Assessment of Urban Solid Waste Logistics Systems: The Case of Kampala, Uganda

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Abstract

Many cities, especially in developing countries, are facing challenges in the management of solid waste. The aim of the study was to develop effective logistics systems for solid waste management in urban areas of developing countries, with a specific focus on Kampala, Uganda. This thesis contains an assessment of the reverse logistics systems that enable effective recapturing of valuable products from urban solid waste. The study mapped the waste collection systems in Kampala using a geographic information system (GIS), *i.e.* ArcGIS software, and examined the existing models of waste collection to the final disposal destinations. It was found that food and yard wastes constitute 92.7 % of the waste that reaches landfills in Kampala. Recyclables and other special wastes constitute only 7.3 % of the total waste. The generation rate of solid wastes on average from poor areas, upscale wealthier areas, business centres and market areas was 582, 169, 105 and 90 tonnes/day respectively.

The study optimised travel distances, number of vehicles and collection time, while maximising total waste collection for environmental sustainability. Results showed that, an increase from a 6-tonne truck to a 10-tonne one reduced the travel distance by 39 %, while an increase from a 10-tonne truck to an 18-tonne truck reduced the travel distance by 34 % considering the current 40 % waste collection. Suggestions regarding the best waste collection routes and a suitable vehicle fleet and capacity to be used by Kampala Capital City Authority (KCCA) have been provided in this study.

The research study further developed an overview of reverse logistics at the Kiteezi landfill. The study analysed in detail the collection, re-processing, re-distribution and final markets of these products into a reversed supply chain network of products delivered to the landfill. Of the products at the Kiteezi landfill, 14 % was channelled into the reverse chain, 63 % could be included in the distribution chain but were left out and disposed of while the remaining 23 % was buried straightaway.

The main conclusion of the work was that solid waste management in Kampala is characterised by inefficient collection methods, insufficient coverage of the collection system and improper disposal of municipal solid waste. The existing system pertaining to reverse logistics suffers from unfavourable economics and legislative, technical and operational constraints that affect the recycling rate in Kampala compared to developed countries. This study presented large-scale data that can be used to improve solid waste management in other cities in developing countries.

Keywords: logistics, reverse logistics, waste management, optimisation, waste collection models, GIS, Kampala

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Dedication

To my mother Mrs Christine Najjuma and my late father Mr Samuel Ssewagudde.

With God everything is possible.
Matthew 19:26

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Kinobe, J. R., Gebresenbet, G. & Vinnerås, B. (2012). Reverse logistics related to waste management with an emphasis on developing countries - A review paper. *Journal of Environmental Science and Engineering* B, 1, 1104-1118.

II Kinobe, Joel R, Charles B Niwagaba, Girma Gebresenbet, Allan J Komakech, and Björn Vinnerås. (2015). Mapping out the solid waste generation and collection models: The case of Kampala City. *Journal of the Air & Waste Management Association* no. 65 (2),197-205, doi 10.1080/10962247.2014.984818.

III Kinobe, J. R., Bosona, T., Gebresenbet, G., Niwagaba, C. B., & Vinnerås, B. (2015). Optimization of waste collection and disposal in Kampala City. *Habitat International*, 49, 126-137. doi: http://dx.doi.org/10.1016/j.habitatint.2015.05.025.

IV Kinobe, J. R., Gebresenbet, G., Niwagaba, C. B., & Vinnerås, B. (2015). Reverse logistics system and recycling potential at a landfill: A case study from Kampala City. *Waste Management,* 42, 82-92. doi: http://dx.doi.org/10.1016/j.wasman.2015.04.012.

The contribution of Joel R. Kinobe to the papers included in this thesis was as follows:

I Paper I: Planned the study, carried out literature review and wrote the paper with revision by co-authors

II Paper II: Participated in planning the study, conducted data collection, analysed and interpreted the data. Had the main responsibility of writing the manuscript with revisions from the co-authors

III Paper III: Participated in planning the study and collected, analysed and interpreted the data. Had the main responsibility of writing the manuscript with revisions from the co-authors

IV Paper IV: Participated in planning the study, analysed and interpreted the data. Had the main responsibility of writing the manuscript with revisions from the co-authors.

Abbreviations

3PL	Third-party logistics
AIDS	Acquired immune deficiency syndrome
GHG	Greenhouse gases
GIS	Geographic information system
GPS	Global positioning system
HDPE	High-density polyethylene
ISWM	Integrated solid waste management
KCC	Kampala City Council
KCCA	Kampala Capital City Authority
MDG	Millennium Development Goals
SCM	Supply chain management
UBOS	Uganda Bureau Of Statistics
UGX	Uganda shillings
US	United States
VR	Vehicle routing

1 Introduction

1.1 Background

The ever-increasing world population has increased resource consumption that has manifested itself in increased waste generation, placing excessive pressure on cities' municipal authorities to provide the services efficiently and effectively (Jin *et al.*, 2006, Zhen-shan *et al.*, 2009, Imam *et al.*, 2008). This is due to the lack of resources and organisation and the complexity of the systems (Zurbrugg, 2003, Al-Khatib *et al.*, 2010, Zhang *et al.*, 2010). Most municipal authorities are unable to provide efficient waste collection. Waste management budgets are normally less than other municipal services because the service is not perceived as deserving a high priority. As a result, unsatisfactory management means public complaints are the order of the day.

The management of waste comes with environmental and financial costs. Solid waste contains toxic and hazardous materials and these substances are difficult to treat if generated in the typical waste context of developing countries (Diaz *et al.*, 2005). Apparently, most Sub-Saharan African (SSA) countries do not have the technical expertise required for solid waste management and frequently this is not included in the planning of many municipal strategic plans (Al-Khatib *et al.*, 2010). Research and development activities in solid waste management are often given low priority. This is because there are other pressing issues that need to be tackled by governments, such as poverty eradication, war and AIDS. This is compounded by the limited budgets directed to the solid waste management sector. Limited available resources provided by developing countries have made it impossible to hire highly skilled labour for employment in the waste management sector. The solution is to hire an unskilled labour force that will demand low wages and deliver unprofessional work. The limited funds are further affected by the corruption rates among many officials in developing countries (Kinobe *et al.*, 2015c).

An increase in the economic development in developing countries means better income levels for most urban people, leading to higher purchasing power. This in turn has increased the waste being generated in the cities of developing countries. Per capita waste generation in developing countries is currently estimated to be 0.3 to 0.6 kg/day (Ojok *et al.*, 2013).

In many developing countries, the wastes generated are heavier, wetter and more corrosive because of their high moisture content (Agunwamba, 1998, Imam *et al*., 2008, Komakech *et al*., 2014, Oyoo *et al*., 2014). This is further worsened by the constant breakdown of trucks due to the poor road network, overuse and the fact that most of the vehicles are purchased second hand. Furthermore, compactor trucks breakdown prematurely because they are used to compact high-density waste; the hydraulic system becomes strained from doing more work than they were designed for.

There is also a lack of legislation in the solid waste sector and where it does exist, the institutional organisations are weak and not so well developed (Okot-Okumu and Nyenje, 2011). There are also social constraints in the context of people’s negative perception regarding the handling of wastes. This can be evident from the indiscriminate waste disposal, for instance in drainage channels and along the side of streets.

Garbage heaps harbour rodents and are breeding areas of disease, causing insect vectors. The leachates from solid waste pollute underground water resources too. All these constraints have forced residents to resort to burying or burning the waste they generate, or disposing it of indiscriminately in open spaces. As a result, in most developing countries only about one to two thirds of the waste generated is collected and transported to the landfill (Zurbrugg, 2003). The rest is left on vacant plots, along streets, in drainage channels, in open sewer lines and on railway lines. The nature and set-up of most of the waste collection points are such that they are located next to drainage channels (Kinobe *et al.*, 2015c). These prevail more in slum areas with narrow, unpaved streets and roads, leading to more problems when it rains and all the waste and soil find their way into the drainage channels. This then leads to blockage and subsequently flooding.

Solid waste management has become a pressing problem and is now frequently called for by many urban masses. This has placed a heavy burden on many municipalities in developing countries to manage the waste effectively. Most of the waste generated in these urban areas is not collected (Imam *et al*., 2008, Wilson *et al*., 2006). Open dumping of solid waste is the cause of environmental and health hazards. For instance methane from the anaerobic decomposition of waste causes fires and contributes to global warming, since the accumulation of greenhouse gases in the atmosphere, particularly carbon dioxide and methane, is believed to be responsible for global warming. Open dumps undergo biological and chemical processes that produce leachates which later pollute the underground water sources. The waste pickers cause intentional fires at the dumpsites and temporary collection points when they burn waste to sort out metals or even reduce the volume of the waste dumped. Still at the dumpsites, food leftovers attract animal rodents and insect vectors transmit diseases to the people leaving nearby (Jin *et al.*, 2006). Flies and mosquitos breed in the blocked drains and these are vectors that spread diseases such as malaria. Furthermore, uncollected waste degrades urban environments, leading to unattractive aesthetic conditions.

Most waste management schemes in developing countries serve a limited minority of the urban population, excluding low-income earners living in the slums. The most vulnerable to this situation are the urban poor, characterised by poor housing, non-existent services and the effects of inadequate urban planning, which exposes them to health risks (Zurbrugg, 2002). Free space in urban areas tends to be on marginal lands such as wetlands and watercourses. Furthermore it is noted that most municipal authorities tend to allocate their limited financial resources to the wealthier areas where residents are believed to pay high taxes and are politically influential.

1.2 Logistics overview

The term "logistics" is used interchangeably to mean supply chain management (SCM). It refers to the strategic management of the overall supply chain including procurement, manufacture, distribution and waste disposal (Waters, 2010). It is the process that involves the flow of materials in an optimal and organised way from the supplier to a consumer. Logistics involves planning, creating and monitoring flows of goods and information. All the definitions encompass processes of moving and handling goods and materials, from the beginning to the end of the production, the sales process and waste disposal, with an emphasis on satisfying customers and enhancing business competitiveness (Lambert *et al.*, 1998a).

One of the defining and most lasting features of the Industrial Revolution in the 18^{th} and 19^{th} centuries was the rise of cities. In pre-industrial society, over 80 % of people lived in rural areas (Bairoch and Goertz, 1986). This saw changes in the agricultural, manufacturing, mining, transportation and technology sectors that changed the social economic status of the people. An increase in incomes meant an increase in the consumer base, and hence increased the generation of waste (Blumberg, 2005). Industrialisation also led to the generation of hazardous waste that had a negative impact on the environment. This catastrophic disaster called for immediate control of the health of the people and the environment. This saw the teaming up of government, private operators and the public to engage in waste removal and recycling activities. The effects of industrial revolution forced many governments to introduce environmental legislation and give manufacturers responsibility for reverse logistics flows, including used products and manufacturing-induced wastes (Blumberg, 2005)

The emergence of green logistics that aims for sustainable logistics has also seen a development in logistics. Companies and manufacturing organisations have started interacting with consumers about the information flow of product quality, proper disposal and product returns (Lambert *et al.*, 1998b).

1.3 Emergence of reverse logistics

In the early 1990s, reverse logistics attracted increasing attention from academic researchers, commercial business actors and government officials. Serious and persistent environmental concerns and government regulations created a motivation to undertake research in this field: Stock (1998) proposes the application of reverse logistics in business and society in general; Kopicki *et al.* (1993) elaborate the opportunities for reusing and recycling; Lambert *et al.*, (1998b) investigate how to start and implement reverse logistics programmes; and Rogers *et al.* (1999) demonstrate a collection of reverse logistics business practices using a comprehensive questionnaire among US industries.

Reverse logistics, as defined by (Rogers and Tibben-Lembke, 1999), is:

> The process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal.

The European Working Group on Reverse Logistics in De Brito and Dekker (2002) defines reverse logistics as:

> The process of planning, implementing and controlling backward flows of raw materials, in-process inventory, packaging and finished goods from the manufacturing, distribution or use point of recovery to the point of proper disposal.

The issue with the first definition is that packaging materials are left out. It focuses on both economic gains and sustainability. Reverse logistics, being a new subject in the area, has been perceived to mean reversed logistics, returns logistics or reverse distribution. However, with all these definitions, there is an element of resource recovery and as such are taken to mean the same thing. However it should be noted that reverse logistics focuses more on collection, value addition and final disposal (Fig. 1). The European Working group incorporates reverse logistics to include product recovery more to other product streams leading to another supply chain than only to products from consumers back to the origin.

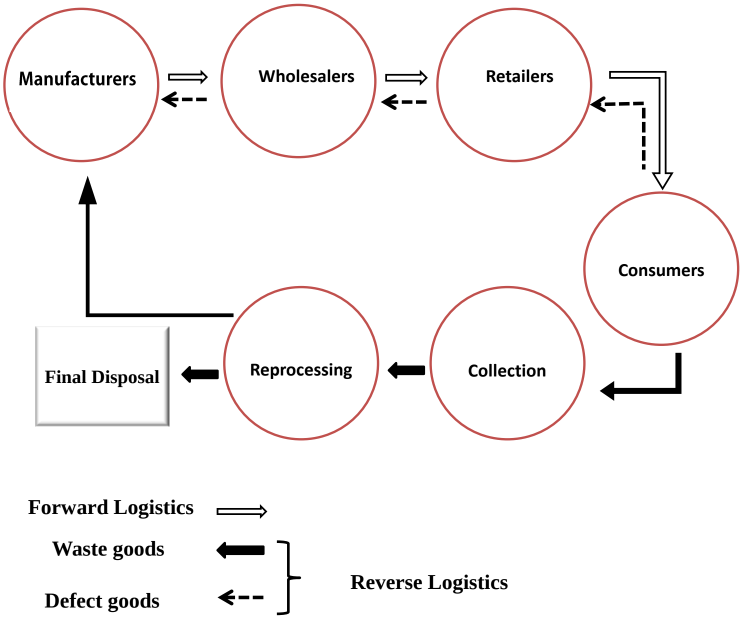

Figure 1. Integration of forward and reverse logistics

In the past, companies were operating and making decisions within the company/organisation, but due to market globalisation, companies started moving away from internal decision-making processes towards a more coordinated and integrated design in order to provide goods and services to their customers at low costs and high service levels, known as supply chain management (SCM). SCM is an area that has recently received great attention in the business community, and is taken to mean the management of product and information flows internally and between manufacturing and distribution centres (Lambert *et al.*, 1998a). SCM focuses on forward logistics, which consists of suppliers, manufacturers, distributors, retailers and customers. Recent ecological ideas of product recovery with a focus on reverse channels extended the scope from traditional logistics to reverse logistics, which consists of consumers, collection, recyclers and remanufacturers (Rogers and Tibben-Lembke, 2001, Rogers *et al*., 1999, Tibben-Lembke and Rogers, 2002, Fleischmann *et al*., 2000). Kopicki *et al.* (1993) point out that the ultimate goal of a company is efficient resource utilisation, which includes minimising the materials used and minimising waste, and saving energy through the production of more environmentally-efficient products by reusing materials and recycling as much as possible. In recent years, attention has been directed at product recovery by extending the end of life of products (Rogers *et al.*, 1999). This system has been practised widely by industrialised countries and involves extending the scope of traditional supply chain management and drawing attention to collection, remanufacturing, recycling and reuse. It is a system that manages the flow of products intended for remanufacture, recycle and final disposal in the SCM and has received a lot of attention as a profitable and sustainable aspect in the business society (Dowlatshahi, 2000). In the business community, reverse logistics has increased competition between different firms due to customer demands for liberal returns, especially for products that are obsolete or out-dated in relation to market demand (Daugherty *et al*., 2001, Richey *et al*., 2005).

Environmental management is attracting increasing attention from researchers and government authorities in SCM. However, despite this attention, it is notable that an incorporation of the greening system into the concept is lacking (Lambert *et al.*, 1998b). In order for a company to become ecologically sustainable, it should have an organisational framework that addresses the natural environment. Van Hoek (1999) asserts that research initiatives to move beyond reverse logistics into the development of green logistics are needed to overcome this problem, hence its emergence.

The emergence of operations around green logistics (concern for the environment in terms of climate change, pollution, vibrations and accidents arising from the activities of companies) as efforts intended to reduce the impacts on the environment of SCM activities have greatly promoted reverse logistics. Activities include returns, refurbishment, repairs and an emphasis on a sustainable environment. These activities are already significant in many companies and they continue to grow (Rogers and Tibben-Lembke, 2001). With green logistics, sound integrated environmental management with a decision-making process for the conversion of product recovery into usable products is promoted.

Proper disposal of electrical and electronic equipment waste at their end of life and hazardous waste has been urged strongly by the European Union because of the hazardous materials contained in these appliances (Fleischmann *et al*., 2000, Flapper *et al*., 2005) and it proposes a planned system that considers a good end-of-life disposal system that includes collection, disassembly, recycling, marketing of the reclaimed products and final disposal. On the other hand, this has created competition between companies, leading to quality products and goods. A customer will no longer be concerned with disposal because reverse logistics looks at the economics, environmental and legislative reasons and strict environmental and packing regulations for instance have forced many firms to become responsible for the final residuals from the sale of products and goods (Dowlatshahi, 2000). With legislation in place, a number of industries, especially the electronic industry, have set up a product disposal system for appropriate product recovery and safe disposal (Nagurney and Toyasaki, 2005).

However the reverse logistics chain in most developing countries is mostly composed of people working in the informal sector, comprising a huge number of waste pickers, street children, waste loaders and small-scale shop traders. Those working in the informal sector are not normally organised, and depend on recyclables collected from temporary collection points and when trucks come to dispose of the wastes (Matter *et al.*, 2012). They reduce the inflow of waste to the landfill, but despite this these marginalised people are never credited for the services they render with respect to waste management. These people, especially waste collectors and pickers, are perceived to be unclean and a public nuisance by many (Wilson *et al.*, 2006). The process is performed by the poor so that they earn minimum wages for survival, and hence they are at great risk from toxic waste since the system does not address safety issues (Bleck and Wettberg, 2012).

Uncertainty is yet another setback to reverse logistics in developing countries, especially when it comes to decisions about what particular product to deal with. Decisions about which particular products to recycle depend heavily on tracking the costs. Furthermore, the reverse logistics of products in developing countries is substandard, and the addition of value so limited since the gains made are small but the reprocessing of some products requires considerable investment within the reverse logistics network (Fleischmann *et al.*, 2001).

In Uganda, reverse logistics as a topic is not known, but the activities embedded with in it are being practised by the people in some form of product recycling. Unlike the sophisticated reverse logistics chain and recycling systems in developed countries, the Ugandan system has developed from the traditional collection of organic matter mainly to feed animals, and then evolved to include the collection of metal scrap from all sources (Kinobe *et al.*, 2015b). The recovery of reusable materials is performed by people working in the informal sector who are driven by poverty and the activity acts as a source of income for many poor communities. The waste recycled and reused includes plastics, metals, food waste, polyethylene bags and sludge. There are no clear definitive conclusions that can be made on how much waste is recycled or reused due to the current lack of information.

Despite the low application of reverse logistics in developing countries, it has attracted significant attention in some operations organisations and waste management systems. For instance no matter what the product is, how it is sold or who the customers are, every organisation needs to focus on recovering the maximum value from returns. The application of reverse logistics in waste management involves the movement of products in the opposite direction of the supply chain, from a customer back to the supplier (Subramanian, 2000).

1.4 Waste management

1.4.1 Overview of waste management

Solid waste management is a growing problem in many urban cities in developing countries. The reason attributed to this is rapid urbanisation due to the population growth rates from rural areas to urban cities in search of a better life (Medina, 1997). On average the generation rates in most developing countries are between 0.3 to 0.6 kg per person per day compared to the 0.9-2 kg per person per day in developed nations (Kaseva and Mbuligwe, 2005, Troschinetz and Mihelcic, 2009, Karak *et al.*, 2011). Future projections estimate that the world's solid waste generation could reach up to 1.42 kg/capita/day (2.2 billion tonnes per year) in 2025 (Hoornweg and Bhada-Tata, 2012).

The limited waste collection in developing countries, including Uganda, is due to inadequate waste management budgets, poor management, weak legislation and equipment failures. In the developed world, legislation, regulations and action plans are in place in the planning of sustainable waste management. Generally, there is a lack of organisation and planning in waste management due to insufficient information about regulations and financial restrictions in many developing countries. The municipalities in these countries do not have the capacity to manage the increasing volume of waste, leading to about 35-40 % of the waste being collected and transported to a landfill (Rotich *et al.*, 2006, Parrot *et al.*, 2009, Nabembezi, 2011). During waste transportation, the trucks overflow and on many occasions litter the city with the waste. The trucks used are also manufactured in the context of developed countries and designed to handle a different kind of waste. This leads to constant breakdowns of these trucks.

The most common disposal method for solid waste in Africa is open landfills, with no environmental control. Many of these landfills have reached their capacities and in most cases the environmental conditions are very poor (Rushbrook, 1999, Remigios, 2010). This has caused considerable land degradation and contamination of underground water sources through leachate pollution. Air pollution is common on many of these landfills when burning waste. Diseases are spread by vector animals such as insects, birds and rodents. It is only recently that the problems of waste management in developing areas are being seriously addressed (Brunner and Fellner, 2007, Parrot *et al.*, 2009). In developing countries, solid waste management as a subject is normally neglected and not mentioned in many strategic planning processes for developments (Al-Khatib *et al.*, 2007).

1.4.2 Waste management and the Millennium Development Goals

Solid waste management has a significant impact on the lives, health and surroundings of all urban dwellers, particularly when there are inadequate waste collection services. Many populations in developing countries depend on waste management for their livelihoods, for instance by being employed in the formal public or private sectors for waste collection or employed in the informal sector collecting recovery products. Waste management can play an important role in achieving the Millennium Development Goals (MDG) (Table 1). Organised waste management can create employment, improve public health and protect the environment.

In September 2000, the Millennium Declaration was approved by 189 heads of state at the United Nations Millennium Summit. The Declaration outlines eight broad goals. Within these are eighteen targets, most of which were set for 2015 using 1990 as a benchmark and forty-eight indicators (UNDP, 2014). These MDGs represent a global commitment by all nations who signed the Declaration to reduce poverty and improve lives. The purpose of the MDGs was to improve the living conditions of poor people by adopting the goals. The policies of MDGs were to target the activities that can lead to the greatest benefits.

The structure below shows the MDGs and their relationship with solid waste management:

Table 1. *Structural relationship between MDGs and solid waste management*

Millennium Development Goal	Relationship with solid waste management
1- Eradicate extreme poverty and hunger	SWM leads to direct employment of people in the formal and informal sectors. In the formal sector, people are employed to manage waste, while informally people engage in waste picking in the case of recycling. These employment activities do lead to income generation.
2- Achieve universal primary education	Children are involved in the activity of waste picking, but these kids would have otherwise been at school. The activity of waste picking is to alleviate poverty and boost family income.
3- Promote gender equality and empower women	It is women in most cases who are engaged in the activity of waste recycling, hence they are vulnerable to all risks associated with hazardous wastes. The men are more inclined to load and transport waste. There is a need for women to be protected. It is mostly from waste materials that women make other products, especially handiwork.
4- Reduce child mortality	Some major killer diseases of children such as malaria and diarrhoea occur because of poor waste collection. Malaria, for instance, is due to the blockage of drainage channels by uncollected waste, while diarrhoea is transmitted by vector house flies from faeces to food. Burning of uncollected waste causes chronic respiratory diseases. Proper waste management will solve this issue.
5- Improve maternal health	Pregnant women working in recycling ventures at a landfill are more susceptible to diseases associated with solid waste, such as chronic respiratory infections and bacterial infections. They lack sanitary facilities at the landfill, hence their exposure.
6- Combat HIV, AIDS and other diseases	It is normally the informal sector that is engaged in waste management and these people are more susceptible to diseases. Hospital and clinic waste is easily infectious to the waste pickers and these people are unaware of the spreading channels of the diseases.
7- Ensure environmental sustainability	Reduction, reuse, recycle and energy recovery avenues should be adopted. Waste disposal in the environment should be checked.
8- Develop a global partnership for development	Need for cooperation with developed countries on issues of proper waste management such as research and new technological innovations.

1.4.3 Kampala waste management status

Solid waste generation and characteristics

In the last few decades waste generation has drastically increased. Approximately 1500 to 2000 tonnes of waste are generated in the city per day and this figure is predicted to increase in future (KCC, 2006). This is attributed to the demographic growth and economic development of the country. The urban population in 1969 was 33,070, in 1990 it was 774,241 and in 2002 it was 1,208,544 (UBOS, 2002) and this has further risen rapidly in the last decade with a population increase of 3.8 % (UBOS, 2012). A similar relationship of increased waste generation due to an increased population has been reported in many Sub-Saharan countries (Rotich *et al.*, 2006, Zhen-shan *et al.*, 2009). Waste composition is not uniform with respect to countries. It differs greatly between developed and developing countries due to inequality in income levels. As incomes increase so does waste generation. For instance in developing countries it ranges from 0.4 to 0.6kg/cap/day (Nabembezi, 2011, Ojok *et al.*, 2013), in middle income countries from 0.5 to 0.9 kg/cap/day and in industrialised countries from 0.7 to 1.8 kg/cap/day (Cointreau, 1982).

The waste generated includes household, commercial/institutional, street cleanings and industrial waste. Waste composition in Kampala, as in many developing countries, is dominated by organics that have a high moisture content due to the high proportion of kitchen waste (Ojok *et al.*, 2013, Oteng-Ababio *et al.*, 2013). In Kampala, the situation is aggravated due to the fact the city is situated in a tropical region that experiences high rainfall intensities (Ojok *et al.*, 2013). Biodegradable matter makes up about 80 % of the waste generated and this is in contrast to the developed world (Troschinetz and Mihelcic, 2009, Karak *et al*., 2011, Okot-Okumu and Nyenje, 2011). The waste is heterogeneous in nature and is not segregated from the household to the disposal site. This mixture includes a range of materials such as plastics, metals and hazardous materials that are difficult to deal with.

Collection

In Kampala, most waste is collected in two phases. The first phase is where waste is stored at the household and then when the need arises it is transported to the collection point, normally the temporary storage. The second phase is when waste is collected from temporary storage points and then transported to the final disposal site (Zhang *et al.*, 2010). Waste that is generated in the city is not segregated. Only about 40 % of the waste collected is transported to the landfill (Nabembezi, 2011, Kinobe *et al*., 2015c). The uncollected waste is dumped in open spaces, on streets, in markets, and in drainage and storm water channels. These uncollected wastes create health risks, while the heaped garbage on the streets becomes an impediment to traffic and an aesthetic nuisance in the city streets. It is the mandate of the city authority (KCCA) to manage waste generation in the city.

KCCA has trucks that are directed to collect waste in the city. The vehicle fleet used consists of old second-hand vehicles previously used by industrialised nations. The vehicles pollute the atmosphere and were not designed for the local conditions in Uganda. They were designed in the context of developed nations to handle the waste they produce and this differs from that of developing nations. These vehicles are sophisticated, expensive and not easy to operate or maintain.

Due to privatisation in Uganda, there has been a shift from a central operation to decentralisation, and hence the outcome of the private operators who obtain contracts from the KCCA to participate in waste collection for a fee. This idea of the privatisation of government organisations was enacted in the 1990s, and with the realisation that services were not efficiently and effectively delivered to the people, the government adopted the system of the decentralisation of services in 1997 (Okot-Okumu and Nyenje, 2011). On the side of waste management, the passing of the 2000 waste ordinance meant that power was passed to private operators from the city authority to collect waste. However, with this the municipal council is still responsible for the city’s solid waste management services. Contracts are awarded to qualified operators. Privatisation was prompted by the city authority being overstretched when it came to operating services and maintaining its fleet.

Disposal

Most landfills in developing countries are open and waste is dumped directly onto the land. There is only one recognised disposal site, known as Kiteezi. It is located about 12 kilometres from the city centre and is where collected waste from Kampala and its surroundings is disposed of. Before the landfill reached full capacity, it was 0.04 square km. After exhaustion, more land was acquired, making a total of 0.11 square km. Kiteezi is an open and unlined landfill with no groundwater protection and limited leachate recovery (NEMA, 2004, KCC, 2006). The landfill is an ecologically sensitive area where groundwater supplies are threatened because it is located on a wetland. There is susceptibility to both surface and groundwater pollution (Kaseva and Mbuligwe, 2005). The area is a breeding ground for rats, flies, birds and other organisms that serve as disease vectors. The landfill is encircled by settlements and housing, posing a health risk to the people living nearby. The waste pickers at the landfill burn the waste to reduce its capacity. The smell is a nuisance and discomfort to the people because the waste is not segregated. Burning of medical and industrial wastes produces gases that when inhaled cause health hazards to the surrounding community (Hu *et al*., 2002, Jang *et al*., 2006).

1.5 Optimised routing of waste

The application of route optimisation in the field of waste management is still a new concept and very few urban authorities in developing countries consider having it in effective waste collection (Badran and El-Haggar, 2006). Waste collection is one of the most important and costly aspects of waste management as it represents over 70 % of the total budget of waste management (Ghose *et al.*, 2006, Rotich *et al.*, 2006, Hoornweg and Bhada-Tata, 2012). Collection of waste has posed a considerable number of operational problems for local authorities in many cities, involving tasks such as optimal fleet size, type and scheduled route (Torres and Anton, 1999). This has provided great opportunity for research to be conducted and to find better cost-saving measures for municipal authorities. Added to the high costs of operating and maintaining vehicles, there is concern that these heavy trucks have a negative impact on the environment due to the quantity of miles driven, fuel type, engine inefficiency and exhaust gases emitted. Sahoo *et al*. (2005) in their study of route optimisation of wastes assert that in order to achieve an effective waste management system, it is necessary to reduce operational expenses and optimise vehicle fleet size.

The major shortfall during waste collection in many developing countries is that the collection vehicles are sent to collect waste from different areas in a random manner, making it ineffective (Kinobe *et al.*, 2015c). The fleet of vehicles is not optimised at all. Transport vehicles do not follow scheduled routes and sometimes double handling of waste becomes inevitable. The available vehicle types are designed to handle one type of waste stream, they lack compartments to collect different type of waste, and none of the waste is segregated. Waste loaders who perform out the action of picking out recyclable products do sort these unsegregated wastes before it is loaded onto the vehicles, taking up a considerable amount of time (Wilson *et al*., 2009, Wilson *et al*., 2006).

Effective decision-making in the field of management systems requires the implementation of vehicle routing techniques capable of taking advantage of new technologies such as the geographic information system (GIS). Since routing models make extensive use of spatial data, GIS can provide effective handling, display and manipulation of such geographical and spatial information (Ghose *et al*., 2006, Bosona *et al*., 2013). These tools eliminate hours spent on unplanned routing, maximise productivity, optimise equipment and staff allocations, and allow better control of waste collection operations. These tools work with a computer software application that generates efficient vehicle routes for solid waste collection over a road network and can be used for recycling collection services.

There is an increasing awareness and need for municipal authorities to reduce their overall operational costs. The use of GIS technology is one aspect that cost-conscious decision makers implement to keep costs down. This is because GIS provides a powerful resource for identifying cost savings in an efficient way. One of the main aims of optimised routing is to minimise travel distances and reduce the fleet size (Nuortio *et al.*, 2006) through the design of the optimal and cheapest distribution pattern to serve scattered customers. Through the optimised routes it is possible to measure the efficiency of a management system, for instance generating an optimal route for a given vehicle will help minimise the cost. The optimal routes are then determined by comparing the different paths. These paths can be calculated by different types of algorithms such as Tabu search, ant colony optimisation and genetic algorithm (Karadimas and Loumos, 2008).

1.6 Facility location

Facility location is one of the most widely studied location problems in operations research as its application is widely used within SCM and reverse logistics (Melo *et al.*, 2009). Facility location involves a selection of a variety of sites where new facilities are to be located and the selection can be based on a number of parameters, for instance a minimum travel distance or less fuel use. An assumption, however, of this is that all the given sites have equivalent terms in relation to the set-up costs for the location of the new site. A variety of factors play an important role in facility location. These include distance, available space, raw materials, labour, market and government policies, to mention just a few. All these factors have to be analysed and a decision reached as to the best site. Siting a location for landfill requires a wide and vigorous evaluation process to come up with a sustainable disposal location that must follow the governing regulations and at the same time consider economic, environmental, health and social impacts (Wilson *et al.*, 2007). Traditionally the closer the facility is to a customer, the better the value of the product function.. However, this is not the case because other factors are left out, such as environment, that could be far more important and high investment costs are associated with the process because it is considered a long-term investment and is expected to remain in operation for a long period of time. As such only a single method has to be used in order to achieve the desired location of the site (Owen and Daskin, 1998). There are a variety of facility location techniques to be used to decide the best alternative for a site's location. The commonly used method in this context is factor rating (Ozcan, 2005, Kumar *et al.*, 2009, Bosona *et al.*, 2013). This method involves qualitative and quantitative inputs, and evaluates alternatives based on a comparison after establishing a composite value for each alternative. The steps taken include:

1. Finding out all the important factors needed to locate a site
2. Assigning a weight to each factor. Normally this ranges from 0 to 1.00
3. Assigning a subjective common scale to all the factors ranging from 0 to 100
4. Multiplying the weight factor by the score factor, then adding the scores together
5. Taking the facility with the highest score as the best option.

2 Objectives and structure

2.1 Objectives

The main objective of the study was to assess urban solid waste management including collection, transportation, recycling and disposal to reduce the impact of waste on health and the environment.

The specific objectives were to:

- carry out an extensive literature review and examination of the theory of reverse logistics and how it is related to waste management in developing countries (Paper I)
- map out the waste collection system in Kampala (Paper II)
- perform an optimisation analysis in terms of determining the location of dumping points and landfill sites and route optimisation of the waste collection system from Kampala to the final disposal landfill (Paper III)
- analyse the reverse logistics systems at the final disposal at the Kiteezi landfill (Paper IV).

2.2 Thesis structure

The thesis structure is based on Papers I-IV and the relationship between these papers is shown in Figure 2. The overall outcome of the study could lead to improvements in the environment, health, the sustainability of resources and the mobility of Kampala's solid waste management.

Paper I reviewed literature that provided a good understanding of urban solid waste management globally and that of Kampala in particular. This in turn enabled the rest of the studies in Papers II-IV to be planned and executed. The paper provided an overview of the state of the art in reverse logistics, and determined the extent of reverse logistics and waste management activity in low income countries. The paper considered waste management aspects including generation rates, composition, collection, storage, reuse and recycling and final disposal. In Paper II, the aim was to map the waste collection system in Kampala, so as to analyse the waste management problems and practices experienced in managing solid waste. In the paper, it was intended to characterise the waste in terms of quantity and quality, and to describe the models of waste collection from the existing official, unofficial and illegal dumping sites in the city. Paper III proposed and designed an optimisation of routes to be followed by trucks during waste collection. The paper suggested an optimal number of vehicles to be used by the authority in waste collection. Furthermore, Paper III proposed an optimal new dumping landfill with regard to travel distance. Paper IV reported reverse logistics activities at the Kiteezi landfill in terms of product distribution channels and information flow through reverse logistics activities of collection, sorting, reuse, recycling, remanufacture and final disposal. Paper IV presents a study of product recovery from the disposal site to other destinations.

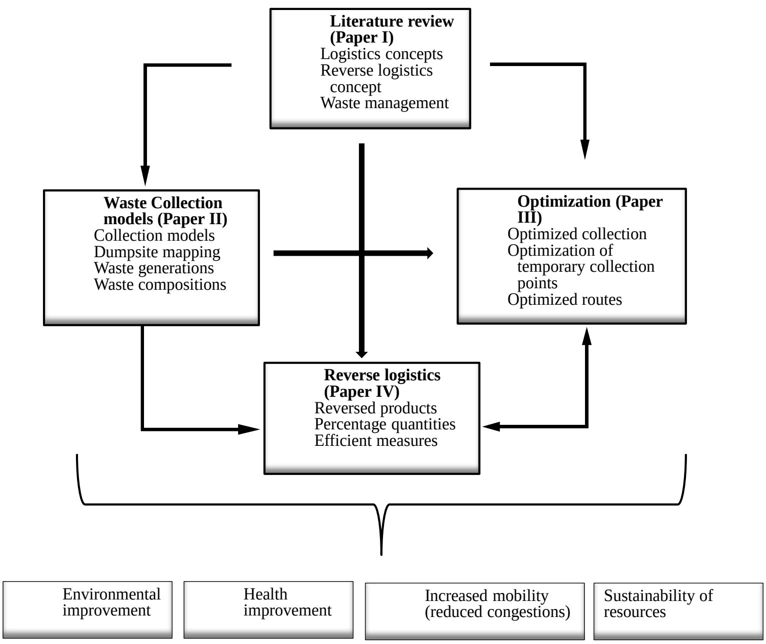

Figure 2. Structural relationship of the thesis

3 Materials and methods

3.1 Study area

The study was carried out in two areas: the city of Kampala and the Kiteezi landfill (Fig. 3). Kampala is Uganda's capital and its only city at the moment. The research was undertaken in the five divisions (Central, Kawempe, Makindye, Nakawa and Rubaga) of the Kampala district. The city has about 99 parishes (townships) with a population of about 1.72 million people during the night (UBOS, 2012). The Kiteezi landfill is the only recognised landfill at which waste from Kampala is disposed. The landfill was opened in 1996 and is located in Gayaza, about 12 km from the city centre. Initially, the total land area in Kiteezi was 0.04 square kilometres. When it reached full capacity, more land was acquired, making a total of 0.11 square kilometres (KCC, 2006). The landfill is an open space with limited restriction for entry, especially when it comes to waste pickers (Papers I-IV).

3.2 Data collection

3.2.1 Literature review and questionnaire development

The research was carried out using both qualitative and quantitative methods to increase the validity of the results. The qualitative approach was applied to study the problem comprehensively using data gathered through different methods such as interviews, questionnaires, observations, surveys and document analysis (Papers I-IV). The quantitative approach was used to analyse quantitatively waste generation, collection, transportation and disposal. These quantitative analyses were based on data gathered using structured data survey formats and interviews, field measurements and field observations (Papers II-IV). A comprehensive and extensive literature review of concept studies was conducted from published and unpublished government and non-government reports and publications.

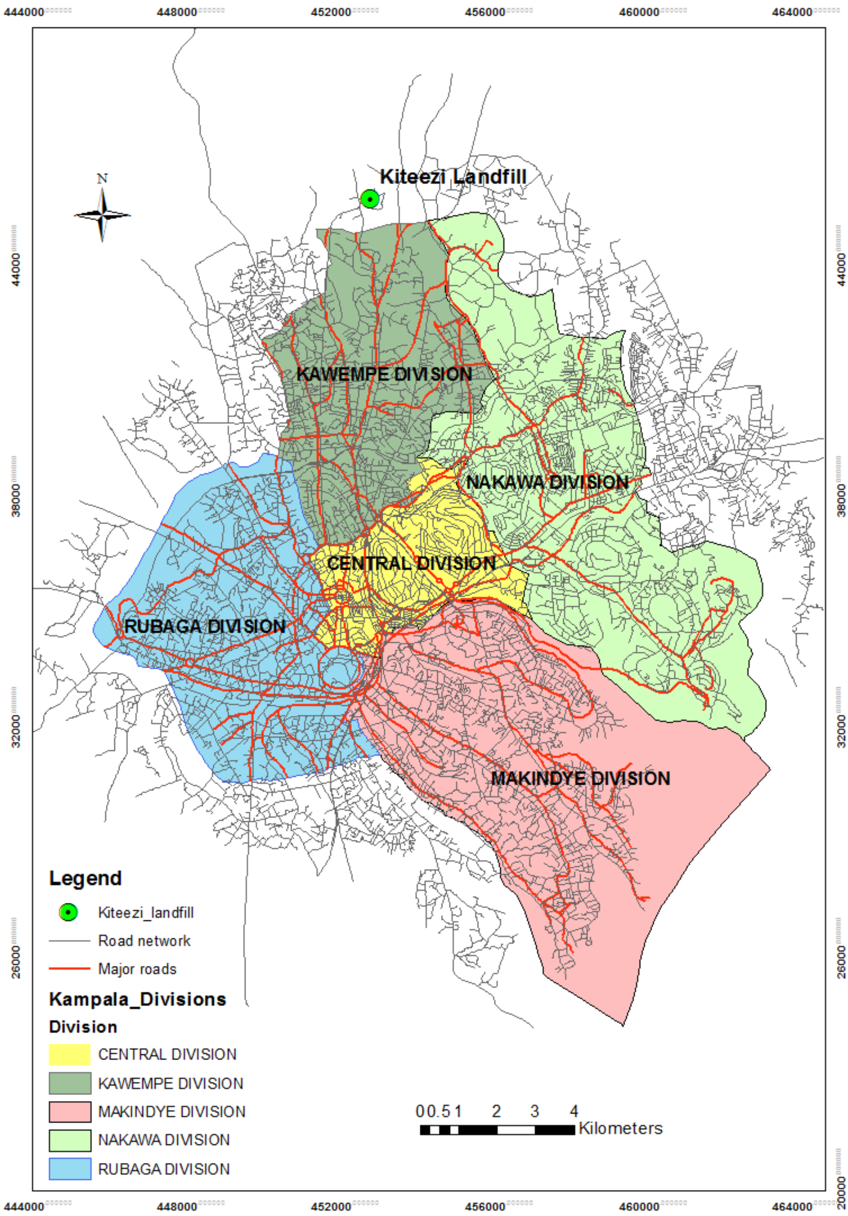

Figure 3. Map of Kampala with divisions and the location of the Kiteezi landfill

A thorough online database search was conducted using particular keywords in academic journal articles to investigate logistics, reverse logistics (Papers I & IV), waste management (Papers I & II), route optimisation, facility location (Paper III) and reverse logistics (Paper IV).

3.2.2 Field work

Field work involved primary and secondary data. Primary data included using structured and unstructured interviews, surveys and observations (Papers II-IV). The reasons for the structured questionnaire were to provide room for flexibility in order to acquire more information and even adjust the questions. The interviews were conducted with formal and informal informants (Papers II & IV).

Structured interviews were conducted with households (Paper II), waste pickers, scavengers, waste loaders, small-scale shop dealers of recyclables and small-scale recycling plants (Papers II & IV). Unstructured interviews were conducted with KCCA staff, the records manager at the Kiteezi landfill, supervisors of solid waste collection at divisional level, private operators of solid waste collection, truck drivers and waste recyclers (Papers II & IV)

3.3 Data analysis

Spreadsheet software in Microsoft Office Excel was used for data entry (Papers II-IV), and for quickly manipulating rows and columns prior to statistical analysis (Papers II &IV). The software has a collection of statistical functions, and a Data Analysis Tool Pak (Paper IV). The software allows integration and modification of several variables used in route modelling (Paper III).

The study involved the use of global positioning system (GPS) and geographical information system (GIS) techniques. ArcGIS was used to manage large amounts of spatial data including maps, locations and distances (Papers II-IV). GPS was used to collect data on temporary collection points and routes (Papers II & III). GPS is highly accurate at collecting and storing data that were later integrated into and managed by GIS software (Fig. 4). In Paper III, the GIS software extension Network Analyst was used to calculate the shortest distance path computed by obtaining the minimum impendences between the temporary collection points and the final disposal landfill. ArcGIS Network Analyst is a powerful extension that provides network-based spatial analysis including routing, travel directions, the closest facility and service area analysis (Ghose *et al.*, 2006).

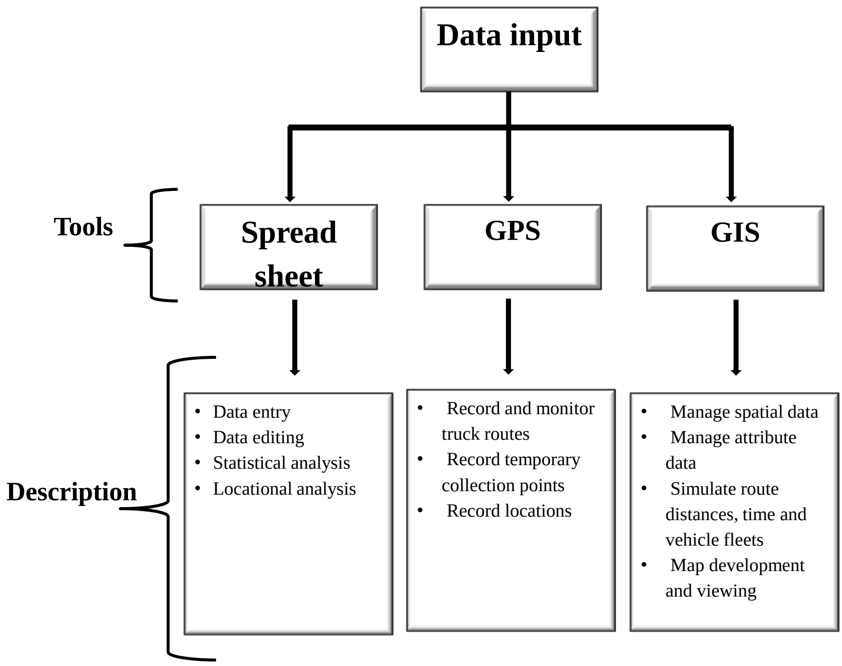

Figure 4. Methodological structure applied in Papers II-IV

3.4 Waste generation and composition

For Paper II, data on the generation of waste delivered to the Kiteezi landfill was collected for a period of seven months, from December 2011 to June 2012. Trucks that collected solid wastes were weighed using a weighbridge and the loaded truck weight recorded (weight one). After offloading solid wastes, the trucks were weighed again (weight two). Weight two was subtracted from weight one to get the actual weight of solid waste. Truck information about the origin of the waste was recorded at the landfill office and this was helpful for distinguishing between the different areas of waste generation. In Paper III a figure of 40 % for the collection of waste generated was obtained for a period of two months (May and June 2013). At 40 % about 615 tonnes are collected and disposed of at Kiteezi and this was the figure that was used for route optimisation.

With Paper IV, the survey was carried out for a period of six months from December 2012 to May 2013. Samples were picked in the first and last week of the month for five consecutive days, with each day allocated to a division

(Central for Monday, Kawempe for Tuesday, Makindye for Wednesday, Nakawa for Thursday and Rubaga for Friday). A truck schedule for that day from each of the five divisions was randomly selected and its waste analysed. Ten Kampala Capital City Authority (KCCA) trucks were sampled per month, giving a total of 60 truck trips for the entire six-month period. Samples were sorted, classified and weighed in ten categories of waste stream, including organics, earth materials, hard plastics, soft plastics, paper, metals, glass, vegetation, textiles and other wastes.

Paper II classified and categorised waste collection models. In the study, waste collection models referred to the classification of the existing waste collection arrangements (concepts) in Kampala. These included poor areas, medium to upscale wealthier areas, institutions, business centres and market areas. Waste from the different areas was weighed and quantified. The aim was to identify waste generation by each model.

In Paper II, a waste composition survey was obtained by randomly picking two KCCA trucks from each division on a bi-weekly basis for a period of two months and separating the waste into the categories of organics, plastics, paper, glass, metals and other special wastes such as medical waste.

The categorisation of waste in Papers II and IV involved collecting, sorting and weighing individual categories of the waste stream. An area at the landfill about 7 m in length and 3 m wide was graded flat by a grader on which waste trucks dumped tips of waste approximately 1 m high at a time. The waste tips were then spread on the flat ground using a forked hoe. The waste was then categorised and deposited on a cleared area covered with a high density polyethylene (HDPE) liner and then weighed. The aim was to know the composition of waste from Kampala.

The classification of waste for the Paper IV study was focused more on the "potential use" and willingness to pay for the products sorted from waste to estimate the amount of waste that leaves the landfill. This was followed by an organisation structure of product collection and redistribution to final destinations. The network of recovery options undertaken were reuse, recycling and final disposal with subsequent approaches and outcomes.

3.5 Description of waste collection points

In Papers II and III, these temporary collection points were used as waste collection sites (official and unofficial) where trucks picked up waste (Table 2 and Fig. 5). These temporary collection points were characterised by waste fluctuations, especially with the unofficial temporary storage sites and illegal collection points. This was because at any time these sites could be removed by the authority in consideration of the laws and policies governing waste dumping and the same collection points would re-appear after some time.

Table 2. *Temporary collection point site type, description and location*

Temporary collection points	Description	location
Official temporary storage sites	Sites demarcated as KCCA waste collection sites. Originally these were sites where KCCA skips were located, but after the introduction of the compactor trucks, these skips/temporary collection sites were removed.	Market areas, public parks, public organisations and roadsides
Unofficial temporary storage sites	Sites that were not demarcated by KCCA but were being used by people for dumping waste and these wastes were collected by KCCA but were not recognised by KCCA as official temporary collection sites.	Along unrecognised places such as roads, open spaces and drainage channels
Illegal dump sites	Areas where people dumped waste and this waste was not collected by KCCA. The waste was left to rot, creating a nuisance to the community and some of it was burnt by a concerned person.	Along unrecognised places such as roads, open spaces and drainage channels

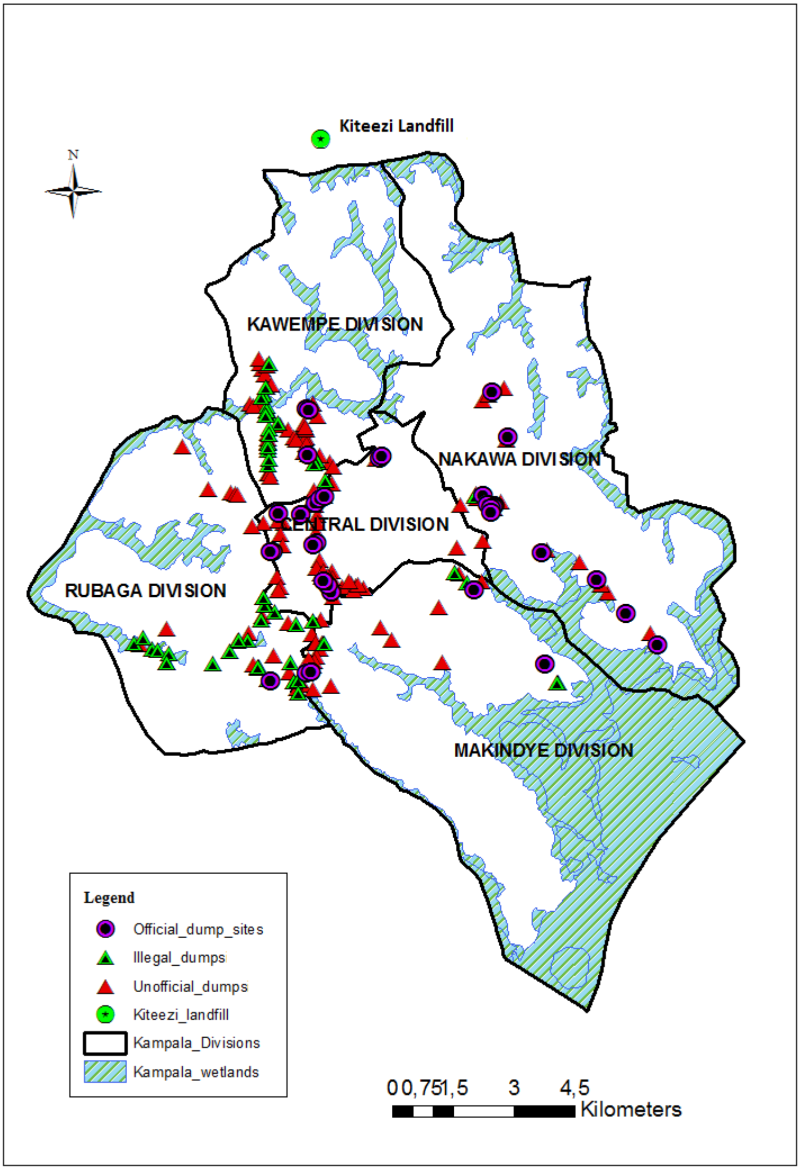

Figure 5. Kampala's official, unofficial and illegal temporary collection points (Paper II)

3.6 Waste generation analysis

The estimation of waste generation in Paper III was calculated with reference to (Robinson, 1986, Ojok *et al.*, 2013) and data obtained at the landfill for a period of two months where a total of 615 tonnes of waste were collected and disposed of at the landfill. The population of the parish was known and the total waste generated in the division was known. Therefore, the per capita waste generated is the total waste generated in the division divided by the population of that same division. This is further multiplied by the population of the parish to obtain the waste generated per parish using the formulae below (Ayininuola and Muibi, 2008):

$$pw = \frac{k}{tp} \tag{1}$$

$$wt = pw \times pp \tag{2}$$

where *pw* is per capita waste generation per day, *k* is the total waste generated per division that is collected, *wt* is waste in tonnes in a parish, *pp* is the parish population and *tp* is the total population of the division. KCC (2006) and Ojok *et al.* (2013) report that about 40 % of the waste generated is transported to the landfill. Figure 9 shows the calculated tonnes of waste generated and the projected waste at 100 % waste collection. With Paper III, a total of 615 and 1538 tonnes of waste per day was generated and collected at 40 % and 100 % waste collection respectively. The waste generated was computed from the population and per capita waste generation. The 40 % waste collected per temporary collection point in each is computed from the total waste generated by the division and the population. This was again computed from the waste generated and the population. The parish waste generation of tonnes was divided by the population to get the per capita waste generation (see formulae 1 and 2). The 100 % waste collection was computed from the waste generated per parish per division from the difference of 40 % using formulae 1 and 2. The amount of waste generated at the temporary collection point was computed by dividing the tonnage of waste produced in the parish by the number of temporary collection points. Table 3 gives an example of the calculated waste generations. The computed results (*wt*) were used for the network analysis for optimisation.

Table 3. *Rubaga division waste generation for temporary collection points*

Rubaga division parishes	Population	Total waste generation at 100 % (tonnes)	Total waste generation at 40 % (tonnes)	Number of temporary collection points	Temporary collection point waste (tonnes)
Busega	32600	22.82	9.12	5	4.56
Kabowa	41100	28.77	11.50	7	4.11
Kasubi	63200	44.24	17.69	14	3.16
Lubia	50500	35.35	14.14	6	5.89
Lungujja	28100	19.67	7.9	6	3.28
Mutundwe	39100	27.37	10.98	5	5.47
Najjanankumbi I	17700	12.39	4.95	4	3.09
Najjanankumbi II	15600	10.92	4.36	10	1.09
Nakulabye	28700	20.09	8.03	7	2.87
Namirembe	22100	15.47	6.18	5	3.09
Nateete	34500	24.15	9.66	8	3.01
Ndeeba	24200	16.94	6.77	15	1.12
Rubaga	30300	21.21	8.48	13	1.63
Total	427700	299.39	111.8	105	42.41

3.7 Waste collection vehicle

In Paper III, the major truck vehicle model used in waste collection was the Faw box body compactor in a category of a diesel heavy duty with a six-cylinder engine and an average volume capacity of 6 tonnes when full to the maximum (Fig. 13). Apaydin and Gonullu (2008) report that on average the truck consumes 0.33 litres of fuel per kilometre. The truck had labourers consisting of a driver and about four to five crew members depending on their availability on a particular day because they were taken as casual labourers for loading waste. The study focused on a daily routine of waste collection where each vehicle was assumed to leave the start point that was the divisional headquarters before moving into the division for pickups characterised by constant stops at temporary collection points until it is full and then driving to the landfill. The assumed travel speed of the trucks was 30 km/hour though the anticipated and required travel speed was estimated at 50 km/hour (MoWHC, 2004). This could no longer be achieved because the speed (50 km/hr) was developed at a time when the city had few vehicles and more so due to the constant traffic jams, nature of the roads with potholes, reckless driving and riding from other motorists, plus the weight of the vehicle when loaded.

3.8 Vehicle routing (VR) methodology scenarios and description

The optimal truck routes were developed using GIS ArcMap software to find the shortest distance from the source (start) point then temporary collection point and finally to the landfill. The speed of the trucks was assumed to be the same because one common type was used. The software calculated the distance and travel time of the truck per trip. Using the GIS software, Arc map tools were used to build a network database of the routes and the data was stored in polylines, shapes, nodes and arcs. Within the GIS software, an extension tool of Network Analysis was applied in vehicle routing to determine the shortest route from the collection points to the landfill (Ghose *et al.*, 2006, Tavares *et al.*, 2009). The software found the closest temporary collection point and capacity of waste to be picked up then built up the route for the whole waste to be hauled. In the study, the service time was assumed to be similar (time of fuelling and loading of waste).

The VR methodology in Paper III comprised two approaches, namely the heuristic and deterministic ones (Nagy and Salhi, 2007) and included the following routing algorithms:

a) recording some of the current routes followed by the trucks and then optimising the routes

b) creating optimised routes to the Kiteezi landfill with reference to the official and unofficial dumpsites per division using the current six-tonne trucks and proposed 10 and 18-tonne trucks to solve the routing problem at the current 40 % and at the projected 100 % waste collection (improving the initial available system with the current trucks and increasing the fleet with a higher tonnage)

c) creating optimised routes by employing an outsourced private operator using 20-tonne capacity trucks to transport waste to Kiteezi and the new proposed landfill sites

d) performing location analysis to propose new landfill sites taking into consideration the sites proposed by KCCA with an emphasis on travel distances.

For the current recorded routes, optimisation was based only on distance travelled and time taken without considering other factors such as weight of waste and loading time.

3.9 Vehicle routing development and assumptions

Optimised routing of distances was solved per division, where the same vehicle model (Faw box body compactor trucks with capacity of 6 tonnes) started the journey at the divisional headquarters and made multiple trips, starting at 08:00

at the divisional headquarters and returning at the end of the day at 22:00, with a service time of 20 minutes at each stop (fuelling at petrol station and loading of waste). With the outsourced private operator, the starting point was the central divisional headquarters because it is centrally located for all the divisions to access. The collection vehicle stopped at temporary collection points (official, unofficial and illegal: 459 in number) (Fig. 6). From the first temporary collection point, the truck moved to the next optimised dump until it filled its capacity and thereafter travelled to the landfill for disposal, taking into account minimisation of distances.

Optimised routes were created using the available six-tonne Faw box body compactor truck and proposed 10 and 18-tonne trucks to Kiteezi and the proposed new landfill to solve the scenario at 40 % and 100 % waste collection. The outsourced private operator was assumed to use 20-tonne capacity vehicles to create optimised routes to the new proposed landfills. The VR constraint faced was the homogeneity in make and capacity of the vehicle used (Faw box body compactor); no route barriers were included, such as the high traffic flow causing the slow speed of the trucks, and waste fluctuations in the parish were not considered.

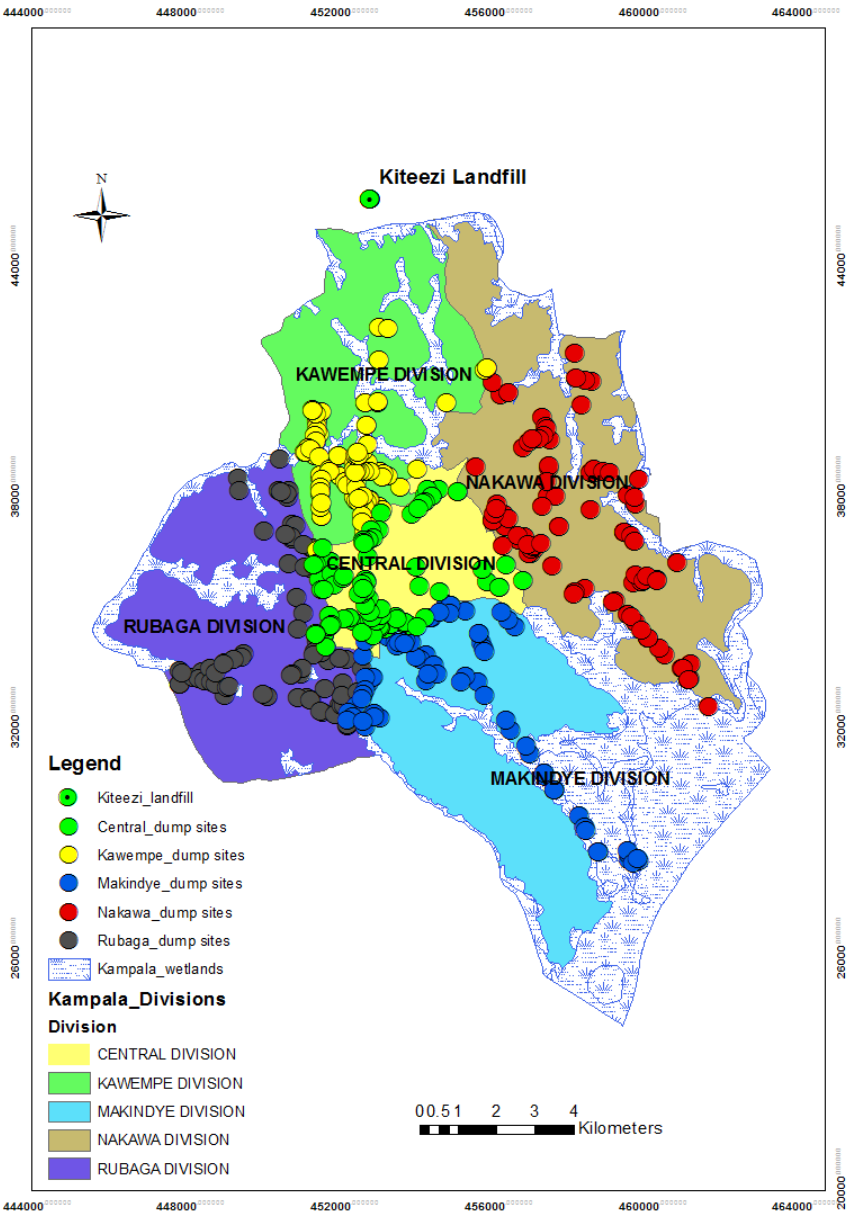

Figure 6. Map of Kampala with temporary collection point locations in each division (Paper III)

4 Results

4.1 Waste generation and composition

In Paper III it was reported that waste generation in Kampala was 1538 tonnes per day, of which only around 615 tonnes were collected and taken to the Kiteezi landfill, constituting 40 % of the waste generated. The distribution of this waste per division at 40 % collection by KCCA and what is projected at 100 % is reported Figure 7. Paper II compared waste collection between KCCA and private operators and the results showed that of the total waste collected and disposed of at the landfill in Kiteezi, KCCA accounts for about 70 % (670 tonnes) of the waste, while private operators only collect about 30 % (270 tonnes) of the waste. In total about 940 tonnes of waste are collected from the city and taken to the landfill by both KCCA and private operators.

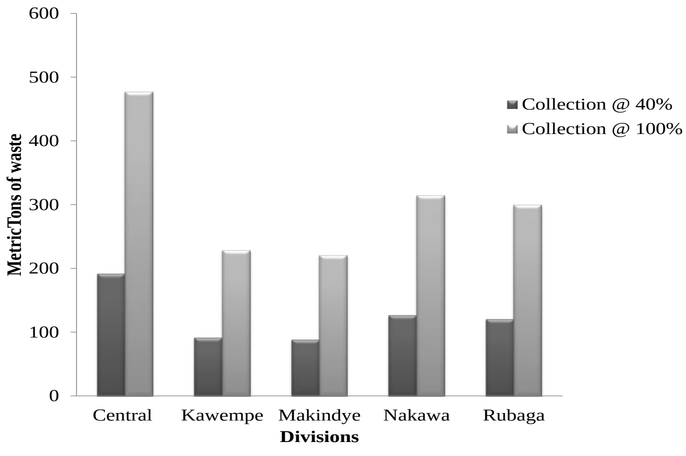

Figure 7. Waste generation comparison at 40 % and 100 % waste collection by KCCA

The major wastes generated were food, vegetation (leaves and stalks, spoilt market residue), paper, plastic, packaging materials, construction debris, broken glasses, textiles, ashes, street sweeping and metal scrap, with 92.7 % biodegradable, as reported in Paper II. The waste was mixed and unsegregated (Fig. 8).

Figure 8. Mixed dumped waste along a road

4.2 Waste collection system model

Waste in Kampala is collected and transported to the disposal area through different systems. Waste collection was wholly done by KCCA in the poor areas and markets, totalling about 71 % of the waste from Kampala to the landfill. The private operators managed about 29 % (business centres and upscale residential areas) of the collected and transported waste to the landfill (Fig. 9). In the study, the identified waste collection systems (four in number) were classified as model collection systems as presented in Figure 10.

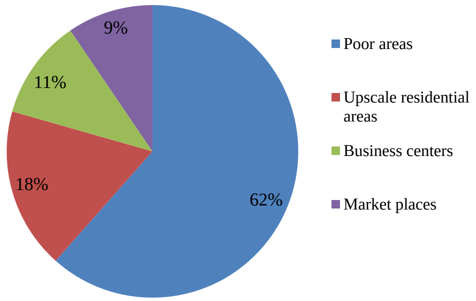

Figure 9. Waste collection per model

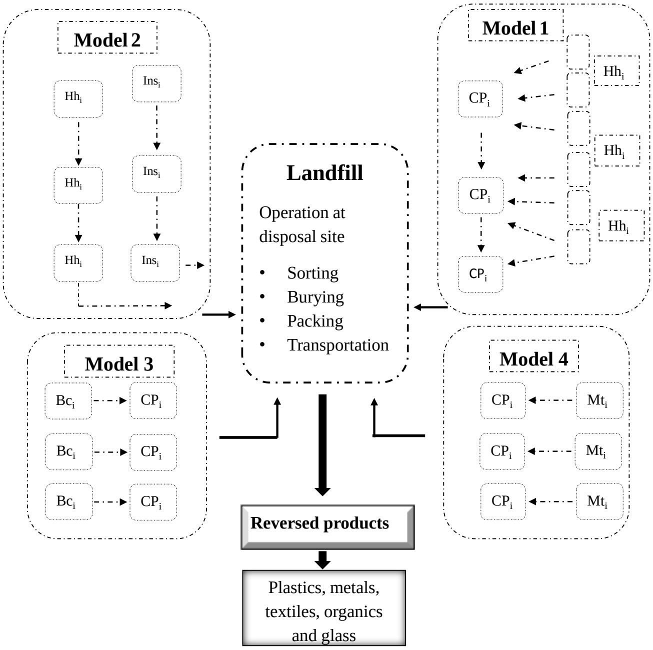

Figure 10. Multi-model waste management supply chain: CP, collection point; Hh, household; Ins, institutions; Bc, business centres; and Mt, markets

4.2.1 Model 1, poor areas/households

In this model, the households are located in informal areas inhabited by low income earners characterised by poor accessibility and poor living conditions. Waste is stored in buckets and old plastic sacks until it accumulates to about 30-50 kg. The waste is then transported to an unofficial collection site, normally located along the main road or street next to drainage channels for secondary collection by the waste management authority or its contractors. However, KCCA is the main operator and the responsible party for waste management in these areas. These areas were responsible for generating 17,449 tonnes (over 60 %) of the waste taken to the landfill.

4.2.2 Model 2, upscale residential areas and institutions

This model is associated with upscale residential areas and institutions inhabited by more affluent people. Waste generated is initially temporarily stored in a legal demarcated place in polyethylene bags and collected regularly to a timetabled schedule. The main operators in these areas are private operators because the inhabitants can afford to pay for the services of waste collection. KCCA carries out some waste collection, especially street sweeping and collection of tree cuttings and leaves. Households pay a monthly bill that ranges from 30,000 to 70,000 Ugandan shillings for door-to-door emptying of the storage bags, while for institutions the bill ranges from 30,000 – 100,000 Ugandan shillings depending on the size of waste generated. Willingness to pay for the service in these areas is high. About 5,059 tonnes of waste was generated per month.

4.2.3 Model 3, city centre and business areas

Here waste collection is targeted at the central business centre and commercial area of Kampala. Both KCCA and private operators carry out the activities where the central business areas are operated by private companies where the beneficiaries pay a monthly bill of 10,000 – 100,000 Ugandan shillings (depending on the size) per shop located in a particular building. Plastic bags and bins of differing colours according to a particular private company are provided and given to the waste generators. These are then collected by each private company referring to the colour they provided while leaving the colours that are not for their company. This model generated 3,319 tonnes.

4.2.4 Model 4, market areas, public park areas, street sweepings and drainage channel de-silting

The main actor in this model is KCCA which collects waste in the major markets of the city. All activities involving street sweepings, drainage channel de-silting or generating waste within the city are taken care of by this model, with the least waste generation of 2,700 tonnes monthly.

4.3 Waste dumping types and locations

A survey performed in Paper II reported that 227 temporary collection points were located and mapped in Kampala, with more unofficial temporary storage sites (133, constituting 59 %), illegal temporary collection points (59, constituting 26 %) and official temporary storage sites (35, constituting 15 %) (Fig. 11). Kawempe division had more temporary collection points (89) than any other division and Makindye had the least number of temporary collection points (23). Rubaga division had more open spaces (30) as illegal temporary collection points and the Central division had only one illegal temporary collection point. Nakawa division recorded more official temporary collection points while Makindye had only one official temporary storage point. Likewise Kawempe division registered more unofficial temporary storage temporary collection points (57) compared to Nakawa with only 15 unofficial temporary collection points.

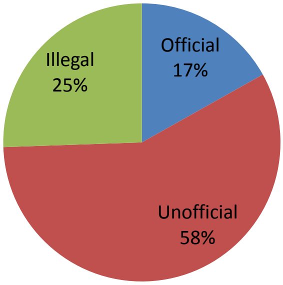

Figure 11. Waste dumping options in the city

4.4 Route optimisation scenarios

4.4.1 Application of recorded routes

A total of 21 truck routes from the divisions were studied and recorded. The recorded distance and travel time of the routes was 624.2 km and 1407 minutes. After optimisation and changing the visiting orders, this came to 506.9 km and 1161 minutes, giving a simulated benefit of 19 % and 17 % respectively of distance and time (see Table 4). One of the recorded and optimised routes is given in Figure 12.

Table 4. *Some of the current routes measured and optimised*

	Recorded		Optimised		Benefit %	
Route	Travel Distance Km	Time mins	Travel Distance Km	Time mins	Travel Distance Km	Time mins
Banda 2	29.3	90	27.0	85	8	6
Central 2	19.1	41	15.5	33	19	20
Ggaba	33.9	71	33.9	71	0	0
Industrial area	27.3	57	24.6	52	10	9
Kisasi	24.6	52	23.9	51	3	2
Kiwatule	25.1	53	24.3	52	3	2
Luzira	32.6	68	32.1	67	2	1
Mulago	20.2	43	14.2	31	30	28
Rubagashp	21.0	45	20.5	44	2	2
Rubaga1	22.5	48	17.7	38	21	21
Banda 1	25.6	82	23.8	79	7	4

Central 1	22.7	48	20.4	44	10	8
Nakawa market	23.8	50	15.5	34	35	32
Nakawa naguru	20.4	44	15.7	34	23	23
Nakawa spear	32.4	108	27.3	58	16	46
Rubaga2	23.9	51	21.3	46	11	10
Rubaga3	51.0	105	35.6	75	30	29
Rubaga4	45.8	95	29.9	90	35	5
Rubaga5	31.9	68	25.9	56	19	18
Kawempe1	19.7	42	15.2	33	23	21
Ggaba2	71.4	146	42.6	88	40	40
Total	624.2	1407	506.9	1161	19	17

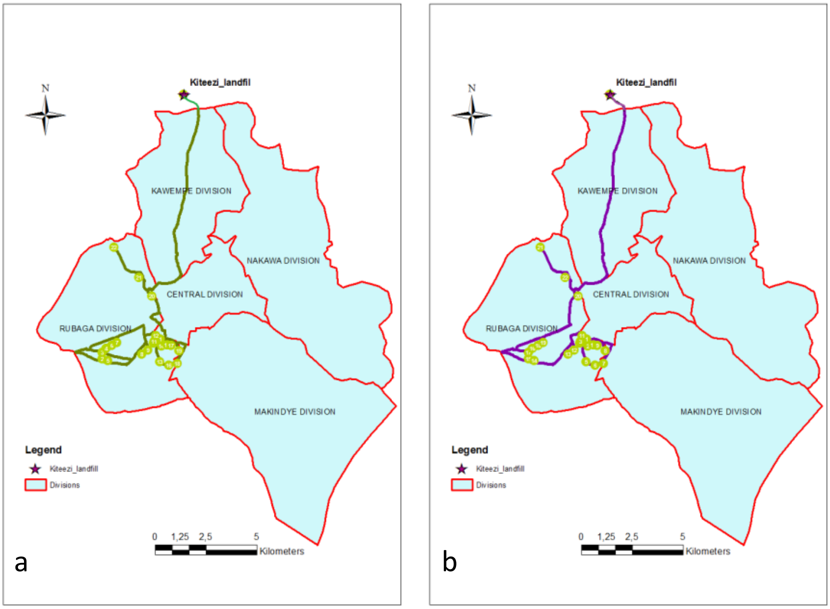

Figure 12. Comparison of a recorded route (a) and optimised route (b)

4.4.2 Optimisation route scenarios at 40 % and 100 % waste collection

Results for routes optimised at 40 % and 100 % waste collection using six-tonne, 10-tonne and 18-tonne trucks per division are presented in Table 5 and Table 6 respectively. The results indicated that in order to increase the waste collection in the city at both 40 % and 100 % waste collection, there should be an increase in truck capacity. There was a significant improvement in the number of trips made and distance covered with an increase in the vehicle capacity that reduced the fleet vehicle number. For instance in the 100 % waste collection scenario, when the truck capacity is increased from six tonnes to 10 and then 18 tonnes, the distance reduced from 3687 km (six tonne) to 2182 km (10 tonne) and subsequently to 1219 km (18 tonne) (see Table 6). This again is reflected in the reduction number of trips made (43 % from 6 to 10 tonnes and 48 % from 10 to 18 tonnes). However, a greater improvement is realised from the six-tonne trucks to 18-tonnes of 67 %, 45 % and 70 % with distance, time and trips respectively.

Table 5. *Optimised routes at 40 % waste collection using six, 10 and 18-tonne trucks*

		Optimised using six-tonne truck			Optimised using 10-tonne truck			Optimised using 18-tonne truck		
Division	Metric ton	Trips	Travel distance km	Time hours	Trips	Travel distance km	Time hours	Trips	Travel distance km	Time hours
Central	191	22	319	56	13	204	45	7	122	39
Kawempe	91	13	126	45	8	86	39	5	59	37
Makindye	88	12	251	42	7	151	34	4	101	31
Nakawa	126	19	410	60	11	225	43	6	165	41
Rubaga	120	16	301	49	9	187	41	5	116	36
Total	615	82	1407	252	48	854	202	27	564	184

Table 6. *Optimised routes using six, 10 and 18-tonne trucks at 100 % waste collection*

		Optimised using six-tonne truck			Optimised using 10-tonne truck			Optimised using 18-tonne truck		
Division	Metric ton	Trips	Travel Distance km	Time hours	Trips	Travel Distance km	Time hours	Trips	Travel Distance km	Time hours
Central	477	56	752	98	40	549	80	18	265	55
Kawempe	228	30	450	68	17	264	52	10	161	43
Makindye	220	32	612	69	17	361	50	9	215	39
Nakawa	314	52	1035	109	27	573	74	15	331	56
Rubaga	299	48	838	92	24	435	61	13	248	47
Total	1538	218	3687	436	125	2182	317	65	1219	241

4.4.3 Optimised routes to proposed new landfills

Due to the exhaustion and near full capacity of the current landfill, there is a need to propose new landfill. The identified proposed sites were Busukuma, Kalagi, Semuto, Wakiso and Zirobwe. Optimised routes at 100 % waste collection using six-tonne, 10-tonne and 18-tonne trucks were used and a comparison made between the current Kiteezi landfill and other sites. Results showed that there was no significant difference in trips made to the proposed landfill sites using the different truck capacity size to all the sites. However, there was a great variation in travel distances by the trucks to the proposed landfill due to the different locations (Table 7), with Wakiso being nearer and Semuto the furthest.

Table 7. *Comparing the Kiteezi landfill and the new proposed landfill sites at 100 % waste collection*

Site	Using six-tonne trucks			Using 10-tonne trucks			Using 18-tonne trucks		
	Trips	Distance km	Time hours	Trips	Distance km	Time hours	Trips	Distance km	Time hours
Busukuma	216	6007	309	125	3547	247	65	1916	204
Kalagi	213	8220	336	126	4885	263	66	2621	212
Kiteezi	218	3687	436	125	2182	317	65	1219	241
Semuto	212	11375	381	125	7155	289	65	3523	228
Wakiso	211	5924	293	126	3493	239	66	1899	201
Zirobwe	216	10746	389	125	6859	291	65	3366	228

4.4.4 Optimised routes by outsourced private operator routes to proposed new landfills

A private operator was included in the optimised scenarios using a 20-tonne truck and starting at the central division because it was considered the most centrally located point to all the other divisions and optimisation was targeted at 100 % waste collection to the proposed new sites. Comparing the outsourced private operator's 20-tonne truck with KCCA's 18-tonne truck, Table 8 shows that the outsourced private operator reduced the total number of trips and distance travelled (392 KCCA trips for a distance of 14,581 km *versus* 342 trips for 13,505 km for outsourced operators), but not the time, which increased by 153 hours. Looking at the improvement benefit, the significance level is low.

Table 8. *Comparison of optimised routes by KCCA and outsourced*

Site	KCCA 18 metric ton truck			Outsourced 20 metric ton truck			Benefit %		
	Trips	Distance km	Time hours	Trips	Distance km	Time hours	Trips	Distance km	Time hours
Busukuma	65	1916	204	57	1800	241	12	6	-18

Kalagi	66	2651	212	57	2389	247	14	10	-17
Kiteezi	65	1219	241	57	1139	225	12	7	6
Semuto	65	3523	228	57	3295	260	12	6	-14
Wakiso	66	1899	201	57	1811	231	14	5	-15
Zirobwe	65	3366	228	57	3072	261	12	9	-14
Total	392	14581	1312	342	13505	1465	13	7	-12

4.4.5 Fuel analysis of trucks

Table 9 shows that there was a reduction in distance travelled by the trucks that had been optimised. This meant that fuel consumption reduced, which subsequently reduced gas emissions from the trucks. The percentage benefit of fuel consumption from a six-tonne truck increasing to a 10-tonne truck and from a 10-tonne truck to an 18-tonne truck was 39 % and 48 % respectively. The truck used was a Faw box body compactor. .

Figure 13. Faw box body compactor truck

Table 9. *Comparing fuel consumptions and distances from temporary collection points to Kiteezi and the proposed sites at 100 % waste collection*

Site		Using six-tonne trucks		Using 10-tonne trucks		Using 18- tonne trucks	
	Fuel	Distance km	Fuel in litres	Distance km	Fuel in litres	Distance km	Fuel in litres
Busukuma	0.33	6007	1982	3547	1171	1916	632
Kalagi	0.33	8220	2712	4885	1612	2621	865
Kiteezi	0.33	3687	1217	2182	720	1219	402
Semuto	0.33	11375	3754	7155	2361	3523	1163
Wakiso	0.33	5924	1955	3493	1153	1899	627
Zirobwe	0.33	10746	3546	6859	2264	3366	1111
Total		45959	15167	28121	9280	14544	4800

4.5 Reverse logistics network chain

In Paper IV there was an identification of the reverse logistics network chain that included stages before reaching the landfill and at the landfill and it extended activities after the landfill (Table 10). The recovery system was organised with actors performing a particular activity in the channel. The activities depended on the demand and supply of the products.

Table 10. *Arrangement of reverse logistics actors at the Kiteezi landfill*

Stages	Reverse logistic actors	Description
Prior to the landfill	*Waste collectors/street children*	This group moves within households and temporary collection points looking for recyclable materials such as plastics, metals, glass bottles, old shoes *etc*. The slight difference between the waste collectors and street children is that the waste collectors sometimes pay for the materials from the households. The street children just search for the products and they are normally sited near temporary collection points waiting for waste which they collect and sell to the refuse loaders.
	Refuse loaders	They move on waste trucks loading waste within the city and are contracted by KCCA and receive a salary for their work. In addition to their formal employment, they also collect and trade recovery materials in order to earn extra income. Their access to the waste sources makes it possible for them to collect and separate waste materials.
At the landfill	*Waste pickers*	These collect different products from the landfill. The quality of products collected by the waste pickers is much lower than those collected by loaders and waste pickers. The main reason for this is that the sorting has already taken place earlier in the system, for instance at household level and at temporary collection points. Therefore the quality of materials that reach the landfill site are of a much lower value.
	Small shop dealers	They buy the products at source, mainly from waste collectors, waste pickers, street children and refuse loaders. They aim for a variety of products available. They are normally situated near the landfill. They go an extra mile to add value to the products by cleaning, washing and sorting them into categories.

	*Traders/agents**	These normally target a particular product. They buy products from the small-scale merchants and dealers and prefer cleaner products. Payment was per kilogram of the products bought and also depended on the quality of the product.
	*Small-scale plastic processing plants **	These are small firms that have sprung up in and around the Kiteezi landfill to target plastic recycling from the landfill. They aim to add value to the products, which are later sold to the bigger factories. They carry out limited processing such as cutting plastics into smaller pellets.
Post landfill	*Factories and industries*	They add great value by processing and remanufacturing the products purchased. They usually require a minimum quantity of sorted and clean materials, which encourages the existence of intermediaries and waste dealers who purchase the recyclables recovered by the waste pickers.

* These groups more or less do the same activities and it is difficult to distinguish between them. The difference is in their size and location, with the small-scale processing plants being bigger and having a permanent location.

4.6 Reverse logistics integration

4.6.1 Distribution network

Reverse distribution management of product return flow starts with the product generators, usually called the suppliers, and these include the households, restaurants, market places and business centres. These provide waste that is normally dumped and unsegregated. This waste is later collected from the temporary collection points by a number of actors, including waste pickers, street children, refuse loaders and waste pickers, who enter into the distribution chain up to the landfill. Waste with these actors undergoes activities such as collection, transporting, separation, cleaning, washing, grading, packaging selling and buying. At the landfill, small-scale traders, small-scale plants, agents and factories enter the chain. This brings about competition from information flow and product acquisitions (Fig. 14). At the landfill in Kiteezi this involved the removal of defective and environmentally hazardous materials.

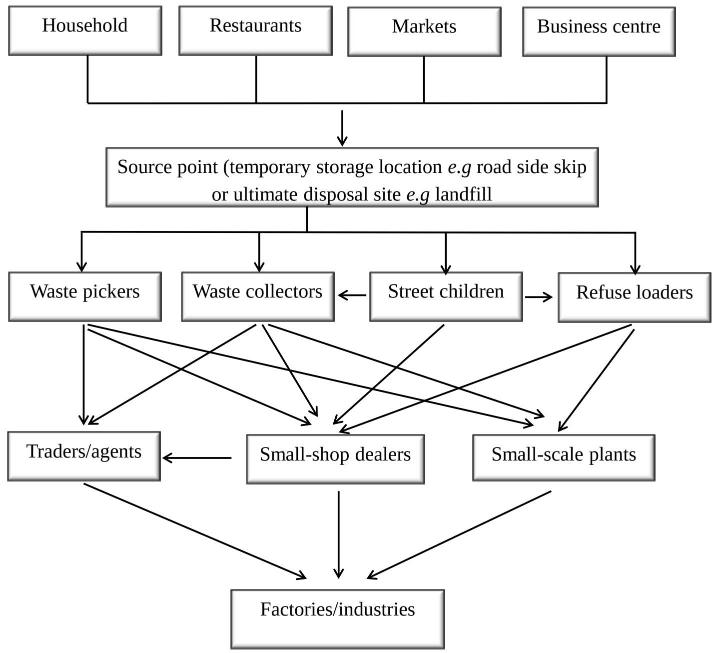

Figure 14. Reverse logistics distribution network channels.

4.6.2 Characteristics of reversed products

At the landfill, waste was characterised into the following waste streams: food waste, plastics, soft polyethylene, paper, textiles, metals, rock soil, vegetation and special waste. After analysis, food waste had a percentage of 39 %, vegetation 23 % and rock soil 21 %. There was no significant difference in generation between these three waste streams at the landfill, but there was a great variation with the other waste streams (Fig. 15). The variation of soft polyethylene at 5 % and plastics at 4 % was not significant, but it was slightly significant with paper (2 %), textiles (2 %), special waste (2 %) and metals and glass (1 %).

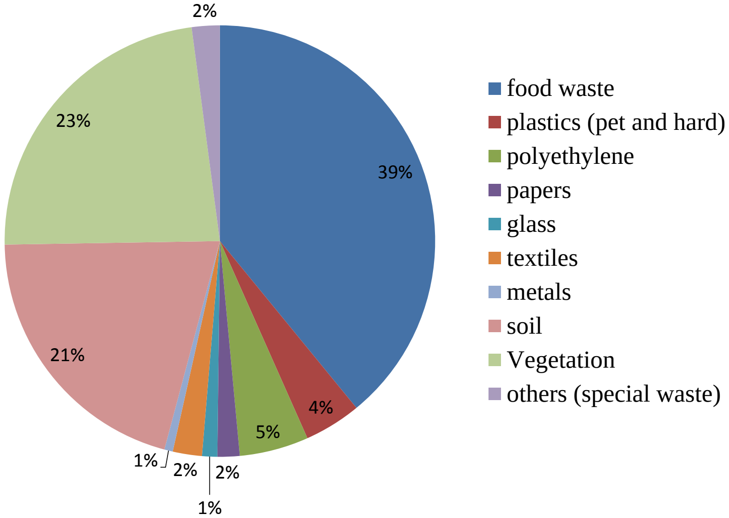

Figure 15. Selected waste stream categories at the landfill

4.6.3 Reverse logistics product recovery

Recovery of products is aimed at recovering the residual value of used products. From the waste stream that was collected and transported to the landfill, five categories of products were identified and were subject to high potential reuse by people: plastics, polyethylene, paper, metals and textiles. The procedure followed in identifying this was the command value of money these products provided at the landfill. The other products are normally buried at the landfill such as glass and rock soil. Vegetation and food residue is compacted with soil and buried. At the landfill, polyethylene constituted the highest generation, with an average of 0.7 tonnes followed by plastics (0.6 tonnes), textiles (0.3), paper (0.2) and metal (0.1). Generally, polyethylene and plastics indicated the highest trends from all the five divisions, with the Central division generating the highest tonnage and Makindye delivering the lowest (Fig. 16).

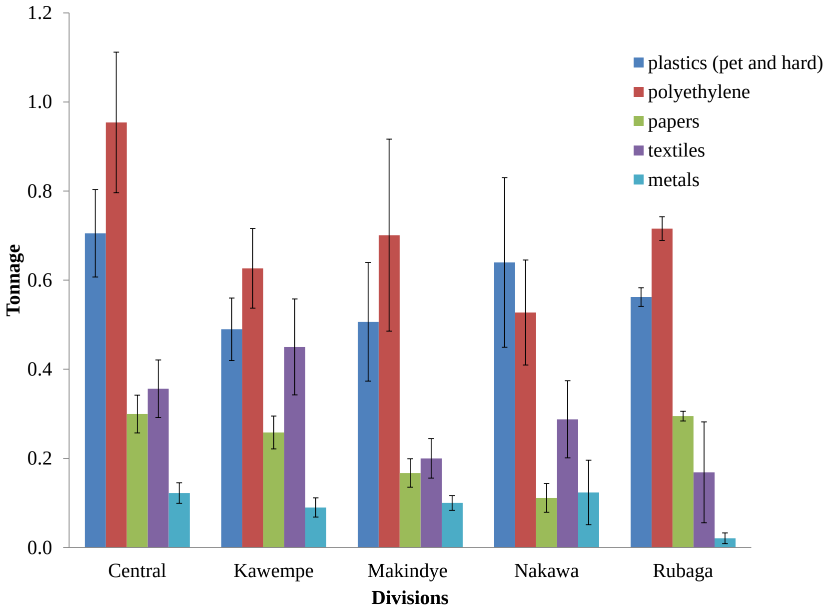

Figure 16. Mean and standard error of reversed products per division

Of the selected recovery products, polyethylene and plastics were the highest generated products at 37 % and 31 % respectively. Paper and textiles trailed at 12 % and 15 % respectively and the metals contributed only 5 %, indicating a high significant variation in the products delivered at the landfill (Fig. 17). This meant that the lower the percentage recording of products at the landfill, the higher the desirability with the users and consequently the higher the cost of the product. Further to that is that some waste delivered at the landfill can be potential recovery products, but they are left out due to a lack of awareness and processing knowledge. These products include glass that can be recycled, and food waste and vegetation that can be changed into compost. An analysis of these potential products was grouped together to give a clear picture of the total reversed products (Figs. 18 and 20).

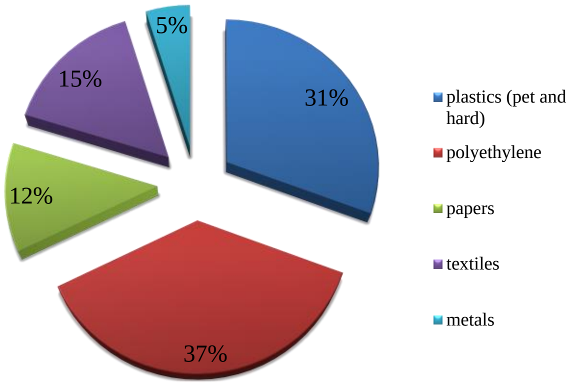

Figure 17. Reversed products from the landfill

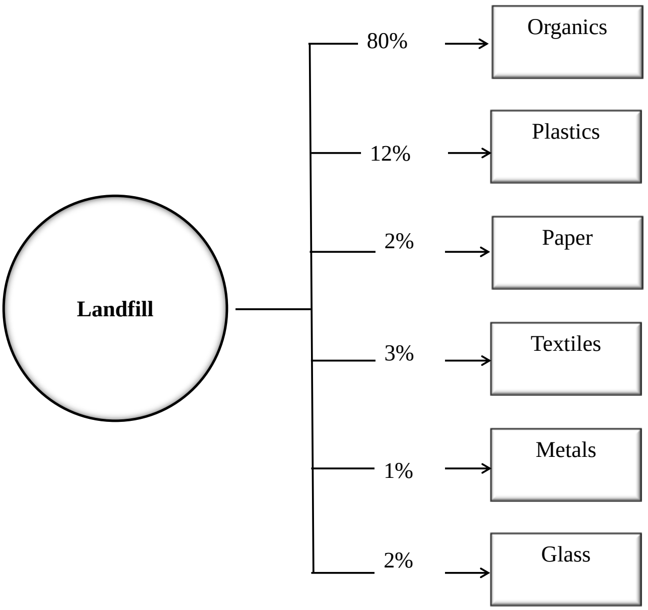

Figure 18. Average percentages of the different products that can be recovered from the landfill

As shown in Figure 18, soil and special waste was omitted because these products do not have any quick potential use and are regarded as items for burial. To obtain a clear percentage recording of them, an analysis was performed and it was found that buried items constituted about 23 %, potential omitted products were 63% and reversed products constituted 14 % (see Fig. 19).

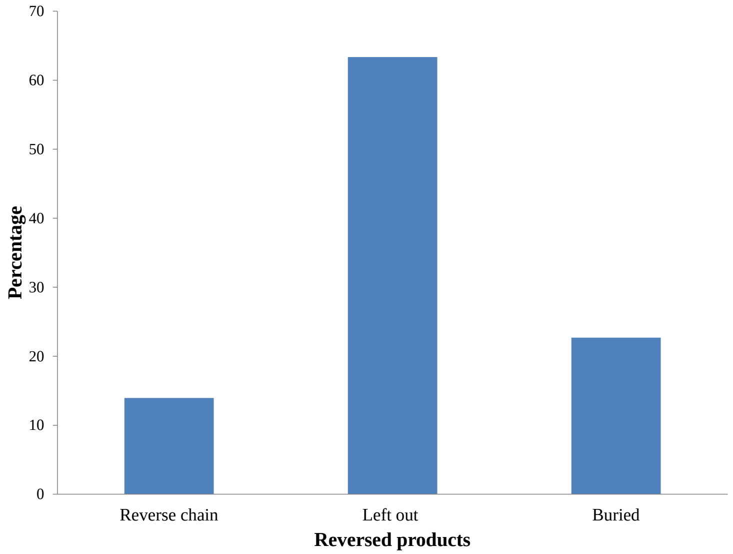

Figure 19. Potential recyclable products if all utilised and others buried

Figure 20. Reversed products at the landfill: (a) aluminium cans, (b) hard plastics, (c) food waste, (d) soft plastics (polyethylene)

5 General discussion

5.1 Current solid waste management status

In the total waste stream generated in Kampala, the highest percentage was constituted by organics at about 92 % (Paper II) and 83 % (Paper IV). The difference in the figures is because in Paper II the survey included both the KCCA authority waste collection and private operators, while in Paper IV the survey only had data on the KCCA authority. The results are not far from what other authors have found who noted that organic waste percentage is between 60-85 % (Mukwaya, 2004, Mukisa, 2009, Parrot *et al.*, 2009). For instance in other developing countries, (Sujauddin *et al.*, 2008) note that it is 88 % in Bangladesh, 85 % in Vietnam (Thanh *et al.*, 2010), 65 % in some Indian cities (Sharholy *et al.*, 2008), 65.5 % in Haiti (Philippe and Culot, 2009) and 80 % in Iran (Moghadam *et al.*, 2009). In developed countries, this is not the case in that they generate less of the organics compared to the other waste streams of paper and plastics: 38 % for the United Kingdom, (Burnley, 2007), 28 % for Wales (Burnley *et al.*, 2007) and 22 % for USA (Daskalopoulos *et al.*, 1998). This is due to the completely different dietary culture.

A high proportion of organic waste is generated from non-edible components during food preparation, including plantain peels, yam peels, beans, fruit peels and fish bones. Most of the food and fruit consumed by Ugandans have a high moisture content or non-edible parts. Whereas developed countries consume more of the fast foods that are packed in paper bags and plastic bags, their counterparts in the developing countries consume more organic foods. There is also a distinguishing future of waste as regards to regions, for instance waste from the tropics consists of a high amount of vegetation debris (Komakech *et al.*, 2014, Kinobe *et al.*, 2015b). Kampala is located in the tropics and experiences high temperatures that increase the rate of waste decomposition. When these wastes are loaded onto the truck, the liquid content in them reacts with the truck bed metal and erodes it, creating holes then later littering the city with the transported wastes.

In Uganda, as in many other Sub-Saharan countries, only a fraction of the waste generated is collected and disposed of to the landfill. About 40 % of the wastes generated are collected and the rest is dumped indiscriminately in many Sub-Saharan African cities. For example, Nabembezi (2011) mentions 40 % for the case of Kampala, Rotich *et al.* (2006) reported 45 % for Nairobi in Kenya, while Kassim & Ali (2006) record 48 % for the city of Dar es Salaam in Tanzania. This is attributed to limited waste management budgets to sustain the activities of collection, weak legislation and a lack of technical capacity (Kassim and Ali, 2006, Rotich *et al*., 2006, Imam *et al*., 2008, Nabembezi, 2011, Tukahirwa *et al*., 2011).

The study in Paper II observed that most of the temporary storage collection points were located along the main roads and in most cases next to drainage channels (Fig. 21). This was because of the difficulty in identifying space that could be used as a temporary collection point and this situation became more profound in the shanty areas of Kampala. When comparing temporary collection points in the city, there were fewer official temporary collection points because they were the designated areas by KCCA. Nakawa division had more of these because of the presence of many institutions (universities, schools and hospitals). These institutions provide organised waste collection points. The division also got the highest share of the waste budget (KCC, 2006). Many unofficial temporary storage sites were found to be located in the Kawempe, Makindye and Rubaga divisions because these areas were inhabited by low-income earners who were unwilling to pay for waste collection and the vast majority of these people lived in unplanned inaccessible areas that cannot be served by KCCA trucks. Rotich (2006) shows in his study that most of the collection points (dumpsites) were not served by all-weather roads. This made accessibility during rainy seasons difficult if not impossible. Illegal temporary collection points were found more in the Rubaga and Kawempe divisions because these areas have vast open bare spaces giving people an opportunity to throw solid waste (Fig. 22).

Figure 21. Solid waste containing a lot of abrasive materials located next to a drainage channel

Figure 22. Illegal temporary collection points in an open space

A large part of a city waste management budget goes towards fuel, maintenance and labour for its fleet of sanitation collection vehicles: 70 % for developing countries (Rotich *et al.*, 2006) and less than 60 % for developed countries (Brunner and Fellner, 2007). KCCA as the authority in waste management in Kampala has limited vehicles for waste collection. The existing vehicles are not specified for waste collection (Fig. 23). The truck beds are open-ended and constantly litter the collected wastes. The common compactors used were not designed to cater for waste in tropical environments and frequently break down. Paper II mentioned that in most cases the trucks were in poor mechanical condition because they were driven carelessly or misused in other ways, causing constant breakdowns on the roads. Imam *et al.* (2008) in their study noted that the shortage of waste collection vehicles in Abuja was due to inadequate maintenance and lack of funding. This meant high operating costs, thus leading to many of the trucks being grounded.

Figure 23. Common trucks used for solid waste collection by KCCA

In Paper IV, it was reported that large amounts of abrasive materials were disposed of unsegregated, containing a variety of products including ash, sand, silt and gravel (Fig. 21). These were from road sweepings, un-surfaced and unlined roads and pavements (21 % of the total waste generated). When such materials are compacted, they break the hydraulics of the truck compaction. In the end, the load capacity of the truck can no longer be attained due to the broken compaction mechanism. The high vegetation quantity (23 %) was due to the pruning of trees, compound cleaning and market residues.

A lack of national legislation in the field of solid waste management and the lack of an existing waste management plan for Kampala are strong indications that an integrated solid waste management approach has not been used in the past or present. Waste management legislation incorporating the will of people is lacking where, for instance, decision making is still taking place with only the top-sector waste management people (Marshall and Farahbakhsh, 2013, Al-Khatib *et al.*, 2007). Okot-Okumu & Nyenje (2011) point out that a decentralised system of waste management and a privatisation drive are alternatives that can be followed and will solve the waste management problem in Kampala. Through decentralisation, there is equitable distribution of resources between the central government and its local government, and this will lead to efficient and effective solid waste management if properly managed and implemented. The privatisation arrangement is also supported by Kaseva & Mbuligwe (2005) who observe that the introduction of private operators in waste collection increases the levels of collection as compared to when it is wholly performed by municipality authorities. The challenge is how the approaches of decentralisation and privatisation are delivered. For instance, in the context of Kampala and Uganda as a whole, most of the waste management contractors are politically interfered with, according to particular political parties that win the elections *vis-à-vis* to whom to award the contract. Moreover some private companies come up with models copied from the developed world with totally different technical, financial and organisational frameworks from that of Uganda. Paper II reported that 30 % of the total waste that was collected in the city and disposed of at the landfill was due to the work of the private operators.

Papers III and IV noted that the employment of third-party logistics operators brought about efficient and effective management operations. Third-party logistics means outsourcing logistical activities including transportation, as was the case in the study. Therefore, contracting private operators in solid waste collection system is efficient because they ensure that their equipment and vehicles are in good shape, they are not affected by bureaucratic tendencies during operation, they are less affected by politics, and they are flexible and innovative. Krumwiede and Sheu (2002) observe that as policies regarding the return of goods continues to be put in place in order to favour customers, the need for third-party companies to provide partial or full reverse logistics services will increase. However, it is not always a guarantee from the private sector that services will be delivered efficiently and effectively because these are mainly business people who aim at profit maximisation. They normally charge highly for the services, yet waste collection should be a basic service that should reach everyone in an area. This is partly the reason why private operators are concentrated more in the upscale areas of the rich than in the poor areas (Paper II).

5.2 Comparing model collection system

Four waste collection model systems were identified from the study. Model 1 involved collection from areas inhabited by low-income earners and was associated with slum areas. The areas were inaccessible by trucks to ferry garbage collection by KCCA due to the narrow road network. This makes waste collection unreliable because the trucks cannot drive through to load the wastes (Gupta *et al.*, 1998, Vidanaarachchi *et al.*, 2006). When they do manage to enter these areas, the collection vehicles tend to break down due to the harsh conditions of the roads. The end point is indiscriminate dumping (Fig. 24) that comes with the associated impacts of groundwater contamination from the leachates and methane and carbon dioxide emissions. The major setback of limited waste collection in these areas by KCCA was due to limited resource allocation and inaccessibility due to the narrow road network. The high volume of waste generated is due to the high density of population in these areas (Kaseva and Mbuligwe, 2005, Okot-Okumu and Nyenje, 2011). Over 60 % of the population of Kampala live in slum areas (UBOS, 2012).

The model 2 waste collection system was inhabited by wealthy people who could pay for the services of waste collection, making the service favourable.

Waste collection was undertaken by private operators who collected waste on a scheduled programme and provided the necessary garbage collection polyethylene bags. The problem with the polyethylene storage bags was that they were subject to scavenging animals and people because they were normally left outside the residential house, and this is also reported by Wilson *et al.* (2006). The amount of waste generated from upscale households per person is much more than that of poor areas due the availability of income. Solid waste generation by the higher income households was estimated to be between 0.66 and 0.9 kg/cap/day on average (Kaseva and Mbuligwe, 2005, Okot-Okumu and Nyenje, 2011, Oyoo *et al*., 2011, Ojok *et al*., 2013). This means that the purchasing power is high and subsequently the consumption behaviour patterns change to demanding more product acquisitions, which later increases waste generation. The ability and willingness to pay for waste collection services is bound to increase the volume of waste collected.

In model 3, collection was directed to the city centre and the central business areas of Kampala. The activity was undertaken by both KCCA and private companies. This was because of the high influx of people from the surroundings of Kampala that come to carry out business activities in the city centre. UBOS (2012) recorded that the population of Kampala during the day and night is estimated to be about 3.8 and 1.7 million people respectively. This exodus of people increases the total amount of waste generated within the city, hence the need to have more waste collection. The challenge faced was that most of the people could not differentiate between KCCA and private operator temporary collection points. Therefore, most waste was dumped at temporary collection points operated by KCCA whose collection however was still not efficient.

Model 4 focused on market areas, public parks, street sweepings and de-silting of drainage channels. The main actor of waste collection was KCCA. A large part of the market waste flow is biodegradable waste, which originates from fruit and vegetables peelings, food remnants and leaves. In addition, most of the temporary collection points are located next to the drainage channels. When it rains, storm water carries large volumes of soil due to unpaved streets that later finds its way in the drainage channels, hence the need for de-silting (Fig. 21). Vegetation pruning in the city's parks and gardens also increases the wastes. The challenges faced included, among others, bureaucracy and delays from the divisional headquarters in providing vehicles to transport the wastes, limited communication between the divisional waste supervisors and municipal administration and political interference, for instance with leaders not following strategic planning and policies, but rather engaged in daily waste management.

In a final analysis, Kaseva & Mbuligwe (2005) and Okot-Okumu & Nyenje (2011) assert that residential areas are the main generators of waste, followed by the markets and commercial districts in urban areas. This was not the case in this study. Paper II noted that the greatest generators of waste were residential areas, both the upscale areas and slums, followed by the business areas (commercial) and then the market areas. The argument with this is that in Kampala there are a limited number of markets (13) and this could be the reason why there is less waste. It should be noted that the study did not ascertain the generation rates of these markets in comparison to other markets in these Sub-Saharan cities. Added to this, another reason could be that in the study of Paper II, the waste analysed included the contribution of private operators' waste collection. This contribution would have increased the total waste collected and transported to the landfill. This could also have been missing from the studies by the quoted authors.

Figure 24. Illegal dumping of waste in the city centre (a) slum area (b)

5.3 Optimised route impacts

To date no significant research into optimising solid waste has been carried out in Kampala and Uganda as a whole. In Kampala, there are no scheduled routings of trucks for waste collection, no details on the location of temporary sites or operational hours, poor driving habits, travel impendences and limited road network information. Paper III mentioned that there was no scheduled plan for waste collection by trucks. The drivers were called upon to haul waste when need arose. There was also no scheduled waste collection in a particular area of operation. The drivers were alerted by solid waste scouts (KCCA employees) who moved within the divisions identifying areas that had accumulated waste. This system caused a lot of delay and incurred operational costs. Truck drivers ended up wasting time and fuel. Teixeira *et al.* (2004) illustrate that static routes are preferred by waste collectors because they ease operations based on the objective of minimising travel distances and time durations. Paper III recorded a 19 % and 17 % benefit on travel distance and time respectively when the recorded routes were optimised.

The common trucks used to haul waste have a capacity of 6 tonnes, limiting waste collection and thereby making many trips to the landfill. Paper III studied and compared different waste truck capacities of six, 10, 18 and 20 tonnes. It was concluded that an increase in truck capacity tonnage reduced trips to the landfill while increasing on the percentage of waste collected, and consequently the distances travelled and time to the Kiteezi landfill. Bosona *et al.* (2011) apply route optimisation to improve food deliveries in local food supply chains.

The economies of 20-tonne large-scale trucks compared to the 18-tonne truck improved the trip and travel distances. However, there was no time advantage from using the 20-tonne truck. A 12 % hour time is lost and the argument for this is that the larger the vehicle capacity, the more waste it will load and carry, meaning that more temporary collection points will be visited, hence more service time will be accrued and thus increase the time. This is confirmed by Li *et al.* (2008) as they show truck scheduling of solid waste collection while modelling the problem without considering the balanced loading of waste.

However, it should be noted that it is not the size of the truck that will lead to proper efficiency of waste collection. Using 20-tonne trucks will mean that a few of them are needed (Table 11). One argument put forward is that with the nature of waste generated in Kampala that include soil, silt and a high organic matter content that erodes the trucks, if one of them breaks down, then a great quantity of waste will not be collected. Another negative impact of these heavy trucks will be the difficulty faced in moving in the unplanned streets of Kampala and also compacting on the roads due to the high tonnage. Moreover, this can be aggravated further with the unplanned road network and the location of temporary collection points that are situated on the roadside. Kinobe *et al.* (2015a) point out that trucks have to be packed half way in the road while loading waste, causing traffic jams. These loopholes of unplanned road networks and lack of details about the location of waste bins are common in many Sub-Saharan African countries and have been suggested by previous studies (Rotich *et al*., 2006, Parrot *et al*., 2009).

On that note, for these high-capacity trucks to be taken on in Kampala, there should be a well-planned infrastructure in terms of a good road network, parking spaces at the collection points and proper operation and maintenance procedures. Added to that is the need for a well-designed truck system that will be able to handle the nature of waste generated in the city. One such solution could be the purchase of trucks designed to handle one or two waste streams with two vaults (Fig. 25). Compacting waste of the same type would be easy and effective and would also reduce the breakdown of the compaction process. However, using such trucks will call for separation of wastes that should start at household level. Studies by Al-Salem *et al.* (2009) and Pires *et al.* (2011) point out that the management of segregated wastes is expensive because it requires high operational costs (for this study the provision of different trucks for each waste stream), in the end being costly. However, in the long run, reprocessing this waste is less expensive than the commingled waste (Zhang *et al.*, 2010). The choice should be left to decision makers as to whether to invest more source-segregated waste with less processing or unsegregated waste with high processing costs.

Table 11. *Comparing the total number of trucks to be used to cover the trips and distances*

	10 truck			18-tonne truck			20-tonne truck		
	Distance km	Trips	Trucks	Distance km	Trips	Trucks	Distance km	Trips	Trucks
Total	28121	752	75	14581	392	22	13505	342	17

Figure 25. Trucks that handle separated waste streams: (a) paper and (b) biodegradables

Greenhouse gases (GHG) are one of the most important sustainability and environmental factors to consider when choosing a waste collection and waste management system. Most trucks used in waste collection have diesel engines. The vehicle' impact on the environment from the collection and transportation of waste comes from exhaust gas emissions from diesel fuel. Emissions from vehicles used to collect and transport waste from the collection point and to the landfill is twofold: one is the fuel consumed by the trucks as they move around; the other is powering the lifting mechanism and compacting the waste. The trucks used in Kampala to haul waste are old and lack scheduled maintenance. There are high levels of emissions from these heavy-duty trucks into the atmosphere, including carbon dioxide (CO_2) and nitrogen oxide (NO_2) (Zielinska *et al.*, 2004). Vehicle route optimisation will mean a reduction in the total number of vehicles to be used and a subsequent reduction in distance, time and trips to be made. Ericsson *et al.* (2006), in their study on optimising routes for less fuel consumption, note that a reduction in fuel intake by diesel vehicles reduces CO_2 emissions in the atmosphere. A further reduction in the costs of operation and maintenance of the trucks will be put to great use. However, this research study did not analyse the gas emissions from these truck. It is a recommendation that further research should be undertaken.

5.4 Reverse logistics and recycling at the landfill

Recently reverse logistics has gained more attention due to growing competition, economic motives and environmental concerns, as well as strategic and managerial implications (Dowlatshahi, 2000). However in Uganda as in many developing countries, reverse logistics is not given much attention as part of the supply chain. The importance of reverse logistics is still not realised and little research has been undertaken on this concept. Despite the challenge, organisations have started realising that reverse logistics is an important concept in the supply chain due to its cost effectiveness and added value for the customer. Reverse logistics can generate direct gains for organisations by reducing the use of raw materials, adding value with recovery and reducing disposal costs (De Brito and Dekker, 2002, Wang and Lin, 2010).

It is imperative to note that much of the focus in the subject of reverse logistics and logistics as a whole has targeted on its narrow application to areas such as computer technology, advanced office automation and military and weapons systems support. It is the emerging green laws and environmental concerns that have had a great impact on many logistics decisions (Dekker, 2004). For example, many products especially e-waste can no longer be placed in landfills and manufacturing enterprises are now forced to take back their products at the end of their useful lifetime. But in Uganda, this concept is still lacking most of these products especially the e-waste and medical waste that has no immediate use or does not have a monetary value ends up being buried. This is one reason why about 23 % (Fig. 19) of the waste that reaches the landfill is buried straightaway. Added to that is that a high percentage (63 %) of waste that would be put to great use is also left out. Such products include biodegradable waste that could be used for compost and glass that could also be recycled. The argument for this low recycling potential is the lack of processing power.

Reverse logistics through the approach of recycling is gaining momentum due to the wide awareness and consequences of resource depletion, economic stress and environmental alertness. Many people, especially those without jobs, have started engaging themselves in the reverse chain such as collection, distribution and processing to get a source of income (Subramanian, 2000) (Fig. 26). The main actors found doing this activity were informal people including waste pickers, waste loaders and street children (Medina, 2000). This activity has become common, especially in informal settlements where waste collection is lacking due to inaccessibility by waste trucks and narrow streets. Waste loaders also separated recyclables before the trucks reached the landfill. This activity was common with all the waste collection crew members on the trucks. These waste loaders later sold the products on their way to landfill or after disposal of other waste, then they share the proceeds. Wilson *et al.* (2006) note that this kind of activity involves a lot of time wasting as the refuse loaders have to spend time looking for products and selling them. The products that reach the landfill are usually broken, very dirty, mixed with other waste and of low quality because the valuable products have been removed by the waste collectors and the waste loaders on the trucks.

Figure 26. Activities at the landfill. Note that the waste pickers wear no protective gear

Whereas in developed countries the end users of the products pay for the services of recycling (Hayami *et al.*, 2006), in Kampala it was discovered that the waste collectors pay for recyclable products from households. This is due to the monetary value attached to the products (Medina, 2000).

Potential recoverable products are plastics, paper and metal that have great recycling and monetary value (Subramanian, 2000). The most recoverable were plastics (hard and soft) at Kiteezi that attracted monetary terms from both suppliers and buyers. Plastics constituted the largest amount of waste entering the reverse chain.

Subramanian (2000) state that the trend of manufacturing and packaging of goods, especially food from markets and shops, has changed and plastics are used as packaging materials. This could be the reason for the high increase in plastic waste in the waste stream. Chung and Poon (2001) report that such trends in the composition of Guangzhou waste is attributed to economic growth, increasing people's purchasing power. These products have increased in the waste stream and this is the case with Kampala. Al-Salem *et al.* (2009) provide an indication that plastics are used in a number of forms in our daily lives. It is realistic to find considerable amounts in the final waste stream. At the Kiteezi landfill, there was good profitable business in these products and most of the recyclers were engaged in plastic recovery. For instance, a kilogram of clean soft plastics went for 150 shillings and 200 shillings, while that of hard plastics was between 250 and 300 shillings. It should be noted that these prices were not fixed and depended on how the products were delivered in shape, appearance and cleanliness.

Glass was left out of the potential recovery products. This was because in Uganda no company is engaged in the recycling of glass products, so they end up being buried at the landfill. Some individuals visited the landfill to collect glass to be put on the perimeter walls of buildings for security reasons. Furthermore, organics and vegetation were other products that were left out due to the zero level commanded in monetary terms. At the landfill these products are just compacted and buried. On rare occasions some people are seen collecting pieces of wood or taking some compost manure. However the quantities taken are too small to be quantified.

Metal was the most expensive waste category to deal with at the landfill. The cost of metals worldwide is rising. Many mining companies are faced with rising costs of mining plus paying for the environmental costs of their operations (Tilton, 1999). This in turn has made metal recycling important. At the landfill, a kilogram of metal costs 500 Ugandan shillings. However, this depended on the type and quality and the fluctuation in market prices of metal contents (Kofoworola, (2007). The low quantity of metal at the landfill was because the products had been sorted and taken from the waste stream before reaching the landfill. The retrieval starts at household level, and then is undertaken by street children and waste loaders. The metal market is readily available countrywide, both on a large-scale and small-scale basis.

Transportation of reversed products to the landfill and also after the landfill was done in a rudimentary way. The transportation methods used included humans, bicycles, motorcycles and old trucks (Fig. 27). This is because the cost of transportation of reversed products is high. To the transporters, these products are considered to be waste and believed to damage vehicles, hence the high costs associated with them. However, Tibben-Lembke and Rogers (2002) state that transportation costs on many occasions greatly influence economic viability in the reverse distribution channel. In addition, this explained why some recycling processing firms and factories provided trucks to small-scale dealers and small-scale plants in order to boost the operations of product transportation. Small-scale plants and dealers that were provided with the incentive of transportation had a higher competition level compared to those that did not. This also confirms that a well-developed transportation network leads to a successful reverse distribution channel.

Figure 27. Common transportation used at the landfill: (a) motorcycle and (b) bicycle

In Paper IV, uncertainty about product flows was yet another challenge identified in reverse logistics due to the inconsistency of material flow. Daugherty *et al.* (2005) indicate that product flows do fluctuate and have different timing patterns. Waste dealers did not know when and in what quantities a particular product would be delivered and most products are unplanned and predicted. This was the reason why many of the small-scale recycling dealers engaged in the purchase of a variety of products so as to stay in business and competitive. There was limited specialisation in the products and where it was practised. It was undertaken on a small scale in small-scale processing plants.

5.5 Efficient reverse logistics operations in waste management

5.5.1 Integrated solid waste management (ISWM)

One major guiding factor in ISWM can be directed at resource conservation and recovery aimed at reduction, reuse and recycling. This approach will minimise the amount of waste from generation to disposal, thus managing waste more effectively and minimising the public health and environmental risks associated with it.

Reduction and reuse

Waste prevention and minimisation at household level will reduce its generation and reduce the associated impacts. There should be precedence with proper storage of household wastes, waste separation and placement of household containers. Waste minimisation is mainly driven by individual habits that value environmental protection and resource conservation. These social values take time to develop and change, however they are essential to environmentally sustainable and cost-effective services. The process of reusing starts with the assumption that the used materials that flow through our lives can be a resource rather than refuse. Waste is in the eye of the beholder. One person's trash is another person's treasure.

Recycling

Through their informal recycling activities, waste pickers broaden their sources of income. They contribute to national industrial competitiveness and benefit the environment (Paul *et al.*, 2012). Maximum benefits will be gained when the authority recognises the importance of the informal sector responsibilities in solid waste management and strengthen their activities in reverse logistics. Government intervention including the reverse logistics chain in waste management should be developed and passed. Another way is to come up with programmes that can join up the reverse chain distribution network of waste pickers, street children and scavengers. These people work in extremely poor conditions, so with the support of the programmes formed they can be registered, then work jointly, hence leading to efficiency. Baud *et al.* (2001) assert that in Chennai in India solid waste management alliances, including formal collection, informal collection, trade and recyclers, teamed up for sustainable development. Nas & Jaffe (2004) state that in Colombia, the establishment of scavenger cooperation meant that the benefits that used to go to the middle-men traders ceased, they were legally recognised, and also received higher proceeds. Much of the waste stream can be recycled, making recycling an important component of integrated solid waste management. Each recyclable product (hard plastics, paper, metals and polyethylene) has a market-based monetary value.

Technologies

In a situation where recycling of some products cannot be effective, technologies should be introduced that will reduce the quantity of both biodegradable and non-degradable waste at the landfill. The available technologies for treating biodegradable waste components are composting, anaerobic digestion, landfilling with methane capture for power generation, and incineration. However, some of these technologies cannot be applied in Uganda. Incineration is not generally considered economically viable for developing countries, because their wastes are too wet and too low in combustibles to burn without supplementary fuel. Where incineration is implemented in a developing country, air pollution control measures that address standards comparable to those required in high-income countries should be implemented. Incineration produces toxic emissions. Composting may be the best alternative because a large percentage of waste generated comprises biodegradable matter. The compost will later be used as manure and soil enrichers (Matter *et al.*, 2012).

Another efficient mechanism that is still lacking in reverse logistics in Uganda is the development of product identification and labelling for the return of products in the reverse chain. Packaging of products was always mixed and on many occasions it became difficult to identify a particular product. One solution to that would be the use of radio frequency identification (RFID) for a particular product. The tagging would make the tracking and retrieval of products easier and faster. The labelling system could be introduced to all the actors that deal in recyclables, such as small shop traders and small-scale plants, with identities such as PET, LDPE, HDPE, paper *etc.* after sorting and grading. This will be a form of value addition.

5.5.2 Policy, legal framework and institutional arrangement

In most countries, solid waste management is a municipal responsibility. In the case of Kampala it is the KCCA that sets the basic standards, including the occupational and environmental health and safety standards to be followed. There are no clear laws around waste management in Uganda and where they exist, they are weak (Okot-Okumu and Nyenje, 2011). Arrangements are complicated and often overlap or have areas where no agency is responsible. Furthermore there is a lack of regulation on certain waste streams such as e-waste and construction waste. One such solution to the regulatory framework is to separate management and planning functions from operational functions, as well as to separate policy development and regulations from implementation activities. Policy implementers need to adopt specific acts and regulations with strong enforcement mechanisms to govern their end use. These policies should also address waste streams that are left out, such as e-waste and construction and demolition waste.

5.5.3 Operational management

This focuses on the human resources and technical factors in waste management. On many occasions, these are scarce and lacking. Officials without technical knowledge of waste management issues are employed to carry out complex work which they fail to accomplish. Another consequence of poor administrative planning is that the majority of these services are directed by personnel with a low educational level and technical training on solid waste management. This in turn results in a lack of coordination between the departments such as public health and environmental conservation.

Operational management would try and deal practically with planning for actual operations, considering the demand for services when they arise. The system should be flexible to handle any disaster with a focus on efficient collection, transportation recycling and proper disposal.

5.5.4 Financial and economic management

In many developing countries, including Uganda, the waste management sector is given a low priority in government budget allocations, making the financial base of its activities weak. This has forced the municipalities to award contracts to private operators to carry out the activities (Okot-Okumu and Nyenje, 2011). However on many occasions, poor communities who cannot afford the services tend to suffer, posing a challenge to those involved in trying to establish sustainable waste management. Another shortfall of this is that the officials responsible for effective management of solid waste in this sector lack accurate information concerning the real costs of operation. There is also a lack of industrial development important for the procurement and maintenance of machinery and equipment in the waste management sector. There should be a cost effective accountability and financial analysis of municipal infrastructure management.

5.5.5 Public-private participation and awareness

Another way to encourage waste reduction is simply by increasing awareness, which often leads to process modifications, alternative disposal practices and product changes. Private enterprises can usually provide solid waste collection and transfer and disposal services more efficiently and at a lower cost than the public sector. Private sector involvement will imply a shift in the key role of government from service delivery to regulation. For this to work, appropriate systems of monitoring and control of these private operators needs to be established. Public-private participation operations assume co-responsibilities for service delivery (Ahmed and Ali, 2006). They come up with the advantages of flexibility, finance, technical knowledge, entrepreneurial and managerial skills combined with social responsibility and environmental awareness. In favourable conditions it is advisable to have both the public and private sectors playing active roles, thus capitalising on each other’s strength. Involving the private and public into the waste management system can be in the form of setting up modern recycling projects, especially for e-waste that contains hazardous materials. The aim of the project should mainly target the health of the recyclers and also protect the environment, open up trade and create valuable jobs in the recovery sector. In so doing the projects would contribute to reducing poverty and at the same time overcome global resource scarcity (Wilson *et al*., 2006).

6 Conclusions and future research

6.1 Conclusions

The increased demographic growth rate and rising urbanisation are challenges that have hindered sustainable development in terms of the provision of basic infrastructure and urban services. This has led to a series of problems such as the high generation and inadequate collection, transportation and disposal of waste. This has become a major threat to the environment and a risk to the health of people that will eventually spread to other areas. Little research has been undertaken concerning proper waste management in Kampala and the little that has been done only focuses on a small area and concept, such as generation and composition, leaving out other concepts that are relatively important. Identifying all the concepts and the organisation of the system is needed and can be a starting point for proper waste management.

Solid waste management in Kampala is characterised by inefficient collection methods, insufficient coverage of the collection system and improper disposal of municipal solid wastes. Approximately 1,538 tonnes of waste were generated in Kampala per day, of which about 40 % (615 tonnes/day) was collected and transported to the dumping site at Kiteezi. This waste constituted 92.7 % organics and the remaining 7.3 % was paper, plastics, metal, glass and other wastes. Waste collection in Kampala is done by KCCA and private companies that are contracted by KCCA. About 70 % of the waste collected and transported to the Kiteezi landfill is done by KCCA and about 30 % by private operators.

Optimisation is one aspect in waste management that has been left out. Its main objective is to minimise travel distances and reduce the fleet size used. Optimised routes can be achieved using new technologies such as GIS, a tool that is able to display and manipulate both geographic and spatial information. Optimisation of waste collection with an increase in truck capacity reduced the distance and travel time to dispose of the waste. An increase in truck capacity from six tonnes to 10 tonnes reduced travel distances by 39 %, trips by 41 % and time by 20 %, while from increasing from a 10-tonne truck to an 18-tonne truck reduced distance by 34 %, trips by 44 % and time by 9 % considering 40 % waste collection.

Reverse logistic activities at the only landfill that serves Kampala suffers from unfavourable economics and legislative, technical and operational constraints. The recycling rate in Kampala is still substantially lower compared to developed countries and the existing non-recycling methods negatively impact on the environment and people's health. Of the products delivered to the landfill, food waste constituted the greatest amount at 39 % followed by vegetation at 23 % and rock and soil at 21 %. The potential reversed products from the landfill include hard plastics and soft polyethylene at 68 %, 15 % textiles, 12 % paper and 5 % metal. These results clearly show how there is still a lack of recycling and this needs to be addressed. Incorporating reverse logistics into the waste management sector will reduce the waste that is disposed to the landfill, emissions from landfill, litter and expenditure on energy, and will also provide income to the groups involved in the practice. The system will further increase the service level of manufacturing firms and reduce the costs of production, and hence increase profitability.

One of fundamental issues in reverse logistics is to establish an effective and efficient infrastructure by creating an optimal network design that is lacking in Uganda. Information flow and physical management of product recovery is not documented anywhere. There is no literature on reverse logistics in Kampala and significant further research is needed. Therefore there is a need to develop an integrated approach in which the public, private and community sectors work together to develop local solutions promoting sustainable waste management. A comprehensive policy framework by the government authority should be put in place to link public health, environmental management, private participation and economic instrument policies to promote coordination in the waste management sector. This framework should include incentives to municipal authorities to deliver better services, recover more costs from users and keep the environment safe. The experiences of some developed countries indicate that reverse logistics related to waste management, if fully incorporated, is a promising solution for developing countries. The potential for reverse logistic activities such as coordination, route optimisation and innovative materials handling will solve the urban waste problem if applied.

In a nutshell, the management of waste in developing countries is a very neglected area in environmental management, leading to increased environmental degradation that is becoming a challenging problem in society. Conservation of natural resources and the reduction of gas emissions are major issues all over the world. With the efficient application of reverse logistics activities, all this will be alleviated.

6.2 Future research

The following research areas could be recommended:

- Education and awareness about the subject of logistics and reverse logistics and how it is related to waste management with emphasis should be made on the magnitude of reverse logistics application in developing countries;
- Optimisation of facility location to determine the optimum location of landfills, which will maximise the benefits of waste management, this will require studies of the geotechnical site characteristics, environmental impact analysis;
- Quantification of emissions from waste collection by trucks in Kampala, and such investigation will help to provide knowledge on how much emissions is produced by these trucks and how they can be reduced;
- Quantification of recyclables that are picked from the waste stream before reaching the landfill, in the long run, this will help to ascertain how many recoverable products are generated right from the source of waste production;
- Incorporation of the aspect of solid waste management in planning, implementing and monitoring with various other departments such as public health, environmental management, financial administration; and
- Encouragement of public/private sector participation in waste management, where private sector participation will work hand in hand with the authorities, leading to better service delivery.

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