚41' South and Longitude 27˚29'East. Lubumbashi is the capital of the Haut-Katanga province, south-east of the Democratic Republic of Congo (DRC). The city is less than 90 km away from the Zambian border. In terms of weather and climatic conditions, Lubumbashi experiences a rainy season from November to March. A rainy season spans about 185 days, while the dry season covers about 118 days (May to September). In between,

the rainy and dry seasons is a transition period which lasts about 62 days (October and April) (Kasongo et al., 2013). The annual average temperature is 20° C, with October and November being the hottest months during the year. The average daily maximum temperature during the hottest months stands at about of 32° C and 23° C is a monthly average temperature. On the other hand, July is the coldest month with the average daily minimum of 8° C, with 17° C being the average monthly temperature (Useni et al., 2019).

On average, January is the wettest month with 261 mm of precipitation and the average amount of annual precipitation is 1 103 mm (World Weather and Climate Information, 2023). Furthermore, the soil cover is of the ferralitic type with a water pH fluctuating around 5.2. These soils are also characterised by a coarse sandy clay texture and are poor in organic matter (Kasongo et al., 2013). The city's vegetation used to be characterised by the miombo-type clear forest (Useni et al., 2019). Currently, the city is surrounded by anthropised vegetation resulting from the degradation of miombo woodland into tree savannah, then shrub and finally grass (Useni et al., 2022).

Founded in 1910 as a base for mining local resources, Lubumbashi city bears the nickname 'the capital of copper (Useni et al., 2022). It is the second biggest industrial and commercial centre of the DRC. The choice of Lubumbashi as the study area was due to the facts that the city is fast growing and waste management become difficult; waste in seen almost everywhere around the city including downtown. There is a hierarchy of public services involved in waste and environmental management in Lubumbashi, starting with commissioner at regional level, then the mayor at the city level, with subdivisions in each municipality. The city is administratively split into seven municipalities namely, Annexe, Katuba, Kampemba, Kamalondo, Kenya, Lubumbashi and Ruashi (Useni et al., 2022).

With regard to spatial planning, the Lubumbashi municipality, which is the study area, is made up of informal settlements and formal settlements called districts. For this study, we chose the three informal settlements (CRAA, Kalubwe, Gambela) and three formal settlements (Baudin, Makutano, Kiwele) based on criteria such as infrastructure, population attitude, waste generation rate and income. Solid WM in Lubumbashi is still a problem as it is very rudimentary and unsystematic (Mpinda et al*.,* 2017).

The study area is illustrated in Figure 1.1.

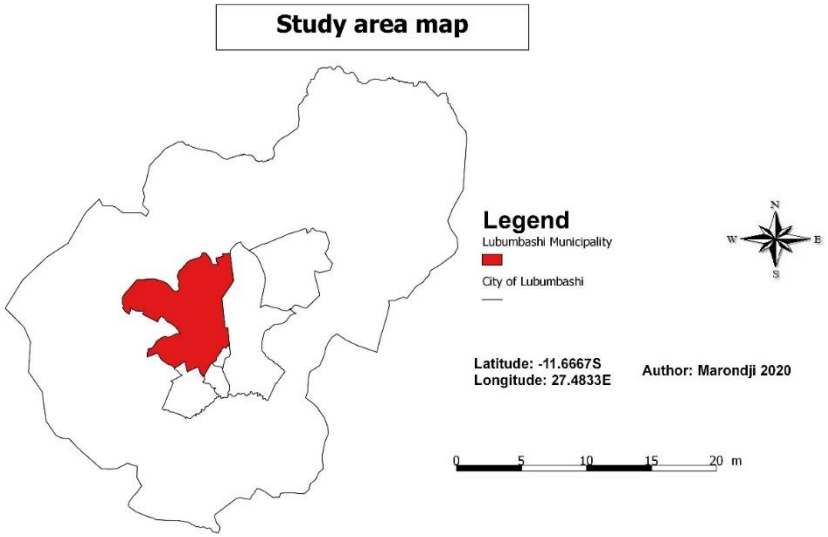

Figure 1.1. Study area map

1.5.2. Demographic characteristics of the study area

Lubumbashi is a diversified city; made up of population coming from all over the country, including foreigners. There has been no recent population census in the DRC. Therefore, in the last 25 years, Lubumbashi's population has grown from 963,000 to 2,608,386 people. The most widely spoken languages in Lubumbashi are French and Swahili. As a result of urbanisation, Lubumbashi's population has increased rapidly, and the generation of waste has increased too, leading to waste being scattered everywhere (Mukemo et al., 2020). It emerged that the government's capacity to deal with household WM remains poor and challenging (Mukemo et al., 2020).

1.6. Significance of the research

The study sought to explore the potential of managing solid waste through composting to promote sustainable environmental management and agriculture in Lubumbashi. This goes alongside the concept of CE which is underpinned by turning waste into other useful forms that provide solutions to aspects of human and environmental problems (Iacovidou, et al., 2021). This is in line with the objective of environmental management which, as a discipline, focuses on finding solutions to problems resulting from the interactions between humans and their environment.

In the DRC, the WM sector is regulated by the Ministry of the Environment and Sustainable Development at national level; regional level, it is managed by the commissioner of the environment; and at local level, by the department of environment within the municipality. Regarding WM policies in the DRC, Section 4 of the environmental official journal, published in 2011, presented WM policies in its article 56. It states that the state, the province and the decentralised territorial entity ensure the rational management of waste so as to preserve the quality of the environment and health. This aligns

with the UN SDG agenda (Goal 3: ensure healthy lives and promote well-being for all ages; Goal 12: responsible consumption and production; Goal 15: life on land; Goal 13: climate action) and mission of the DRC Ministry of the Environment and Sustainable Development, which is to protect and preserve the environment, thereby improving the quality of life for current and future generations. Environmentally and socio-economically, the project brought some benefits as discussed above.

The outlines of the dissertation are as follows:

Chapter 1 provides the introduction and describes the main objectives of the research while also presenting the research questions.
Chapter 2 presents the literature review to give an idea of what other authors have published on composting and waste management.
Chapter 3 of the dissertation captures the methodology used to answer the research questions, Chapter 4 provides the results and discussion.
Chapter 5 reflects on the study and draws conclusions, also providing some recommendations.

The literature relevant to this study will be reviewed in the next chapter.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This section covers topics around waste generation and waste management in the developing country including African context, circular economy and sustainable development, composting and agriculture. Waste management (WM) challenges are a global problem. In recent years, the rapid population growth and urbanisation (more people moving to bigger cities) in Lubumbashi, in the Democratic Republic of Congo (DRC), have led to an increase in waste generation, while the management thereof becomes difficult. To tackle the problem, Integrated Solid Waste Management (ISWM) has been proposed as a sustainable method of managing solid waste (McDougall et al., 2008). Thus, a circular economy (CE) appears to have become the right tool to support this cause. In recent years, the concept of CE has gained significant importance among businesses, policymakers and researchers according to KPMG and the Fight Food Waste Cooperative Research Centre report (KPMG & FFWCRC, 2020), Desmond and Asambaa (2019) and ACEA (2021). Furthermore, they all agreed and discussed how the world can adopt this principle to solve WM problems.

KPMG and the Fight Food Waste Cooperative Research Centre are private entities that come together to find ways to facilitate the transition from a linear method to CE. They argue that the concept of CE is not new. They highlight the opportunities that exist in managing food waste through CE practices. In the same report, a case study in Australia has shed light on Australian companies that are putting CE into action to fight food waste and how they are benefiting from new products, new markets and new business models. The Woolworths Supermarkets' case study in Australia shows that through CE-thinking, large quantities of discarded bread have been recovered from which beer was made through recycling processes (KPMG & FFWCRC, 2020).

In 2017, the ACEA was launched with a mission to spur on Africa's transition to a CE that delivers economic growth, green jobs and positive environmental outcomes (ACEA, 2021). To achieve this mission, the 2021 ACEA report identified the following enablers that could assist African governments to promote circularity on the continent such as: supportive policies, business development services, increasing relevant data availability. Alongside information to support knowledgeable policy-making and investment decisions, including encouraging increased access to technology to facilitate consumer use of CE solutions, growing access to pertinent financial services for CE enterprises and access to sustainable markets (ACEA, 2021).

On a positive note, Desmond and Asanda (2019), spoke of the available case studies on CE practices in African countries such as Ghana, Kenya and South Africa, even though these remain hidden as they have yet to be disseminated through academic publications. There have been proposed approaches in addressing solid waste in Africa, first for the private and public sectors of civic society; second, for

everybody focusing on how to reduce and make better use of waste. These approaches are presented in Figure 2.1 (first approach) & Figure 2.2 (second approach). In Lubumbashi, like other African cities, WM remains a problem. Lubumbashi produces above the 1 kg per day per person benchmark of solid waste generation (Mpinda et al., 2016).

Figure 2.1: A model of private-public partnership in waste management (Godfrey, 2019)

Figure 2.1 presents an approach to dealing with solid waste in Africa, which involves the private and public sectors of civic society. There are strong institutions that develop policies that are implemented, building capacity and awareness around WM by civic society and improving partnerships between public and private sectors to implement technological solutions that promote sustainable WM in Africa.

Figure 2.2: Multi-stakeholder approach to waste management (Godfrey, 2019)

Additionally, Figure 2.2 presents the approach involving everybody to focus on how to reduce and make better use of waste in five steps, namely, (1) prevent waste when shopping, (2) repair and reuse, (3) sort, recycle and compost, (4) turn waste into energy, and (5) send as little as possible to the landfill.

2.2. Circular economy and sustainable development

The principle of CE and sustainable development are discussed below. The United Nations Environment Programme (UNEP) noted in 2016 that CE-thinking was becoming popular and recognised it as one of the ways towards achieving the sustainable development goals.

2.2.1 Circularity and sustainability principles

The ACEA (2021) defines CE as an economy in which products and materials are not just disposed of, instead they are recycled, repaired and reused. The CE popularly used definition is a green economic system that replaces the end-of-life concept or products with reducing or reusing, recycling and recovering materials in the businesses production, distribution and consumption processes (Kirchherr, Reike & Hekkert, 2017: 229). It aims at accomplishing sustainable development, thus concurrently building environmental quality, economic prosperity and social equity to benefit the current and future generations (Kirchherr, Reike & Hekkert, 2017: 229). The principle of CE is rapidly gaining traction as a new model for sustainable growth (Awan, Sroufe, & Shahbaz,2021; Paladini, Saha, & Pierron, 2021).

According to the United Nations Environment Assembly (UNEA) final report (2019), the concept of CE has been developed by drawing on disciplines such as ecology, economics, engineering, design and business. CE has moved through three major stages, namely, (1) a linear economy which is from the industrial revolution and overexploitation of resources; (2) the awakening of the first theoretical and practical initiatives of industrial ecology and industrial revolution, where waste and resources could continuously be circulated and an interest for a greener economy emerged in this stage; (3) the final stage began in early1990s when, following Boulding's study, coined the term 'circular economy' to describe the feasibility of taking into account environmental awareness in economic flows by closing industrial loops (Prieto-Sandoval, Jaca, & Ormazabal, 2018).

In a PWC report (2021), titled 'the road to circularity: why a circular economy is becoming the new normal', the concept of CE is centred around three pillars, namely, prioritising renewable energy, maximising product use and recovering by-products and waste. In the CE world, it is believed that nothing is wasted, and everything can become a resource. This is proposed to operationalise the sustainable development principle. The UNEP recognised the role of CE to achieve sustainable development in 2016 (Fusco & Nocca, 2019).

In addition, the shift from the linear economy to a CE represents a great contribution to achieving the Sustainable Development Goals (SDGs no.3, 12) about responsible consumption and production (Rodić & Wilson, 2017) by 2030. Thus, reduce global food waste by half per capita at retail and consumer levels. Also reduce food losses along production and supply chains, including post-harvest losses (target 12.3); by 2030, substantially reduces waste generation through prevention, reduction, recycling and reuse (target 12.5) (Rodić & Wilson, 2017). The CE concept is closer to slowing the depletion of natural resources, reducing environmental damage caused by the extraction and processing of virgin materials, and decreasing pollution from the processing, use and end-of-life of materials (Rodić & Wilson, 2017).

Therefore, there are three conceptual ways of thinking about sustainable WM, such as Reduce, Reuse and Recycle (the 3Rs) which can be done at home. From the 3Rs' waste management practices, the principles of circularity get promoted through reuse. A CE mode of thinking is principally aimed at encouraging reuse of resources, hence recycling for reuse to reduce resource exploitation and environmental pollution (Ghisellini, Cialani, & Ulgiati, 2016). Moving towards a circular economy is critical from both environmental perspectives and provides the basis for a sustainable and competitive economy while reducing pressure on natural resources.

2.2.2 Waste composting and sustainable agriculture

This section focuses on one of the ways to manage biodegradable solid waste called composting and how it contributes to sustainable agriculture and improves environmental conditions. Additionally, it deals with technical aspects and considerations related to composting.

According to Ngongo et al. (2014), 95% of the population growth takes place in tropical regions which lead to rapid land-use changes resulting in soil fertility being affected. However, soil fertility is influenced by land-use changes leading to soil poverty. Furthermore, the proper utilisation of soil is crucial for sustainable agriculture as well as economic development (Ngongo et al., 2014). Composting is the natural process of transforming organic matter, such as leaves and food scraps, into a valuable product called compost or organic fertiliser that can enrich soil and plants (Ayilara et al., 2020).

To simplify, composting is the turning of degradable organic wastes into soil nutrients with the aid of microorganisms. The type of waste to be considered for composting are food waste (potato peelings, apple cores, coconut husks, orange peel, cauliflower leaves and pumpkin flesh, coffee grounds and plastic-free tea bags), garden waste including branches, twigs, dead flower heads, grass cuttings, fallen leaves, fruit dropped from trees, clippings from pruning and animal dung such as manure or chicken droppings (Allan, 2023). There are different types of composting namely: cold composting (easy method but takes longer to break down), hot composting (the bin is closed to heat up till 60 degree Celsius), Tumbler composting (using a tumbler), leaf composting, worm composting (known as vermicomposting, use worms to break downs organic waste), Bokashi composting (is an anaerobic way of composting), sheet composting, trench composting(Allan, 2023). For years, composting has been practised as one among many other methods of WM such as source reduction and reuse, recycling, fermentation, composting, animal feeding, landfills, burning and land application (Abdel-Shafy & Mansour, 2018). Therefore, this practice has proven to be beneficial to environmental management in terms of sanitation and prevention of environmental degradation. Taiwo (2011) and Ayilara et al. (2020) presented some of the benefits of composting in their work: the low cost of operation, lessening environmental pollution, producing biofertilisers (compost) and soil amendments, protecting underground water from being contaminated compared to the landfill waste disposal method, and combating climate change.

Composting contributes to sustainable agriculture where compost is used as a soil amendment (organic fertiliser, see Figure 2.3). Therefore, sustainable agriculture practitioners seek to incorporate three main components in their work: (1) a healthy environment, (2) economic profitability, and (3) a social and economic equity (Kumari & Bandy, 2018). Growers, food processors, distributors, retailers, consumers, and waste managers involved in the food system have an important role in guaranteeing a sustainable agricultural system. Sustainable agricultural methods promote soil health, minimise water use and lower pollution levels on the farm (Kumari & Bandy, 2018). Thus, technical aspects to be considered when composting are a certain balance of carbon-rich materials (green-brown), aeration, water, the quality of

compostable materials (Environmental Protection Agency,2023). The above mentioned contribute to enhance soil quality and productivity that is paramount for agricultural activities and increased produce yield needed for food security as well as financial gain/economic growth.

2.2.3 Barriers/challenges and opportunities related to CE

This section presents barriers/challenges and opportunities related to CE, and more specifically composting of waste. Challenges such as: pathogen detection, low nutrient status, long duration of composting, long period of mineralization, and odour production are encountered when composting (Ayilara et al.,2020). However, Composting presents opportunities with regard to CE such green jobs creation, financial gains, environmental protection, credits offset (Hijbeek et al., 2019).

Figure 2.3: Compost (organic fertiliser)

2.3. Poor environmental management conditions and associated health hazards

According to Yoada, Chirawurah, & Adongo (2014), waste poses a threat to the environment and public health if not handled properly. Improper WM is detrimental not only to the environment but also to human health (Aluko et al., 2022). The authors also refer to the presence and proliferation of open dumpsites (ODs) around residential settlements that are associated with poor environmental health outcomes in urbanised settlements of developing countries. Thus, in urban areas indiscriminate waste dumping creates risks of diseases, flooding and environmental contamination (Godfrey et al., 2019). Research has revealed a correlation between the proximity to open dumpsites and incidence of disease (Godfrey et al., 2019). Therefore, significant economic, social and environmental impacts in Africa are caused by poor waste-collection systems, combined with uncontrolled and controlled waste dumping, often associated with open burning (Godfrey et al., 2019).

The open waste burning causes significant air pollution which has an impact on human health. Direct contact with solid waste causes different types of infections and chronic ailments, such as Tuberculosis (TB), Asthma and skin rash (Kenekar & Kenekar, 2022). In the bigger picture, pollution of the air, soil and water is caused by improper solid waste disposal while indiscriminate dumping of waste contaminates surface and ground water supplies leading to environmental and humans' health problems (Kwun Omang et al., 2021). The author further presented several harmful effects of poor solid waste management such as: waste disposed by the roadside, which is commonly seen in different parts of the world and can become the breeding ground for mosquitoes, cockroaches and rats (Kwun Omang et al., 2021). These rodents are known for spreading diseases like Malaria, Dengue and can cause food poisoning as well; they are also called vector diseases (Kwun Omang et al., 2021). Additionally, diseases like Cholera, Diarrhoea and Dysentery can result from human consumption of polluted water bodies.

Therefore, other authors added; disease-carrying pests that could affect public health on a large scale could be caused by littering and improper solid waste disposal (Kenekar & Kenekar, 2022). When referring to organic solid waste, Kenekar and Kenekar's (2022) research shows that organic waste generated by households such as food waste, kitchen waste, vegetable waste, fruit peels, paper and so forth, constitutes about 52% of the total waste. The authors further emphasised on the fact that organic waste also called biodegradable waste can undergo a fermentation process, which create a favourable environment for microbial pathogens development and growth. Thus, it may become a serious threat and cause health hazards. Experts point out that children are the most vulnerable to pollutants (WHO et al., 2021; Kenekar & Kenekar, 2022; Negative effects, 2022).

Poor waste management contributes to changing climates. Thus, extreme weather can be caused by climate change when harmful greenhouse gases such as methane, carbon dioxide, carbon monoxide and so forth, are released or created by decomposing waste, which rise up to the lower atmosphere and trap heat. Thus, the accumulation of these greenhouse gases in the atmosphere adversely causes extreme weather reactions in the form of extreme heat, drought, the rising of sea levels, storms, typhoons, amongst other climatic disasters. Furthermore, an earlier study revealed that apart from rising temperatures, the level of precipitation in the air is also drastically affected (Pacheco, et al., 2021). These impacts can be far-reaching as they are not always local. Methane and black carbon released through open waste burning are short-lived climate pollutants with strong effects on regional and global climate change (Godfrey et al., 2019).

Thus chemical, physical or biological factors in the environment can have short- or long-term negative health impacts on both people and the environment (Public Health Ontario, 2021). Ziraba, Haregu, & Mberu, (2016), discuss what the exposure means through touch, inhalation or ingestion. Understanding the risks of these hazards can help one to take action to avoid or mitigate against these risks (Open.edu.,2021). From the Environmental Health Hazards, 2021 report, Environmental health hazards

include traditional hazards such as poor sanitation and shelter as well as agricultural and industrial contamination of air, water, food and land. Additionally, coming into contact with toxic substances and pollutants from waste can lead to skin irritation and blood infections (U.N., 2022). Open dumps and landfill gases have been known to cause cancer and create respiratory and visibility problems (Etea, Girma, & Mamo, 2021). Ayilara et al. (2020), also pointed out that, apart from being unsightly, waste causes air pollution, affects freshwater bodies and soils when waste is dumped in them or transported by surface runoff into the water, as well as depletes the ozone layer when waste is burnt, thereby increasing the impact of climate change.

Waste is often improperly managed through conventional methods (Ayilara et al., 2020). Which are traditional and ordinary methods such as food donation, animal feed production, composting, wastewater treatment, burning and landfilling (Trabold, & Nair, 2018). Directly or indirectly, poor waste management affects our health and well-being in many ways. The release of methane gases contributes to climate change. Therefore, air pollutants are released into the atmosphere, freshwater sources are contaminated, crops are grown in polluted soil and fish ingest toxic chemicals which end up on our dinner plates. Improving poor environmental management conditions through composting is seen as a proper way to reduce exposure to pollution for both the environment and the people as well as mitigating the possible health risks.

2.4. Conclusion

Chapter 2 captured what other researchers have done around waste management. Topics such as CE and sustainable development, waste composting and sustainable agriculture, poor environmental management conditions and associated health hazards were explored. Thus, CE works hand-in-hand with sustainable development while composting has been proven to be one of the best methods for solid WM. It has been recommended that people can practise composting at their homes to prevent placing the burden of waste on communities. Proper waste separation should be done while composting should be produced from organic waste.

Lastly, poor WM can lead to water, air and soil pollution which has an impact on health, while the indiscriminate disposal of waste results in flooding, skin irritation, cancer and respiratory problems, amongst others. Thus, local authorities and the government should promote this practice of composting through an awareness education campaign to mitigate environmental pollution.

In the next chapter, the research design and methodology will be discussed.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

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3.1. Introduction

The purpose of this chapter is to plan the stages of the research. The study used a mixed-method research design that included field observation, qualitative and quantitative research methods. Interviews and weighing exercises were used to collect the data. Mixed method is a study approach whereby both quantitative and qualitative data are collected and analysed for the same work by researchers (Halcomb, Hickman, & Gunowa, 2015: 125-137).

A quantitative study method is the process whereby numerical data is collected and analysed (Toyon, 2023). It can be useful in finding patterns and averages, make predictions, test causal relationships and generalise results with wider populations (Toyon, 2023). A qualitative research method is defined as a market research method where open-ended and conversational communication are used to obtain data (Khan, 2014). Field observation is a qualitative research method that uses observation to gain an inside view of the community and the setting (Smart Villages, 2021). By observing what is happening and talking to people about the topic of interest or about the problem, these methods provide a deeper understanding of the problems in their (local) context. An interview is an important qualitative research method in which the researcher collects data directly from the respondents (Parveen et al., 2023). According to Parveen et al. (2023), other research methods like surveys and focus groups are mostly paired with interviews for significant results and they are always goal-orientated. They are significant in unfolding opinions, experiences, values, and various other aspects of the population under study (Parveen et al., 2023).

Data collection was done through interviews during which the researcher asked questions to respondents. The choice of this method was made to get more information on the subject matter of poor waste management (WM) in Lubumbashi. The printed questions were guide the interview.

The interviews were conducted with members from different households and WM officials from Lubumbashi municipality. On the other hand, the weighing exercise was done with selected households, affiliated clients of MarZ Compost SARL which is a waste management company based in Lubumbashi. This choice was made because of the ability of these clients to sort waste at the source as there was no available data about the number of households in the study area. Therefore, the Raosoft online tool was used together with the current human population data from the world population review (2022) to calculate the sample size for this study in term of households (Raosoft, 2021). The

number of households in the city of Lubumbashi equals the population number divided by the average number of people in a household (6,2) = 2,695,331/6,2= 434,731. From the calculation, 434,731 households are in the city of Lubumbashi. The method and methodology are explained further in the summary in the next section.

3.2. Summary of research approach

Table 3.1: Summary of research approach

Objectives	Sub-questions	Assumptions/hypothesis	Variables	Sub-hypothesis	Methodologies
To explore composting of household biodegradable waste as an alternative approach to waste management.	Is it possible to manage solid waste through composting? What challenges do households and local government officials face when attempting to tackle the problem of waste management in the city?	Composting of household biodegradable waste contributes to improving poor solid waste management. The number of people and their education level might influence how they manage waste. The level of education and field of study and years of experience in the service might determine how officials deal with the problem of waste management.	• Composting to manage waste. • Age of respondents • Experience and qualifications in the field • Level of education • Number of years living near the dump sites	• Respondents of different ages might behave differently when it comes to waste management. • Experience and speciality may influence how policies are implemented. • Education level might influence how people perceive waste. • Years of living near dumping sites makes an impact on the state of health of people.	• Questionnaire/Interview
To assess the quantities of biodegradable waste generated by an average household in Lubumbashi.	Is there a solid waste management problem in Lubumbashi?	Yes, there is. We assume that biodegradable waste is dominant compared to non-biodegradable and I want to know how much is generated per day, per week, per month by an average household in Lubumbashi and project the	• State of waste management in the city • Quantities of biodegradable waste	• The state of waste management in the city varies. • There is a difference in the quantity of waste generated per day, per week and per month by an average household in Lubumbashi.	• Field observations and Questionnaire/ • Weighing exercise

		quantity of waste generated in a year to get a sense of the danger of poor management of such a quantity of waste and the environmental problems that could result from that.			
To understand common modes of treatment or disposal of household waste,	What are the common modes of treatment or disposal of household waste?	There are none (no common modes of treatment) around the city.	• Common modes of treatment/recycling of waste • Alternative modes	• The city could have a common mode of waste treatment. • Composting can be used as one of the affordable modes of recycling.	• questionnaire
To assess the environmental policies for sustainable environmental management	What are the environmental policies in place to deal with waste or help manage waste in the city? Are people aware of them?	We assume that there are environmental policies in place to deal with waste or help manage waste, but people are not aware of them meaning the implementation of these has not been successful.	• Environmental policies in place to deal with waste in the city • Implementation of waste management • Awareness of environmental policies	• The city might have environmental policies in place to deal with waste. • These policies might be successfully implemented. • People might be aware of the implemented policies.	• Interview

3.3. Data sampling and analysis

Data sampling and analysis is consistent with the qualitative research approach used in the study including field observations while sampling procedure followed the qualitative and quantitative research domains. For this study, qualitative and quantitative data were used. Additionally, data collected from the formal settlements were compared to the informal settlements of the Lubumbashi municipality in chapter four: results and discussion.

3.4. Data collection and materials

As referred to earlier, qualitative data were collected and used for this study. This consisted mainly of interview data. Data-collection instruments and tools included a notebook to record information or data, open and closed questions printed in the form of a questionnaire to guide the interview and a pen. Open-ended questions are questions that allow respondents to answer in open-text format based on their knowledge, feelings and understanding (Aityan & Aityan, 2022). There is a difference between open-ended and close-ended questions for respondents. In the open-ended questions, respondents share what is in their minds while in the close-ended questions, respondents focus their attention on specific responses chosen by the investigator (Aityan & Aityan, 2022: 343-357).

As a result of the Covid-19, the researcher contemplated conducting the interviews online; however, this approach could not work due to very poor access to the internet service in the study area. Therefore, the interviews were done face-to-face with strict adherence to existing Covid-19 protocols including the wearing of face masks, using hand sanitiser and social distancing. Since the subject matter was of interest to many people, this led to respondents willing to share more information. Therefore, the use of questionnaires was abandoned and relied only on interviews, following the contents of the questionnaire.

The sampling procedure was as follows. First, respondents were selected based on the specific objectives of the study. In this regard, two groups of respondents were targeted, namely, formal and informal settlements, which were further divided in local government officials involved in environmental and WM and households. Two local government officials involved in environmental, and WM were also interviewed. The household category was grouped into two: one consisted of the formal settlements (colonial) and the other the informal settlements. Three districts were selected based on their similarities and differences. Table 3.2. presents the districts with their characteristics. The formal settlements districts included Boudouin, Makutano and Kiwele, while the informal settlements included CRAA, Kalubwe and Gambela. Between 15 to 20 households per district participated in the first phase of the study through face-to-face interviews of 40 minutes to one hour per interview. This took place weekly in the afternoons (from

Mondays to Sundays) of the interview period allocated to the Lubumbashi municipality. A total sample of 162 households participated in the interview. This took place from 8 November 2021 to 7 January 2022. Thus, participants were randomly chosen to participate to interview and the biodegradable waste weighing exercise.

Furthermore, Raosoft was used together with the human population data from the Lubumbashi municipality report of 2020 to calculate the sample size for this study (Raosoft.com., 2021 and Lubumbashi municipality data, 2020). Since there was no household's data available, the population size was divided by the average number of people par household in the Lubumbashi municipality which is 6,2 people per household to have the total number of households in each district withing Lubumbashi municipality.

Table 3.1: Districts with their characteristics

Characteristics	
Formal settlements	**informal settlements**
• Clear and bigger avenues • Access to regular waste-collection services • Middle and upper classes	• Small or no avenues • No access to regular waste-collection services. • Majority the lower classes

The second phase of the study constituted the weighing of household compostable waste to quantify compostable waste generated by an average household in Lubumbashi. For this phase, 15 households were selected from MarZ Compost SARL's client base. The selected households were trained how to sort the waste into compostable and non- compostable waste to enable the researcher to get realistic weights for households' compostable waste. The respondent households were given composting buckets to put biodegradable waste, known as kitchen scraps, into, which included vegetables, fruit, left-over vegetables, porridge, tea bags, coffee grounds, fish and meat waste. Households' compostable waste were picked up every Thursday and Friday. The collected compostable waste was taken to the treatment site for weighing, recording and composting. Lastly, the collected information from formal and informal settlements was used for further analysis using Microsoft Excel 2022 and IBM SPSS.

3.5. Delineation of the research

The study was conducted in the six selected (formal settlements being Baudin, Makutano and Kiwele, and informal settlements being CRAA, Kalubwe and Gambela) of the Lubumbashi municipality in the city of Lubumbashi, DRC. As shown in Table 3, there are seven local

government divisions in Lubumbashi and Lubumbashi municipality is one of them. Lubumbashi municipality was chosen for this study because of its size, construction in terms of districts and how poorly solid waste was managed in the area. Additionally, the choice of settlements located only in Lubumbashi municipality was based on the fact that all public services were concentrated there. The study focused on WM, particularly the CE principle where composting waste was targeted to combat poor solid WM, improve environmental conditions and agriculture in Lubumbashi, DRC.

3.6. Ethical considerations

This project was submitted for ethical clearance as per CPUT requirements. Thus, ethics approval letter Reference no: 216006457/10/2021 was issued by the research ethics committee of the faculty of applied sciences of the cape peninsula university of technology. This is paramount because some of the ethical principles and aspects that are important in this research were respected namely: respect for persons, justice, and confidentiality. In the case of this study, the researcher introduced herself to respondents and gave them the research background and why she was there. Once the interviewees agreed to be part of the study, they signed a consent form and a confidentiality agreement before participating in the interview. Lastly, when filling out the transcripts, the researcher made sure, it is anonymous.

3.7. Conclusion

In this chapter, the research design was discussed. The selection of the target population was described, and the research methodology and methods used to collect the data were discussed. In the next chapter, the results of the data collection will be discussed.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Introduction

This chapter presents the research results, findings and discussion. The chapter is structured in sections. Section 4.2 presents the field observation detail about the two groups of households' waste management (WM) in Lubumbashi. This is then followed by the presentation of the themes that emerged with regard to the composting of household biodegradable waste, quantities of biodegradable waste generated by in each household, common modes of treatment, the environmental policies for sustainable environmental management and health hazards associated with the non-treatment of household waste and, lastly, the weighing exercise.

4.2. Field Observations

This section presents the observations done during the data collection compared to the results of the collected data for this study.

Table 4.1: Socio-economic characteristics of studied households

	Field observations		Data collected	
	Formal settlements	Informal settlements	Formal settlements	Informal settlements
Households' income	Households with a high income, generated more waste	Generated less waste	Households with a high income, generated more waste	Generated less waste
State of waste management in Lubumbashi.	Looked a bit organised compared to informal settlement where you see piles of waste on street	Poor waste management conditions were observed	Generated more waste compared to informal ones. The state of waste management looked okay	Generated less waste. Poor waste management conditions.
The composting of household biodegradable waste,	It was observed that household here generated more compostable waste than recyclables but still had more recyclable compared	They generated more compostable waste but less recyclables.	They generated 60% and the rest recyclables	They generated 60% compostable waste even if the quantity is not consistent but less recyclables.

	to informal settlements			
Quantities of biodegradable waste generated monthly by in each household,	-	-	27kg	-
Common modes of waste treatment	Burning and disposal to open dumps	Threw on the streets or dig in the compound, incinerated	Burning and disposal to open dumps	Threw on the streets or dig in the compound, incinerated and disposal
The environmental policies for sustainable environmental management	None was implemented and people were not aware of them	None was implemented and people were not aware of them	None was implemented and people were not aware of them	None was implemented and people were not aware of them
Health hazards associated with the non-treatment of household waste	They were aware of the hazards and did not live close to open dumps	It was observed that these people did not look healthy and were not aware of the health hazards.	They were aware and did not live close to open dumps	They were not aware.
The weighing exercise	-	-	They participated and homes with less people generated less waste compared to those with many people.	Did not participate due to their low interest in waste management.
Recycling habits	The majority of people in formal settlements was recycling conscious even if they did not recycle due to lack of recycling systems locally.	The majority of people in informal settlements was not recycling conscious.	The majority of people in formal settlements was recycling conscious even if they did not recycle due to lack of recycling systems locally.	The majority of people in informal settlements was not recycling conscious.
Public waste bins	There were public bins which were not emptied	No public bins available	-	-

4.3. Waste management and generation in Lubumbashi

In this section, the discussion revolved around accessibility to WM services (Figure 4.1). Information was provided about who offered the service, the choice of the service provider and how much was spent on a monthly service. Details of where the collected waste ended up and

the level of satisfaction with the way in which waste was handled were explored. Finally, the type of waste (Figure 4.2) that was generated was discussed as well as various opinions about biodegradable waste and awareness-raising on WM, ending with the interest shown in attending WM awareness training and opinions on managing waste through recycling and composting to improve environmental sanitation (Table 4.1).

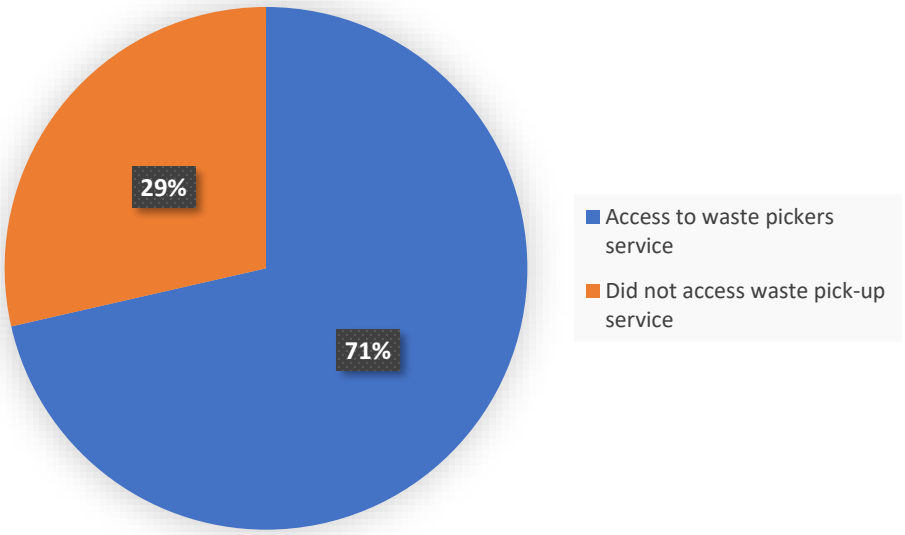

Figure 4.1: Access to waste management service

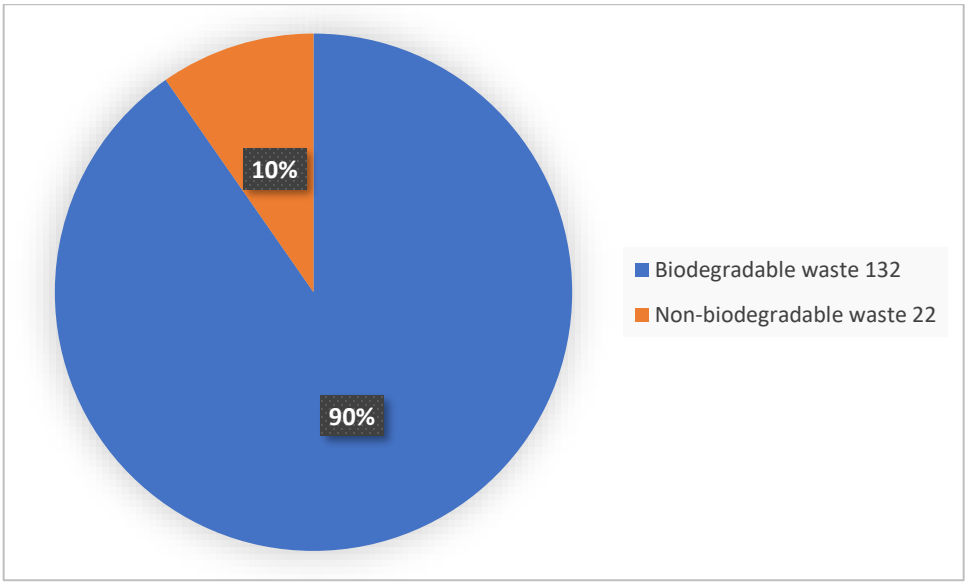

Figure 4.2: Types of waste generated

The majority (71%) of the respondents from the formal settlements pointed out that they had access to waste pickers who collected waste and took it to open dumpsites. The other 29% of respondents from the informal settlements believed they did not need a waste pick-up service

because they were used to throwing their waste in a hole that they dug in the compound. Culturally, people in the study area (specifically in the informal settlements) who owned larger spaces dug a hole or pit in their compound to throw waste. The pickup service was offered by informal waste pickers and only few waste-collection companies came into the area, according to most respondents from the formal settlements.

Furthermore, respondents found formal service providers too expensive, so they chose informal waste pickers as these were both physically and economically more accessible, with their prices ranging from US $5 to $10 per month. These prices were affordable compared to formal WM companies whose prices can range from US $10 to $25 per month. Additionally, most respondents from both groups did not know where their collected waste ended up and were not satisfied with the way waste was handled. In the city of Lubumbashi, there is no WM system in place, where waste is collected and taken to a treatment or recycling sites; instead, waste is picked up and then dumped in open dumps (see Appendix D showing the state of WM in Lubumbashi).

With regard to the type of waste generated in their households, biodegradable waste (kitchen craps and dead leaves) was dominant with 90% of respondents from both groups saying they generate more biodegradable compared to non-biodegradable as shown in Figure 4.2. They believed that biodegradable waste should be managed because it smelt bad, attracted rodents which could become diseases vectors, while 10% indicated they used biodegradable waste as fertilisers in their gardens.

Additionally, in terms of awareness raising on WM, all the respondents brought it to the researcher's attention that no awareness campaigns had taken place and most of them were interested in attending WM awareness training. Lastly, all the respondents were of the opinion that managing waste through recycling and composting could improve environmental sanitation and their recommendations are summarised in the recommendations section below. With regard to waste generation in Lubumbashi, the results showed some resemblance to those from Mpinda et al.'s (2016) research in the DRC for a case study in Katuba one of Lubumbashi's municipalities. It was found that more than one kg of waste was generated per person.

Table 4.2: Respondents opinions on how to improve waste management in Lubumbashi

No	Respondents' opinion on how to successfully manage waste	Number of people who provided the same responses
1.	Organise city clean-up service often	1
2.	Training in and organisation of awareness sessions (tell households how to manage waste and put them in contact with waste management companies through awareness programmes promoting personal discipline and good waste management habits).	55
3.	Create a waste management system with trash bins in public places and streets.	17
4.	Poor waste management should be taken seriously by each individual citizen (population must get involved and manage waste).	11
5.	Construct public dumps/landfills very far from the population. Dispose of waste away from people (where waste is regularly moved to a treatment site far from the population). Government should canalise the money received from the public open dump to build proper landfills.	6
6.	Create more waste management companies that collect waste regularly (dispose of waste regularly, good waste management including recycling to avoid pollution)	34
7.	Kitchen waste including cardboard should be managed (produce fertiliser with biodegradable kitchen waste).	9
8.	The government and the population should work together to tackle poor waste management (encourage public–private partnerships for good waste management for the benefit of the population).	27
9.	The government should manage, and the population should pay even 1500 Congolese franc (US $0,75) to prevent informal collectors from throwing waste away on the street.	17
10.	Take individual responsibility (Let waste management start from home)	6
11.	Provide disinfectant services and properly manage waste at a lower cost and efficiently	2
12.	Bring about a change of mentality (keep the trash to throw in the bin)	11
13.	Create gutters and water channels.	3
14.	Use a dictatorship to make people manage waste	2
15.	Dig holes in the compound to bury waste	4

16.	Put in place waste management policies and implement them (paying fines for throwing garbage on the road, producers of plastic bottles to recycle their waste,	15
17.	Avoid throwing waste away during the rainy season, as this annoys others	2

4.4. Households' monthly compostable behaviour

This section presents findings from the households' (formal and informal) monthly compostable behaviour.

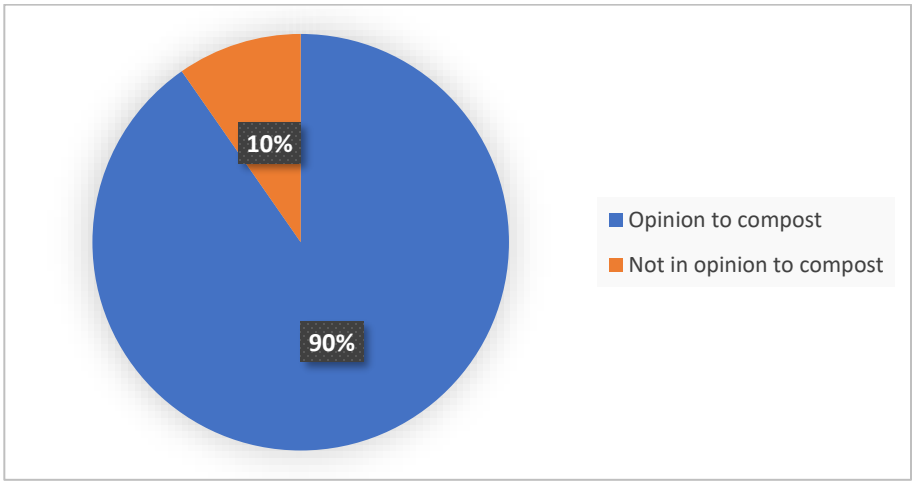

Figure 4.3: Respondents' inclination to compost

From respondents' behaviors, their level of awareness about composting and inclination to compost if they have an opportunity were assessed. The research found that respondents recognised that compostable waste could be used as organic fertiliser and they called it *mboleo* in the local language and dialect, meaning organic fertiliser. Furthermore, 90% of formal and informal settlements respondents even said that they generated nearly 60% compostable waste daily. This supports the findings Published by UN Habitat (2021) who found that 'sixty-eight per cent of solid waste is organic waste'. Also said that 'the people could manage it if they were informed about making it valuable'. Furthermore, Debrah, Teye, & Dinis, (2022) and Godfrey et al.'s (2019) findings revealed that sub-Saharan Africa has a large (57%) composition of organic waste. However, only a few individuals from informal settlements kept their organic waste and dumped it in their gardens to mix with soil before sowing seeds or burning it later. None of the respondents made compost in a real sense but they showed a great deal of interest to learn how to do it.

4.5. Modes of treatment or disposal of household waste

From the researcher's investigation, it was discovered that burning and the disposal of waste by taking it to open dumps were the common mode of waste treatment in the city (shown in Figure 4.4) as 90% of the respondents from both groups stated this. The minority of 10% also said they had dug a hole or pit in the compound to dispose of their waste.

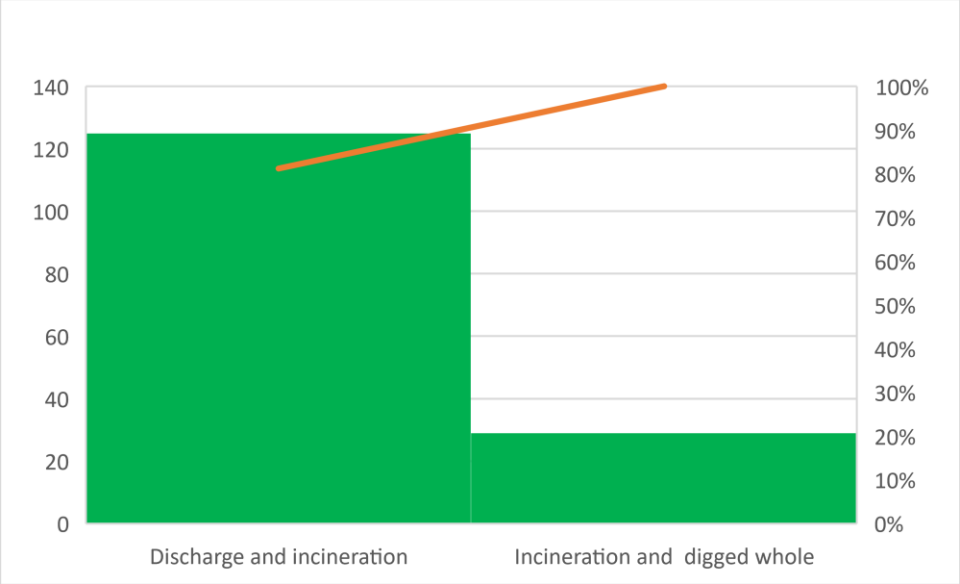

Figure 4.4: Mode of waste treatment among respondent households

Waste disposed of in an open dump

Burning of solid waste

Disposal of solid waste into a hole/pit

4.6. Environmental policies for sustainable waste management

This section presents the findings related to environmental policies to regulate WM. Respondents here were two government officials working in the WM sector. They were approached regarding the existence of legal frameworks or policies about the treatment of waste and told the researcher that there were policies to regulate WM but these were not implemented and the homeowners were not aware of them. They mentioned policies such as littering was prohibited and if someone was caught littering, they paid a fine. These respondents were from different knowledge backgrounds such as economics, finance and law. They had been appointed based on family or political party ties. The fact that the system was in place did not promote excellence because knowledge and expertise in the field of Environmental Science was not part of the requirements when appointing officials. This may explain why they were not successful in the implementation of WM policies.

4.7. Health risks associated with poor waste management

In this section, awareness of risk associated with living close (approximately within 100 meters) to open dumps, diseases that one could develop and how much could be spent on the treatment were investigated. All the respondents living within a 100 metre radius were aware that they were living close to open dumps or in an environment where waste was poorly managed and could cause health issues. Furthermore, most respondents pointed out some of the common diseases they had suffered, or which were experienced by the community as a result of living in an unclean environment. The diseases ranged from Malaria, Typhoid, with symptoms like coughing and diarrhoea.

Additionally, it was surprising to hear about one respondent who was comfortable living one metre away from the open dump with her family. She told the researcher that she was happy living there with her family and they did not get sick even if they ate with flies present. Further investigation of the respondent's education showed that she had none. Therefore, a lack of education may also be a contributing factor to poor WM consequences as a person with no basic education would not be able to understand the negative effects of living in the proximity of an open dump. Moreover, the respondents (informal settlements) told the researcher that they spent between US $50 and US $100 monthly for treatment relating to the above-mentioned diseases. This amount spent on health issues are important considering the poor financial situation of the people living near the dumps.

4.8. Weighing compostable waste exercise

This section presents the findings from households' compostable waste inventory exercise. This exercise involved weighing compostable waste to enable the researcher to determine how much an average household in Lubumbashi generated per week and per month to project how much was generated per year. The other goal of the exercise was to enable the researcher to grasp the sense of the impact that a household's compostable waste generation had on the environment, assuming that this was poorly managed.

Table 4.3 presents the summarised findings from households' compostable waste inventory exercise.

Table 4.3: Statistics from weighing of compostable waste

Parameters	Quantities		
	number	Kg	Tons
Average number of people in a household	6	-	-
Number of Respondents	15	-	-
Total average amount of waste generated per week for 15 households in kg	-	101.96	-
Total amount of waste generated per month for 15 households in kg	-	792.39	-
Average waste generated per week per household/kg	-	6.797333333	-
Average waste generated per week per household in tons	-	-	0.006797333
Average waste generated per month per household/kg	-	27.19	-
Average waste generated per month per household in tons	-	-	0.027189333
Estimated number of households in Lubumbashi city	434 731.00	-	-
Projected waste generated per week for 434 731 households in Lubumbashi	-	2 955 011.52	-
Projected waste generated per week in Lubumbashi in tons	-	-	2 955.01
Projected waste generated per month in Lubumbashi in tons	-	-	11 820.05
Projected waste generated per year in Lubumbashi in tons	-	-	141 840.55

The results showed that households in Lubumbashi have an average number of six people. From the 15 respondents who took part in the weighing exercises, the results showed that they generated an average of 6.797 kg (0.006797333) per week and 27 kg (0.027) per month of compostable waste per household. With the average number of people in a household which is six people from the total population of 2 608 386, the estimated number of households in Lubumbashi is 434 731. Therefore, using the average amount of compostable waste generated monthly 0.027189333 tons X 434 731 households X 12 months= 141 840.55 tons of compostable waste per year is projected to be generated by households in Lubumbashi, DRC. It was also observed that households with a high income generated more waste than households with less income. This aspect of the data has been captured by Mpinda et al*.* (2016) with the finding that the municipality of Lubumbashi generated more waste (212%) than other municipalities. Lubumbashi municipality, where the study took place, is known to be a municipality with wealthier people.

According to Brown (2013), one ton of compostable waste could produce 65kg of methane. This translated into 141840.55 tons X 65kg = 9 219,6 tons of methane gas that could be released each year into the atmosphere from disposing compostable waste in open dumps in Lubumbashi.

Previous studies have shown that the significant components of landfill gas that actively contribute to the greenhouse effect are methane and carbon dioxide (Brown, 2013; Fallahizadeh et al., 2019; Chandrasekaran, 2022; Oukili, 2022). Additionally, methane gas is one of the most important greenhouse gases that has the potential of causing global warming 21 times more than carbon dioxide gas (Nikkhah et al*.*, 2018; Falla hizadeh et al., 2019).

Furthermore, other authors also mentioned food waste which represented 76.6% of the municipality's solid waste management (SWM) (Fallahizadeh et al., 2019). This study supported composting because in the compost heaps, methane generation is limited as a large amount of oxygen is present, food waste, paper and even biodegradable plastics. This argument is in line with previous findings by other authors such as Masullo (2017) and Jouhara et al. (2017). Locally, Mwene-Mbeja & Vaneeckhaute's (2019) conference paper on the Green Industry in the DRC also recognised composting as a way to manage biodegradable waste in order to promote environmental sanitation and sustainable agriculture.

Table 4.4. presents the correlation between the quantity of waste generated and the number of people in a household.

Table 4.4: Correlation between household size and quantity of waste generated

		Quantity of waste generated per month per household	Number of people in the house
Quantity of waste generated per month per household	Pearson correlation	1	0,771**
	sig. (bilateral)		0.001
	Sum of squares and cross products	2343.605	352.061
	Covariance:	167.400	25.147
	Number of respondents	15	15
Number of people in the house	Pearson correlation	0,771**	1
	sig. (bilateral)	0.001	
	Sum of squares and cross products	352.061	88.933
	Covariance:	25.147	6.352
	Number of respondents	15	15

**. The correlation is significant at the 0.01 level (two-sided).

Table 4.4 presents the correlation between the quantities of waste generated per household per month and number of people in a household. The correlation is significant at the 0.01 two-sided level. This means the number of people in a household influence the quantity of waste generated. In the bigger picture, with the rapidly growing population, the amount of waste generated will increase. This may lead nations to come up with or create strategies providing a proper and sustainable waste management service. Therefore, in term of prevention, birth rates should be controlled, and sustainable WM systems should be created now.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. Introduction

WM remains a worldwide problem including in the DRC and Lubumbashi. The study explored composting as a way of managing solid waste and promote sustainable environmental management as well as agriculture in Lubumbashi. The study used a mixed-method research design that included qualitative and quantitative research methods such as field observation and interviews. Interviews and the weighing exercise were used to collect the data where 162 households participated in the interview and 15 participated in the weighing exercise. The household category was grouped into two: the formal settlements (colonial) and informal settlements (self-built) category.

5.2. Key findings

Results showed that there was a need for urgent action and attention to address poor WM in Lubumbashi, DRC. Waste is not managed in the city. It is dumped onto open dumps that release methane gas which contributes to climate change along with other pollutants that are responsible for health hazards such as skin irritation, cancer, respiratory problems, Cholera, Malaria, Dengue, Typhoid, to name a few, as well as having huge financial implications for the communities living in proximity of the dumps.

Additionally, it was discovered that an average household in Lubumbashi generated 0.006797333 tons of waste per week and 0.027189333 tons of compostable waste per month. This represents 141 840.55 tons of compostable waste annually that went to open dumps leading to 9 219,6 tons of methane gas that is released into the atmosphere by disposing compostable waste in open dumps in Lubumbashi each year. This could have a huge negative impact on human health and the environment if not management sustainably.

5.3. Concluding remarks

Managing waste in Lubumbashi city of the DRC seems to be a significant challenge for municipalities in the country including the municipality of Lubumbashi which was used as the study area. Some respondents have lived in the study area for up to 10 years and they have never received attention from the government in terms of waste management. This is a proof that poor waste management is a problem. The municipality occasionally gathers the scattered waste and takes it away using waste excavators in the area; however, short term solutions have proven fruitless in combating waste management issues in Lubumbashi. For as long as the municipality cannot provide municipal waste bins accompanied by regular waste pick up service for the residence in these areas then efforts to manage waste in the city will remain ineffective.

Furthermore, the issue of illegal dumping remains a common practice and visible in the city. Lubumbashi's residents don't seem to be involve in waste management instead they keep blaming the government for the waste issue in the area. The municipality should provide environmental education for the residents and get them involved in recycling. The 3R's otherwise known as reduce, reuse and recycling offer environmentally friendly ways of decreasing the negative impacts caused by rising quantities of waste on the natural environment. In sustainable waste management, it is recommended to manage waste as high up the waste hierarchy as possible. Therefore, adopting a culture where objects/mattes are reused in the system for a different use is essential in the management of waste, recycling, and composting. As part of this study composting was explored. Therefore, composting biodegradable waste in Lubumbashi municipality will help divert 141,840.55 tons of biodegradable waste which represent 9,219.6 tons of methane gas from the environment and slows down the degradation of soil caused by chemical fertilizers.

5.4. Recommendations

The section captured the researcher's recommendations:

- The relationship between the municipality and communities should be improved by promoting public participation in the management of waste in the study area as it is still non-existent.
- The municipalities should be empowered through environmental education to improve their knowledge with regard to the importance of sustainable waste management.
- Municipality should start municipal services like municipal waste bins, and regular waste collection using municipal trucks; also acknowledge that informal and formal settlements exist and should be serviced equally.
- Municipality should identify waste pick up points, install public bins and ensure regular waste pick up.
- Get the community involved in waste management campaigns where they are encouraged to reuse items that would, in turn, assist in reducing the volume of waste that is disposed to the open dumps/areas.
- The government should employ experts in the field of waste management, and they should produce and implement policies that are promoting sustainable waste management in the city. Also make these policies known by the citizens.
- The government should encourage creation of waste management companies by providing exonerations and incentives.

- Researcher recommends that further investigations be done in quantifying how much food waste is generated by businesses, specifically restaurants, hotels and supermarket/local market.

5.5. Limitations of the study

Covid-19, hindered the researcher's possibility to collect data using questionnaires as initially planned. Additionally, the lack of household's data did not make a data collection process easier.

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APPENDICES

APPENDIX A: Authorisation for data collection

REPUBLIQUE DEMOCRATIQUE DU CONGO
PROVINCE DU HAUT –KATANGA

VILLE DE LUBUMBASHI
COMMUNE DE LUBUMBASHI

N° K014/423/C.L'SHI/2021

Concerne : Accusé de réception
Dossier : **Demande d'autorisation pour mener des recherches académiques dans la Commune de Lubumbashi.**

A Madame MARONDJI BUKOKO Pacy
11, Avenue Katota, Quartier Gambela I,
C/Lubumbashi, Haut-Katanga/R.D. Congo.
+243841001562; marondjibukoko@gmail.com
à Lubumbashi.

Madame,

J'accuse bonne réception de votre lettre sans référence du 03 Août 2021 relative à l'objet bien renseigné en concerne et en prend bonne note.

Y faisant suite, je marque mon accord pour effectuer vos enquêtes et expérimentations académiques sur ma juridiction, en vue de pallier la théorie à la pratique dans le cadre de la revalorisation de déchets biodégradables.

Par ailleurs, je vous prie d'œuvrer dans le respect strict des lois et règlements qui régissent notre pays ainsi que le respect des mesures barrières édictées par les autorités nationales dans la lutte contre le COVID 19.

La présente, donne lieu à **une autorisation des recherches académiques** dans toute la commune de Lubumbashi, et par conséquent les autorités tant civiles que militaires sont priées d'assister la porteuse de la présente autorisation en cas de nécessité.

Mes sentiments patriotiques.

Fait à Lubumbashi, le 04/AOUT/2021

Le Bourgmestre

NGOY KYAMUSUNGA GUSTAVE
BOURGMESTRE

APPENDIX B: Consent form for waste weighing exercise

The aim of this research project is to explore the potential of biodegradable waste management through composting which links waste to agriculture and thus leads to the conversion of waste into wealth while improving environmental sanitation. This is a research project led by MARONDJI BUKOKO Pacy, a student at Cape Peninsula University of Technology based in Cape Town. You are invited to participate in this research project because you live in the study area which is Baudin, Makutano, Kiwele, CRAA, Kalubwe and Gambela in Lubumbashi, Democratic Republic of Congo.

Your participation in this study is voluntary. You can choose not to participate. If you decide to participate in this research, you may withdraw at any time. If you decide not to participate in this study or if you withdraw at any time, you will not be penalized.

The procedure consists of (1) being trained about waste sorting, receiving a composting bucket, putting the waste there for a week and having your waste collected for free every week for a month.

We will do our best to keep your information confidential. All data is stored in a password-protected electronic format. To help protect your privacy, surveys will not contain personally identifiable information. The results of this study will be used for academic purposes only and may be shared with representatives of Cape Peninsula University of Technology.

If you have any questions about the research study, please contact MARONDJI BUKOKO Pacy at marondjibukoko@gmail.com/ 216006457@mycput.ac.za, +243 84 100 1562.

Name and signature of respondent

Name and signature of researcher

MARONDJI BUKOKO Pacy

APPENDIX C: INTERVIEW QUESTIONS

Local government officials involved in environmental and waste management: interview questions

Postgraduate project (master's level)

Topic: Recycling biodegradable waste to combat poor solid waste management in Lubumbashi, Democratic Republic of the Congo

Name of researcher (s): MARONDJI BUKOKO Pacy

Name of supervisor (s): Dr TOMBO

Name of the co-supervisor (s): Prof USENI

I am a master's student in the Environmental Health programme at the Cape Peninsula University of Technology based in Cape Town, South Africa. I am conducting a study on the topic mentioned above. This study intends to explore the potential of managing biodegradable waste through composting which links waste to agriculture and thus leads to the conversion of waste to wealth while improving environmental sanitation.

NB: All information collected will be kept anonymous and used for academic purposes only.

General information about the respondent		**Please circle yes or no/good answer**					
Gender		F	M	Other			
Education	**Level**	None	primary	High school		University	
	Qualification						
Age		< 20years	21–30years	31–40 years		41–50 years	>50
How many years have you worked here?		<5years	5-10 years	11-20 years		> 20years	
Waste management in Lubumbashi, DRC							
Question 1. Provision of waste management services							
Do you offer waste management services to the community?		Yes		No			
What does this service entail?							
How much do you charge for the service per household per month		< 5$	5-10$	11-20$		> 20$	
Where do you dispose of your collected waste?		Public authorised dumps		Landfills		Any open dumps	
Are you satisfied with the way the waste is managed in your community?		Yes		No			
If not, what are your suggestions to help improve the situation? list 3 max.							
Do you work with private companies?		Yes		No			
Do you facilitate/assist the population with training or awareness programmes around waste management?		Yes		No			
When did the programme start and how is it going?							
Please list common methods of treatment or household waste disposal that you know about in Lubumbashi		Composting	recycling	Reuse		dumping	
Environmental policies for waste management in Lubumbashi, DRC							
Question 1. Environmental policies in place		**Please circle yes or no/good answer**					
What environmental policies are in place to manage waste in Lubumbashi?							
Are the mentioned policies implemented successfully?		Yes			No		
If not, what is missing to successfully implement these policies?							
Do you fine people who dump waste by the roadside?		Yes			No		

Households' Research interview Questions

Postgraduate project (Master's level)

Topic: Recycling biodegradable waste to combat poor solid waste management in Lubumbashi, Democratic Republic of the Congo

Name of researcher (s): MARONDJI BUKOKO Pacy

Name of supervisor (s): Dr TOMBO

Name of the co-supervisor (s): Prof USENI

I am a Master's student in the Environmental Health programme at the Cape Peninsula University of Technology based in Cape Town, South Africa. I am conducting the study on the topic mentioned above. The intention of this study is to explore the potential of managing biodegradable waste through composting which links waste to agriculture and thus leads to the conversion of waste to wealth while improving environmental sanitation.

NB: All information collected will be kept anonymous and used for academic purposes only.

General information about the respondent	**Reponses**				
How many years have you lived here?	<5	5-10	>10		
How many are you in the house?	<6	**6-10**	>10		
Gender	F	M	Other		
Education level	No formal	Primary	High school	university	
Age	< 20years	21–30years	31–40 years	41–50 years	>50
Waste management in Lubumbashi, DRC					
Question 1. Access to waste management services	**Please circle yes or no/good answer**				
Do you have access to waste management services?	Yes	**No**	Good answer		
Who does this service mean to you?	Government	Private companies	Informal waste collectors		
Why did you choose the service provider you have	affordability	availability	good service		
How much do you pay for the service	< $5/month	$5-$10/month	>$10		
Do you know where your collected waste goes / ends?	Yes	No	If yes, mention :……		
Are you satisfied with the way the waste is managed in your community?	Yes	No			
If not, what are your suggestions to help improve the situation?	Government to take the matter seriously	People to take the matter seriously	Both		
What type of waste do you generate the most? (Biodegradable or non-biodegradable)					
Do you think kitchen waste should be taken seriously and well managed? And why?					
Please list common methods of treatment or household waste disposal that you know about in Lubumbashi					
Does the government give/facilitate training or awareness programmes around waste management?	Yes	No			
Would you like to see the government facilitate training or awareness programmes around waste management?	Yes	No			
Question 2. Health risk associated with poor waste management	**Please circle yes or no/good answer**				
Do you to live near an open dump?	Yes	No			
Did you know that living in a poorly managed waste environment can expose you to illnesses such as asthma, cuts, diarrhoea, upset	Yes	No			

stomach, relapsing flu, cholera, malaria, cough, skin irritations and tuberculosis					
Which of the above-mentioned diseases have you developed or are bothering you?	asthma, cough, relapsing flu	cuts, skin irritations	diarrhoea, upset stomach, cholera,	malaria,	tuberculosis
How much do you spend on drugs / hospital bills every three months?	< $50	$50-$100		>$100	
Do you think if waste was well managed through recycling, it would have reduced problems on the environment and people's health?	Yes	No		Maybe	

APPENDIX D: OBSERVATION PICTURES: STATE OF WASTE MANAGEMENT IN LUBUMBASHI

Waste disposed on top of a water channel

Waste incinerated to be used in the garden as organic fertilizer.

Disposal of solid waste into a corner of the compound

Burning of solid waste at household level

Municipal solid waste disposal bac

Cassava grown close to an open dump.

Waste disposed in a water channel.

Waste disposed in living neighbourhood.