Optimization of waste collection and disposal in Kampala city

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abstract

Waste collection and transportation is an important municipal service that involves high expenditures if not handled efficiently. This has hindered waste management in many Sub-Saharan African countries. In this study, Geographic Information System (GIS) tools were used to optimize travel distances, trips and collection time, which leads to maximizing total waste collection, yielding large savings and keeping the environment clean. The study suggested the best waste collection routes, and determined a suitable vehicle fleet and capacity to be used by Kampala Capital City Authority (KCCA), which is the body responsible for waste management in Kampala. The use of the GIS tools led to the reduction in the total number of trips and travel distances, which decreased fuel consumption and vehicle emissions. In addition, the model can be used by the various outsourced private operators, collecting and disposing of solid wastes. Since the current municipal landfill for Kampala city is almost full, the GIS tool was used to identify the optimum location of a new proposed landfill site, based on optimized travel distances. The results of this study can help KCCA to decrease costs of managing wastes and environmental as well as social impacts.

1. Introduction

Waste management involves a lot of difficulties during operation and among these, waste collection is the most aggravated due to the high costs that are involved (UNEP, 2009). Waste collection cost represents over 70% of the solid waste management budget of many municipalities in developing countries (Rotich, Yongsheng, & Jun, 2006; Tchobanoglous & Kreith, 2002) and about 60% or less for the developed countries (Brunner & Fellner, 2007). In many municipalities of cities in the developing countries, the total cost of the solid waste management includes the transportation cost of the waste to different facilities such as transfer stations, temporary storage sites, landfills and also the fixed costs and operational of these facilities (Chang, Lu, & Wei, 1997; Dyson & Chang, 2005). This has forced many municipalities especially in the developed world to start up research that is aimed at cost effectiveness such as route optimization (Chang et al., 1997).

Route optimization is one of the most studied aspects in optimization problems in transportation research, consisting of the design of optimal and cheapest distribution pattern to serve scattered customers (Badran & El-Haggar, 2006; Bosona, Nordmark, Gebresenbet, & Ljungberg, 2013). The common objective of route optimization is to minimize travel distances and reduce the fleet size used so as to reduce on operational costs and minimize on emissions (Apaydin & Gonullu, 2008; Ljungberg, Gebresenbet, & Aradom, 2007; Nuortio, Kytöjoki, Niska, & Bräysy, 2006). Collection of wastes has posed a lot of operational problems for local authorities in many cities involving tasks such as optimal fleet size, type and scheduled route (Torres & Anton, 1999). Sahoo, Kim, Kim, Kraas, and Popov (2005), in their study of route optimization of wastes asserted that in order to achieve effective waste management system, reduction of operational expenses and optimization of vehicle fleet size is necessary. The importance of optimizing waste collection vehicle routing is to minimize on fuel consumption rather than finding shortest distances (Tavares, Zsigraiova, Semiao, & Carvalho, 2009). This is because in the city areas, some of the shorter distances may be inconvenient for driving leading to more fuel consumption, pollution, and/or congestion.

Routing involves the use of extensive spatial data making it possible to use new technologies such as Geographic Information System (GIS). GIS is able to provide effective handling, display and manipulation of both geographic and spatial information. GIS tool

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has been found to play a potential role for solving various types of engineering and management problems in siting of waste disposal sites. GIS enables development of a multi objective model for collection vehicle routing and scheduling for solid waste management systems such as reduction of travel time, cost of site selection and provides a data bank for future monitoring (Sumathi, Natesan, & Sarkar, 2008).

Many surveys have been done in the field of location analysis theory but little has been done on facility location and routing (Salhi & Nagy, 2009). Facility location and routing have aspects related but many scholars have not considered the interaction of the two aspects. Salhi and Nagy (2009) noted that locating a facility is part of strategic planning while routing is a tactical practice. Their explanation was that optimizing of routes is flexible and can be changed anytime. However, locating a facility for instance a dumpsite is more or less permanent and can stay for a longer time. Combining the two into the same framework of work is unsuitable yet both are related (Nagy & Salhi, 2007).

Kampala City is one of the cities facing challenges of solid waste management. On an average, about 1500e2500 metric tons of waste is generated in the City per day (Ojok, Koech, Tole, & OkotOkumu, 2013). The city has a single recognized landfill known as Kiteezi (see Fig. 2). Only about 40e45% of the generated waste is collected and disposed of at Kiteezi landfill (KCC, 2006; Mugagga, 2006; Oyoo, Leemans, & Mol, 2011). From the collected waste, about 600 metric tons are collected by the city authority and approximately 300 metric tons are collected and transported to the landfill by private operators adding up to about 900 metric tons that reaches Kiteezi landfill (Kinobe, Niwagaba, Gebresenbet, Komakech, & Vinnerås, 2015). The majority of the remaining waste is indiscriminately disposed of in drainage channels or open land spaces, where it is later burned. Only a small proportion of the waste comprising of plastics and metals in Kampala is re-used or recycled.

Route optimization of solid waste as a management sphere has not yet been used in Kampala city and the existing waste collection systems are developed based on limited data. As such, an effective and integrated solid waste management system that will consolidate routes; reduce haul distance, time and cost; balance the distribution of waste collection in all the parishes; ensure equitable involvement of all assigned vehicles in waste hauling is needed, not only to reduce costs of waste disposal but also to keep the city environment in a good manner. The main objective of this study was to optimize the collection and transportation of waste to the

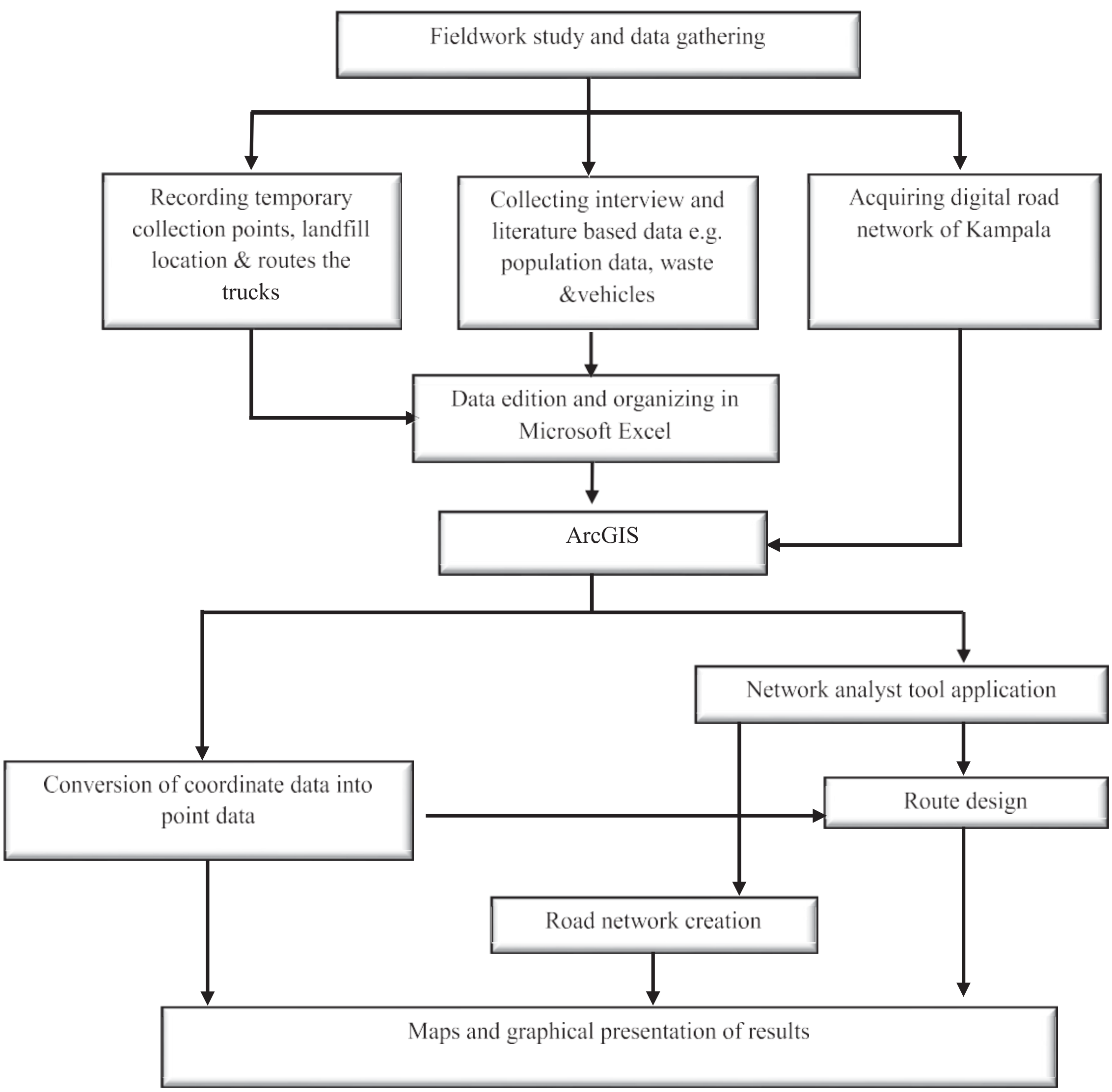

Fig. 1. GIS methodological structure.

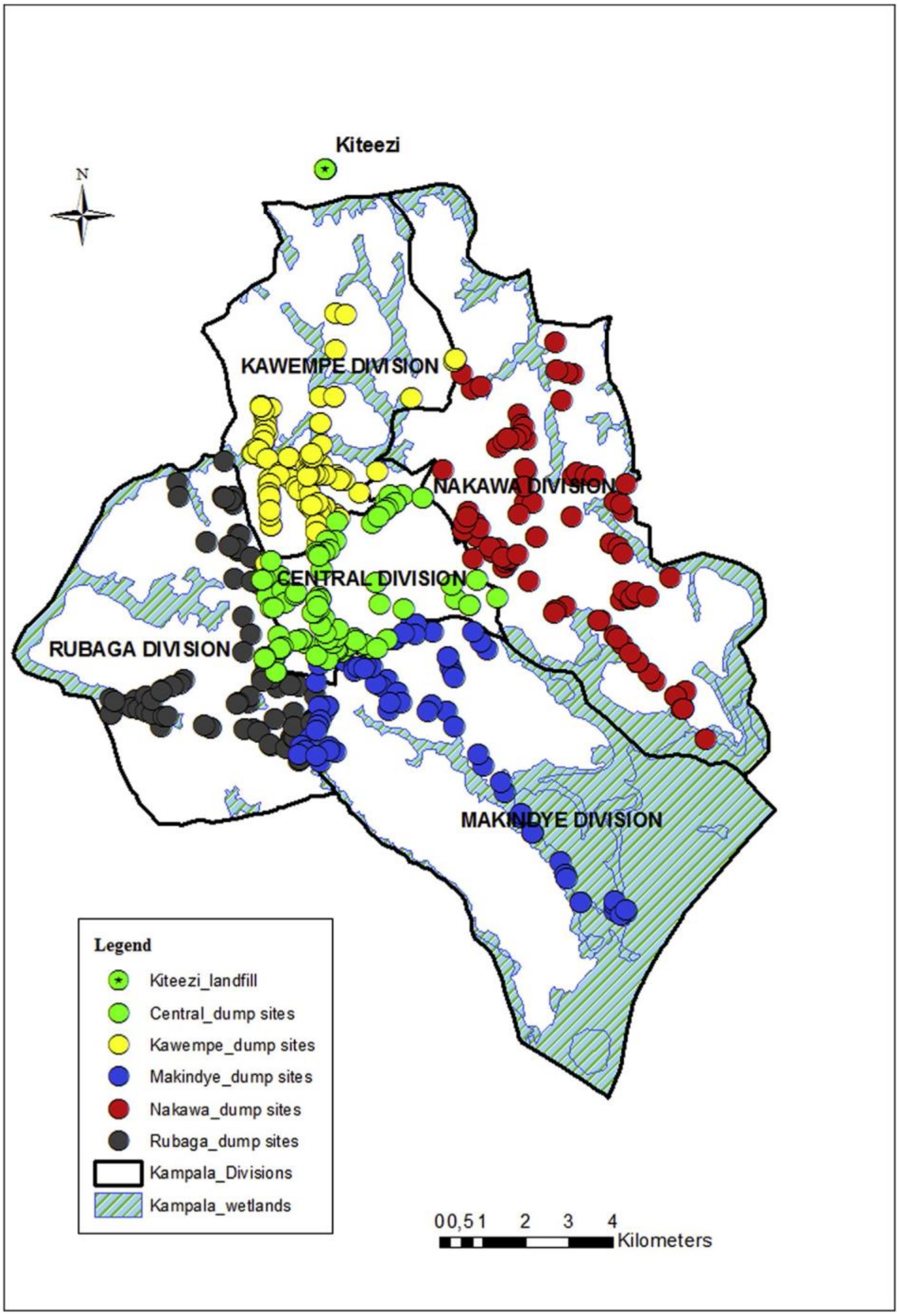

Fig. 2. Kampala Map with temporary collection points location in 5 divisions.

landfill. This includes waste estimation at each temporary collection point and determining best routes with regards to travel distance and time as well as trips. A further objective was to determine the optimum location for a new landfill to be proposed. As a consequence, this will reduce on the total costs of waste management and the negative environmental impact of waste in Kampala City.

2. Methodology

2.1. Study area and waste management status

Kampala City has five divisions (Central, Kawempe, Makindye, Nakawa and Rubaga divisions) (Fig. 2), with each division having a responsibility of managing its own waste. KCCA has the mandate of solid waste collection in the city and also contracts out the service to private operators. Solid waste in the City is mainly thrown on the ground and stored in temporary collection points that are official (recognized by the municipality) and unofficial (not recognized by the municipality) (Kinobe et al., 2015). The temporary collection points are normally located along a defined road or near drainage channels. From the temporary collection points, KCCA trucks and private operator trucks collect and transport the wastes to Kiteezi landfill. The city authority also introduced a system known as self-loading, where a truck moves into an area and people are allowed to load their waste on to the vehicle. The frequency of waste collection at the temporary collection points varies depending on waste deposited. If there is little waste at the temporary collection points, the trucks are directed to other pressing sites that have huge quantities of illegally dumped waste. Current routes are designed by the city authority based on where waste is deposited and the drivers also follow routes depending on their experience and knowledge of the area. In other words the trucks don't work on a scheduled route time table. Most of the waste collection trucks in the city are loaded manually by humans. When the truck is full to its capacity, it goes to dispose of the waste to the landfill at Kiteezi. Each truck can normally make more than 2 trips per day to the landfill.

The study was carried out in all of the 5 divisions that make up Kampala City district. The city has 99 parishes with a population of about 1.72 million people during night time (UBOS, 2012) and estimated to be generating 1200e1500 metric tons of waste per day. Only about 40% of the generated waste is collected and transported to the landfill in Kiteezi (located 12 km from the city center) by the combined trucks that belong to the city authority and those of the private sector (KCC, 2006; Mugagga, 2006; Nabembezi, 2011). On an average, the generation of waste per capita in Kampala city is about 0.6 kgs (Table 1).

2.2. Waste generation model

The waste generated was calculated with reference to (Kinobe et al., 2015; Ojok et al., 2013; Robinson, 1986) and data obtained at the landfill. The population of each parish was collected from (UBOS, 2012) and the total waste that is generated in each division was obtained from the landfill. Therefore, the per capita waste generated was computed as the total waste generated in the division divided by the population of that same division. This was further multiplied by the population of the parish to obtain the waste generated per parish using the formulae below (Ayininuola & Muibi, 2008). The formulas gave results in Fig. 3 that were used for routing analysis.

$$pw = \frac{k}{tp} \quad (1)$$

$$wt = pw*pp \quad (2)$$

where pw, is per capita waste generation per day in metric tons

k is the total waste generated in metric tons per division that is know
wt is waste in metric tons in a parish
pp is the parish population
tp is the total population of the division

The 40% waste collected per temporary collection point in each parish was computed from the total waste generated by the division and the population. The parish waste generation tonnage was multiplied with the parish population to get per capita waste generation (Formulae1 and 2). The 100% waste collection was computed from the waste generated per parish per division as a projection of the 40%.

To ascertain the amount of waste generated at a temporary collection point, the parish tonnage of waste was divided with the available temporary collection points (Formulae 3)

$$tcp = \frac{tpw}{ttcp} \quad (3)$$

where tcp = waste at a temporary collection point (metric tons).

tpw = total waste generated in the parish (metric tons).
ttcp = total number of temporary collection points (metric tons).

Based on this information, the waste to be transported to the landfill was estimated for two options: (i) transporting only 40% of the total generated waste, and (ii) transporting 100% of the generated waste. Therefore, at 40% about 615 tons of waste could be collected from the city to the landfill in Kiteezi. The figure was reached after data collection at the landfill for two months (May and June). This was also related to a survey done by Kinobe et al., (2015) that recorded about 672 tons of waste. From the calculated results of 40%, it was further computed to get the projected 100% waste generated from the city to give 1538 tons.

2.3. GIS model application

The Global Positioning System (GPS) technology was used to collect data on dumpsites and routes. A Magellan® Triton 1500 model GPS was used in collecting and storing data that was later integrated into and managed by GIS software. With the GIS application through the Network Analyst extension, an optimization module was developed to calculate the shortest distances. The GIS software took into account parameters in solid waste management such as location of dumpsites, truck capacities, the road network as well as the waste generation volumes of the area. The structure of the methodology that was followed is shown in Fig. 1.

2.3.1. Description of the vehicle routing (VR) using GIS software

Arc GIS map program was used to create and store layers of data and maps. A heuristic-deterministic approach method was used during waste collection. Truck routes were developed using Arc GIS map software to find the shortest distance from the source start point via the temporary collection point and finally to the landfill. The speed of the trucks was assumed to be the same because one common type of vehicle 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.

The GIS based software and its tool of Network Analysis was used in vehicle routing to determine the shortest route from the collection points to the landfill in the same manner as it has been used in urban network analysis by (Ghose, Dikshit, & Sharma, 2006; Tavares et al., 2009). The software builds up routes one by one, finding the closest temporary collection sites and the capacity

Table 1
Solid waste information in Kampala City.

Details	Rate	References
Divisions	5	(KCC, 2006)
Parish	99	(KCC, 2006)
Population	1.72 million night population	(UBOS, 2012)
Waste generation	1200e1500 metric tons/day	(Nabembezi, 2011)
Per capita waste generation	0.3e0.6 kgs/day	(Ojok et al. 2013; Okot-Okumu & Nyenje, 2011)

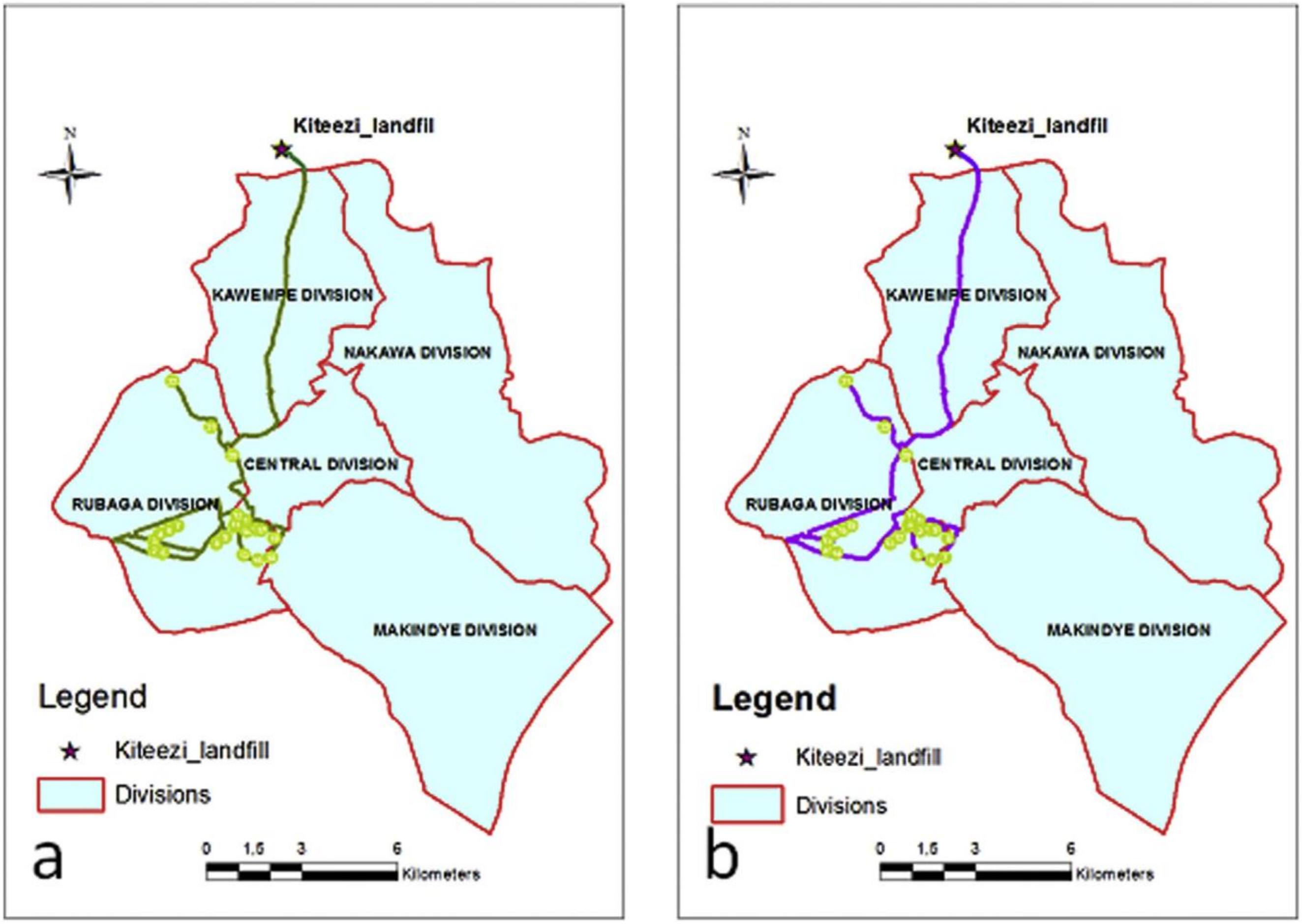

Fig. 3. A current route (a) and an optimized route (b).

of waste in metric tons picked at various sites until all the waste was hauled. The VR had input parameters that could be defined as; the temporary collection sites with corresponding waste in metric tons that are serviced by a truck (in the study assumed to be homogenous) to pick waste at a given travel time, also taking into account the service time. Similarly homogenous values (i.e. 20 min) were assigned as service time at each stop for fuelling the vehicle and the same 20 min also for loading of waste at each temporary collection point. The truck started the journey at the start point which was the division headquarters at a permitted time that was (08:00:00) and after fuelling, it went to the first optimized temporary collection point. The latest time for the truck to start work was 10:00:00. From the first temporary collection point, the truck moved to the next optimized temporary collection point taking into account minimization of distances as stipulated in all route optimization studies. The truck continued with its movement in optimized routes of temporary collection sites until it filled to capacity and thereafter travelled to the landfill for disposal.

2.4. Solid waste collection vehicle

The main truck model used in the collection of waste was the Faw box body compactor. The truck is in a category of a diesel heavy duty with a 6 engine cylinder and average volume capacity of 6metric tons when full to the maximum. On an average, the truck consumes 0.33 L of fuel per kilometer (Apaydin & Gonullu, 2008). Therefore, this figure on the fuel consumption was adopted in this study. Larsen, Vrgoc, Christensen, and Lieberknecht (2009) used the transportation simulation software based on the linear correlation of the vehicle weight and the diesel consumption. The calculations of Larsen et al., (2009) were faced with uncertainties. For instance, the fuel consumption of the day as recorded by the driver was taken as the fuel consumption of the truck. The labourers consisted of a driver and 4 to 5 crew members depending on their availability on a particular day, because they were taken as casual labourers for loading of the waste.

In the present study, a daily routine of waste collection was considered, where each vehicle was assumed to leave the start point i.e. the division headquarters then move into the division for pickups characterized with constant stops at temporary collection sites until it filled and departed to the landfill. The trucks were assumed to travel at an average speed of 30 km/h even though the anticipated and required travel speed was 50 km/h, according to the City speed limits (MoWHC, 2004). The average speed of 30 km/h was considered in order to account for traffic jams, bad roads with a lot of potholes, reckless driving and riding from other motorists and the weight of the vehicle when it is loaded.

For the current status of waste collection from the temporary collection points in the city, recorded routes followed by the trucks were noted by following the truck through its path. Data was collected for 21 different routes within the City of Kampala as follows: 3 in Central, 2 in Kawempe, 2 in Makindye, 8 in Nakawa and 6 in Rubaga divisions. (Fig. 3) reports one of the current recorded and optimized routes.

2.5. Vehicle routing (VR) methodology scenarios

The VR developed was based on 2 approaches as indicated in the (Table 2). The Heuristic method was adapted and used because it is designed to solve real world problems considering the flexibility of the observable fact as changes can easily occur (Nagy & Salhi, 2007). The work comprised of the following routing algorithms:

a) Recording some of the current routes followed by the trucks and then optimizing the routes.
b) Creating optimized routes to Kiteezi landfill with reference to the official and unofficial dumpsites per division using the current 6metric tons trucks and proposed 10and 18metric tons to solve the routing problem at the current 40%; at the projected 100% waste collection (improving the initial available system with the current trucks and also increasing on the fleet with a higher tonnage).
c) Creating optimized routes by employing an outsourced private operator using 20 metric tons 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 emphasis on travel distances.

2.5.1. Vehicle routing assumptions and development

Distances of optimized routes were determined per division where the same vehicle model (Faw box body compactor trucks with capacity of 6metric tons) made multiple trips starting from 08:00:00 at the division headquarters and returning at day end at 22:00:00 with a service time of 20 min fuelling at petrol station and 20 min of loading waste at each waste collection point. The outsourced private operator start up point was the central division headquarters because it was centrally located for all the divisions to access. The collection vehicle stopped at 459 temporary collection sites (both official and unofficial) (Fig. 2). The vehicle's optimal path to be followed was determined by computing the minimal impedances between the temporary collection sites and the final landfill. When full, the headed to the landfill (Kiteezi) at a speed of 30 km/h and this speed accounted for barriers such as time in traffic jams, potholed roads and other driver obstructions. In order to understand how efficient the existing routes are, the recorded routes were recreated (simulated) using ArcGIS analyst tool with optimized (shortest distance) option. This optimization was based on only distance travelled without considering other constraining factors such as weight of waste, driving time and time window. In scenario (40% and 100% waste management) based analyses, optimized routes were created using the available 6tons truck Faw box body compactor and the proposed 10 and 18 tons trucks to Kiteezi and the proposed new landfill to solve the scenario at 40% and 100% waste collection. The outsourced private operators were considered to use 20 metric tons capacity vehicles to create optimized routes to the new proposed landfills. The outsourced startup deport was assumed to be taken from the Central division headquarters because it was centrally located in central Kampala and can be accessed by all the other divisions.

2.5.2. Vehicle routing limitations

The vehicle routing was based on assumptions which could limit the accuracy of the results such as driving time and vehicle load rate. One assumption was that the waste collected was constant at each temporary collection point, although fluctuations in waste generation in the parish and at each collection point are expected. The average speed used was 30 km/h based on the explanation given in Section 2.4.

3. Results

3.1. Waste collection with current routes

Since there were no scheduled routes that were provided by KCCA to their truck drivers, the routes made were normally due to the demand of waste to be collected in the parish of divisions, also basing on the driver's discretion on the route to be followed. The recorded distance and travel time of the routes was 624.2 km and 1407 min (Table 3, Figs. 3 and 4). After optimization and changing the visiting orders, this came to 506.9 km and 1161 min giving a simulated benefit of 19% and 17% of distance and time respectively.

3.2. Scenarios

The application of the VR in Kampala city was presented based on facts and assumptions. From that, 6, 10 and 18 metric tons trucks capacities were used.

3.2.1. Scenario 1 optimized routes using 6,10 and 18 metric tons trucks at 40% waste collection

(Table 4), focuses on optimized hauling waste tonnage generated per day per division using the current 6 metric ton Faw box body trucks available. It reported the needed trips required in each division to collect the generated wastes. The daily tonnage was estimated at 40% waste collection by the city authority vehicles. In order to increase on waste collection, 10 and 18metric tons trucks were proposed in the scenario to solve waste collection at 40% as indicated in (Table 4). There is a significant improvement in the number of trips made and distance covered with increase in the vehicle capacity that reduces the fleet vehicle number.

3.2.2. Scenario 2 optimized routes using 6,10 and 18 metric ton trucks at 100% waste collection

There is a significant improvement of travel distances with increase in vehicle capacity that is to say, when increasing the truck capacity from 6 metric tons (3,687 km) to 10 metric tons (2,182 km) and subsequently to 18 metric tons (1,219 km) (Table 5). A percentage improvement of 41% from 6 metric tons trucks to 10 metric tons truck is realized and further improved to 44%, when increased from 10 to 18 metric tons trucks. This again applies to the number of trips made (43% from 6 to 10 metric tons and 48% from 10 to 18 metric tons). However, a higher improvement is realized from 6metric tons trucks to 18 metric tons67%, 45% and 70%, with distance, time and trips respectively.

Table 2
Approaches of VR development.

Heuristic approach	Deterministic approach
a) Tonnage to be hauled	a) Waste generation in the city
b) Number of trips to be made	b) Location of collection points and amount of waste
c) Distance to be travelled	c) Location of disposal site and proposed land fill sites

Table 3
Some of the current routes that have been measured and optimized.

Route	Recorded		Optimised		Benefit %	
	Travel distance km	Time mins	Travel distance km	Time mins	Travel distance km	Time mins
Banda 2	29.3	90	27	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	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	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		
Average benefit					19	17

3.2.3. Scenario 3 comparison of optimized routes using KCCA trucks and outsourced private operator using 20 metric tons truck at 100% waste collection to Kiteezi and proposed new landfill sites

(Table 6) presented computational results comparing Kiteezi the current landfill and the other proposed new landfill sites transporting the same tonnage at 100% waste collection. 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 great variation in travel distances by the trucks to the proposed landfill due to the different locations.

On part of the outsourced private operator, it was assumed that a 20metric ton truck was used to collect waste from the city center to Kiteezi and the new proposed landfills. The outsourced private operator reduced the total number of trips and distance travelled for all the landfill areas shown in Table 6 but not with the time that actually increased to 153 h in total for all the sites. The improvement benefit that was calculated using the KCCA 18 metric tons truck can be seen in Table 7 and the significance level is low.

3.3. Fuel analysis for trucks to Kiteezi and proposed new sites

Fuel consumption in waste collection depended on the type of vehicle, travelled distance and the condition of the vehicle. Faw box body compactor truck has an engine with 6 cylinders with an average fuel consumption of 0.33 L of diesel per kilometre. (Table 8) shows that with an increase of truck tonnage, the total fuel consumption reduces and this subsequently reduces on the emissions. The percentage benefit of fuel consumption from 6 metric ton truck increased to 10 metric ton truck, 10 metric ton increased to 18 metric ton truck is 39% and 48% respectively.

3.4. Location analysis for the new sites

The purpose of this analysis was to analysis the differences in travel distance from temporary collection points to the new proposed landfill by KCCA. The aim was to come up with the minimum travel distance. From the analysis, Wakiso-Mende was found to have the shortest distance travel from the optimized temporary points for all the different fleet sizes followed by Kalagi (Table 7 and Fig. 5).

4. Discussion

4.1. Generation of solid waste in Kampala City

Waste generation is affected by income levels, demography of the area, and climate (Hockett, Lober, & Pilgrim, 1995). For better waste management and integration, waste generation data is a necessity yet this kind of data lacks in many Sub-Saharan African countries and most models are developed in the context of the developed countries (Dyson & Chang, 2005; Lebersorger & Beigl, 2011). Li, Borenstein, and Mirchandani (2008) asserts that most studies work with developed waste estimation models. In this study, the data used to generate waste information based on two sources of data collected. One source of data was collected at the landfill and another was computational data calculated from waste generated per month per division, per parish and consequently per capita waste generation. According to Okot-Okumu and Nyenje, (2011), UBOS (2012) and Ojok et al., (2013), the per capita waste generation in Kampala is approximately 0.6 kg ca^{-1} d^{-1}. However, Nabembezi (2011) quotes a higher per capita waste generation at 1 kg ca^{-1} d^{-1}. This high value may be because of the fact that the author's study area was tagged to only one division and a sample of only households. Kinobe et al. (2015) and Komaketch et al. (2014) estimated a monthly waste generation of Kampala at 28,346 metric tons and 28,000 metric tons respectively. When these total tonnage of wastes are distributed within the 30 days and lessened by what the private operator collects and transports that is about 300 metric tons d^{-1} (Kinobe et al., 2015), then the waste generation rate is similar to that found by this study.

4.2. Solid waste collection routing in Kampala City

Solid waste collection in the city was carried out using three types of vehicles namely the tippers, tractors and compactor (FAW box body), the latter being the commonly used and with the highest fleet number. Collection of waste experienced a number of

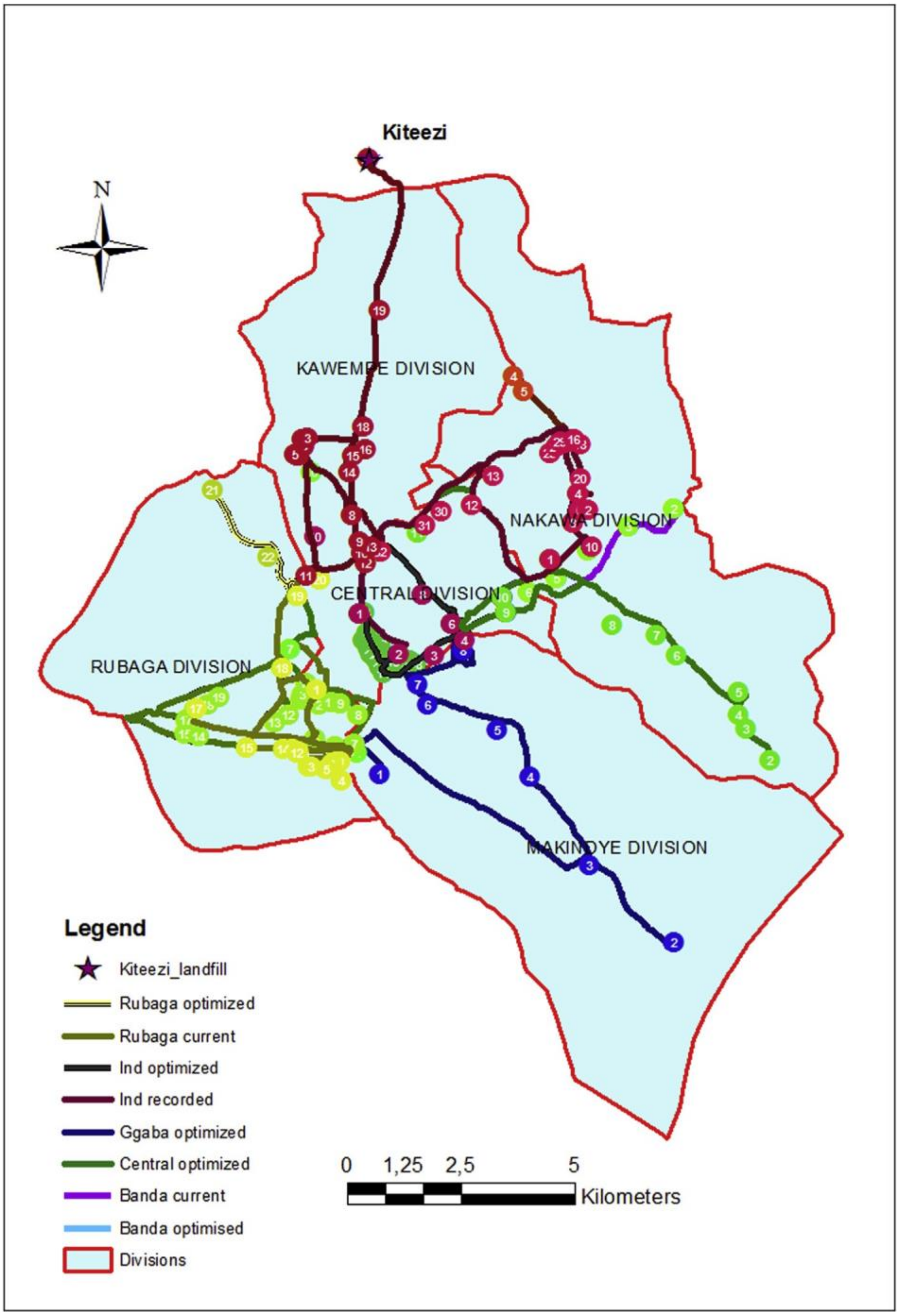

Fig. 4. Some routes from temporary collection points per division to Kiteezi.

loop holes ranging from technical to administrative including the constant breakdown of the trucks; nature of waste collected that is not segregated and corrodes the truck bed due to the high moisture content of the waste; lack of a clear and demarcated scheduling routing system. These loop holes are common in many Sub-Saharan African countries (Parrot, Sotamenou, & Dia, 2009; Rotich et al.,

Table 4
Optimized routes at 40% waste collection using 6, 10 and 18 metric ton trucks.

Division	Tonnage generated	Optimized using 6 metric ton truck			Optimized using 10 metric ton truck			Optimized using 18 metric ton truck		
		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	853	202	27	563	184

Table 5
Optimized routes using 6, 10 and 18 metric ton trucks at 100% waste collection.

Division	Tonnage generated	Optimized using 6 metric ton truck			Optimized using 10 metric ton truck			Optimized using 18 metric ton truck		
		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	240

Table 6
Comparing Kiteezi and the new proposed landfill sites at 100% waste collection.

Site	6 metric ton trucks			10 metric ton trucks			18 metric ton trucks			20 metric ton trucks		
	Trip	Distance (km)	Time (hrs)	Trip	Distance (km)	Time (hrs)	Trip	Distance (km)	Time (hrs)	Trip	Distance (km)	Time (hrs)
Busukuma	216	6007	309	125	3547	247	65	1916	204	57	1800	241
Kalagi	213	8220	336	126	4885	263	66	2651	212	57	2389	247
Kiteezi	218	3687	436	125	2182	317	65	1219	241	57	1139	225
Semuto	212	11,375	381	125	7155	289	65	3523	228	57	3295	260
Wakiso	211	5924	293	126	3493	239	66	1899	201	57	1811	231
Zirobwe	216	10,746	389	125	6859	291	65	3366	228	57	3072	261

Table 7
Percentage improvement benefits of outsourced 20 metric ton from 18 metric ton KCCA truck.

Outsourced 20 metric ton truck benefit %			
Site	Trips	Distance (km)	Time (hours)
Busukuma	12	6	18
Kalagi	14	10	17
Kiteezi	12	7	6
Semuto	12	6	14
Wakiso	14	5	15
Zirobwe	12	9	14
Total	13	7	—12

2006). In Kampala City, KCCA has no defined "route schedule" that is constantly followed by the truck drivers for every day routine work in each division. From the survey, the truck drivers revealed that they are normally called upon to go to a particular parish that has accumulated solid wastes to be collected. The drivers are aler- ted by solid waste scouts (KCCA employees) who move within the division allocating areas that have accumulated waste to be collected. This system has caused a lot of delay and costs. Truck drivers end up wasting time and fuel. Teixeira, Antunes, and de Sousa (2004) noted that static routes were preferred by waste collectors because they ease operation works based on the objec- tive of minimizing on travel distances and time durations.

4.3. Optimized routing impacts

Comparing the available 6 metric ton trucks and the proposed 10 and 18 metric tons trucks, the increase in the truck capacity generally reduces the number of trips made and consequently the distances travelled and time to Kiteezi landfill hauling the current 40% waste collection. By using trucks of 10 metric tons capacity instead of 6 metric ton trucks, improvements of 41% trips, 39% km, and 20% hours have been gained. Similarly, improvements of 44% trips, 34% km, and 9% hours have been realized with increase in truck capacity from 10 to 18 metric tons. The benefit is more significant when the increase is from 6 metric ton to 18 metric ton trucks in which case, the benefit realized is 67% trips, 60%km and 27% hours. However, bigger trucks could have negative consequences as they may have impacts on roads and accessing some waste collection sites with large sized trucks may be difficult. Other researchers revealed that route optimization could lead to improvement in driving distance, time and trips. For instance, Bosona & Gebresenbet., (2011), applied route optimization and logistics integration techniques to improve food deliveries in local food supply chains. Similarly, Gebresenbet and Ljungberg (2001); Ljungberg et al., (2007) applied route optimization to improve agricultural goods and animal transportation activities.

4.4. Optimized routing to the new proposed landfill sites

4.4.1. Outsourced private operator

With the growing managerial activities in developed countries, outsourcing has become one of the most used strategies in management. Firms are increasingly engaging themselves in outsourcing reverse logistics activities to third party logistics providers mainly to compare the running of business within the firm

Table 8
Comparing fuel consumptions and distances from dump sites to Kiteezi and proposed sites at 100% waste collection.

Site	Fuel	Using 6 metric ton trucks		Using 10 metric ton trucks		Using 18 metric ton trucks	
		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	2651	875
Kiteezi	0.33	3687	1217	2182	720	1219	402
Semuto	0.33	11,375	3754	7155	2361	3523	1163
Wakiso	0.33	5924	1955	3493	1153	1899	627
Zirobwe	0.33	10,746	3546	6859	2264	3366	1111

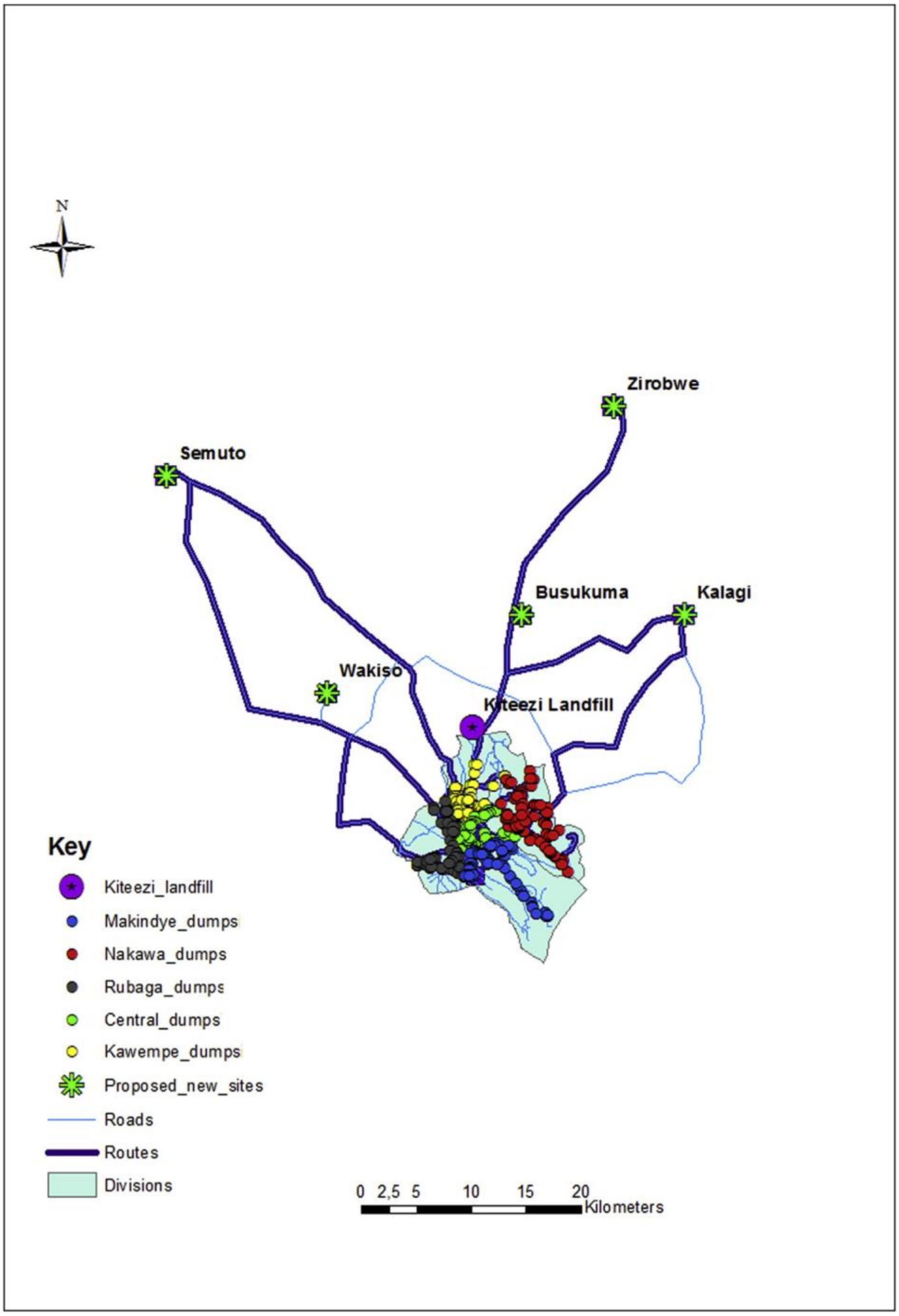

Fig. 5. Location of temporary collection points and proposed new landfill sites.

and outside the firm. Cheng & Lee., (2010) developed a decision making approach to be adopted by firms on the degree of outsourcing third party logistics and focus on its management as an activity to be under taken externally by firms. Outsourcing activities from third party organizations also has an advantage of developing infrastructure and coming up with better managerial skills due to the adequate resources and capabilities and do provide room for flexibility and effectiveness (Katusiimeh, Mol, & Burger, 2012). This was evident from a study by (Kinobe et al., 2015), where areas that were capable of paying for solid waste collection in Kampala City (Nakawa and Makindye divisions) had less illegally dumped waste and less un official dumpsites. From the survey, the outsourced operator was assumed to have truck capacity of 20 metric tons due to available resources and capability. The improvement by reducing the trips by 13% and travel distance by 7% compared to KCCA optimized routing was because of the larger vehicle capacity and the one centrally located start-up point unlike the four start-up points operated by KCCA. However, there is no time improved by outsourced operator (see Table 7). A time loss of 12% in terms of hour was estimated (i.e. total time was increased by 12% when 20 ton truck was used). The argument for this is that, the bigger the vehicle capacity, the more waste it will load and carry. Added to that is that more dumpsites will have to be visited hence more service time will be accrued thus the increase in final total time. Similar results was noticed from the study by Li et al., (2008) who worked on truck scheduling of solid waste collection while modelling the problem without considering balanced loading of waste.

4.5. Facility location of new proposed landfill

Cheng, Chan, and Huang (2003) notes, very many multi-objective programming models have been developed to solve the problem of location analysis but these models are largely mathematical and many a times leave out other important aspects that concern the protection of the environment such as pollution. The environmental aspects normally conflict with other aspects like socio-economic hence leading to the destruction of the environment in the name of development. In this study, only travel distance was considered to identify the best location. This study suggested new optimal sites that would have less travel distance and hence costs. However, with the location analysis, there is need for further research into the site proposed. For example, conducting an Environmental Impact Assessment (EIA), soil test analysis, ground water depth analysis, cost benefit analysis etc., are needed to ascertain in-depth information before making final decision to use the new landfill.

4.6. Environmental and cost impacts of optimized routes

Waste collection is usually carried out by trucks with diesel engines, which use a lot of the fuel. Due to old age and a lack of scheduled maintenance, the heavy duty trucks emit high levels of carbon dioxide (CO_2) and nitrogen oxide (NO_2) to the atmosphere (Zielinska, Sagebiel, McDonald, Whitney, & Lawson, 2004). The authors noted that the greatest pollution emitters are from diesel trucks and also contained the highest molecular weight of naphthalene in fuel and oils. Exposure to large amounts of naphthalene may damage or destroy red blood cells. With optimized routes, reduction in the number of trips, travel distance and time will lead to reduction in fleet size hence reducing on Green House Gases (GHG) emissions to the atmosphere, reduction in the costs of operation and maintenance (fuel), and above all the trucks will be put to great use. Ericsson, Larsson, and Brundell-Freij (2006) in their study of optimizing route choice for lowest fuel consumption stresses that a reduction in fuel intake reduces on CO_2 emissions.

5. Conclusion

The paper proposed a route improvement compared to the current routes taken by the solid waste collection trucks in Kampala; and shows a better performance in terms of fuel consumption, emissions from the trucks and less operational costs, making it a solution to urban environmental management. In order to further improve on the vehicle operation, vehicle capacity should be increased in volume so as to increase on the utilization, gather more waste at temporary collection points and reduce on time and distance to travel. The GIS based routing procedure is flexible and could be used in planning of waste collection policies and decision making mechanisms in waste management.

Optimization of waste collection with increase in truck capacity reduced distance and travel time to dispose the waste. From 6 metric tons truck to 10 metric tons, the reduction in travel distance was 39% while from 10 metric tons truck to 18 metric tons truck, the travel distance reduced by 34% considering a 40% waste collection. The reduction in time of waste disposal for the change from 6 metric tons truck to 10 metric tons truck, and from 10 metric tons truck to 18 metric tons truck was 20% and 9% respectively considering a 40% waste collection. The total number of trips was 82 with 6 metric tons truck, which reduced to 48 with 10 metric tons truck, further reduced to 27 trips with the 18 metric tons trucks giving a percentage benefit in terms of reduction in travel distance by 41% and 44% respectively. However, if the truck tonnage reduced from 6 metric tons straight to 18 metric tons, the improved percentage saving for distance, time and trips would be 60%, 27% and 67% respectively.

With waste collection taking over 70% of most waste management budgets, it is normally the fuel price with the highest cost portion that also brings about undesired emission pollutants. Therefore optimized routing to reduce on fuel consumption by trucks would not only reduce costs on man power, time and operational costs, but also environmental benefits such as reduction in greenhouse gas emissions during waste collection and transportation.

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