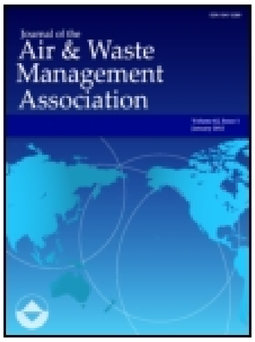

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TECHNICAL PAPER

Characterization of municipal waste in Kampala, Uganda

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In Kampala, Uganda, about 28,000 tons of waste is collected and delivered to a landfill every month. Kampala Capital City Authority (KCCA) records show that this represents approximately 40% of the waste generated in the city. The remaining uncollected waste is normally dumped in unauthorized sites, causing health and environmental problems. However, the organic fraction of domestic waste can provide an opportunity to improve livelihoods and incomes through fertilizer and energy production. This study characterized the municipal waste generated in Kampala and delivered to Kiteezi landfill between July 2011 and June 2012, that is, covering the dry and wet months. On each sampling day, waste was randomly selected from five trucks, sorted and weighed into different physical fractions. Samples of the organic waste from each truck were analyzed for total solids, major nutrients, and energy content. During the wet months, the waste consisted of 88.5% organics, 3.8% soft plastics, 2.8% hard plastics, 2.2% paper, 0.9% glass, 0.7% textiles and leather, 0.2% metals, and 1.0% others. During the dry months, the waste consisted of 94.8% organics, 2.4% soft plastics, 1.0% hard plastics, 0.7% papers, 0.3% glass, 0.3% textile and leather, 0.1% metals, and 0.3% others. The organic waste on average had a moisture content of 71.1% and contained 1.89% nitrogen, 0.27% phosphorus, and 1.95% potassium. The waste had an average gross energy content of 17.3 MJ/kg. It was concluded that the organic waste generated can be a suitable source of some plant nutrients that are useful especially in urban agriculture.

Implications: The result of the waste characterization in Kampala was found to be significantly different from that obtained for other Sub-Saharan African (SSA) cities, showing that studies assuming average values for the waste fractions are likely to result in erroneous results. Furthermore, no reduction in organic fraction of the waste was noticed when compared with a study done two decades ago in spite of greatly improved economic status of Kampala city, a finding that is not in agreement with several other similar studies done for other SSA cities.

Introduction

Human activities create waste, but it is the way in which these wastes are handled, stored, collected, and disposed of that can pose a risk to the environment and public health. In places with intense human activities such as urban centers, appropriate and safe solid waste management is of great importance in providing healthy living conditions for residents. Though most governments in developing countries acknowledge this fact, many municipalities struggle to provide even the most basic of services (Zurbrugg, 2003). In the case of Kampala, Uganda, Kampala Capital City Authority (KCCA) is mandated by the Local Government Act of 1997 to provide solid waste management services to all five divisions of Kampala City (Banadda et al., 2009, KCCA, 2012). Some of the solid waste management services provided by KCCA include the collection and disposal of wastes from households, market areas, hospitals, industries, and city center areas (National Environment Management Authority [NEMA], 2000). Efforts to manage wastes in the city are continuously overwhelmed by the ever-increasing population of city residents, increased levels of economic activity, and reduced funding from central government. As a result, incompetence and low service coverage characterize the waste collection and disposal system in Kampala City. Most of the time, the services are not on schedule and are only provided in crucial areas such as marketplaces, upscale residential areas, and politically sensitive areas (Tumuhairwe et al., 2009). In an effort to alleviate this situation, KCCA has contracted private companies to assist with the management of solid waste collection so as to improve the cleanliness of the city. Despite this, less than half the total amount of waste generated, estimated to be 1,500 tonnes per day, is collected (Office of Auditor General [OAG], 2010). The uncollected waste is normally dumped in open areas, streams, open drainage channels, and other areas inaccessible to waste collection vehicles, thus creating environmental and public health hazards for local residents (OAG, 2010).

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The solid waste that is collected from the five divisions of Kampala City is dumped at the Kiteezi landfill site, located 12 km from the city center. However, people living near the landfill site have complained that this landfill has made their place uninhabitable and that their land has lost value. These conflicts stem from bad odor, leachate (which pollutes water resources), scattering of wastes from the dumping sites by wind and scavengers like Marabou storks, and other nuisances such as vermin, mosquitoes and flies (Mwiganga and Kansiime, 2005). Furthermore, although landfilling was regarded as an economical and readily available means of municipal solid waste disposal in developing countries (Mwiganga and Kansiime, 2005), high land prices as a result of rising populations and incomes in these areas (Idris et al., 2004) have greatly reduced its economic attractiveness. In addition, landfills are recognized as a major source of anthropogenic methane emissions and an important contributor to global warming, accounting for up to 19% of methane emissions in the world (Kumar et al., 2004). This implies that waste management by landfill disposal is an option that is not sustainable, especially in the face of environmental awareness and concern. It is therefore important to identify other, more sustainable waste management methods for waste generated in Kampala.

In this context, it should be noted that domestic waste is a vital resource that, if well exploited, can go a long way toward improving the livelihoods of urban residents. According to Nzila et al. (2010), biowastes could play a critical role in future energy supply, mainly through thermochemical, physicochemical, and biochemical transformation and conventional combustion. Furthermore, Cofie et al. (2009) reports that the organic fraction of domestic waste can be exploited through composting, thus returning vital nutrients to the soil. According to Amoding (2007), about 50, 10, and 130 metric tonnes per year of nitrogen, phosphorous, and potassium, respectively, are bound up in market crop wastes in Kampala City alone. This provides great potential for nutrient recycling, especially to urban farms, which often require large amounts of nutrients to replace the losses from intensive farming.

A comprehensive study on the waste generated in Kampala was conducted in 1989 (Ministry of Lands, Housing and Urban Development [MLHUD], 1993). However, the urban population size and living standards in Kampala have changed significantly since then (NEMA, 2007). The aim of this study was therefore to investigate the mass and composition of the waste entering the Kiteezi landfill site serving Kampala city, in order to determine the potential for recycling organic matter and plant nutrients contained in the waste. The study included an assessment of the different materials in the waste, as well as the content of energy and nutrients in the organic waste fraction. Moreover, monthly variations and variations between different parts of the city were investigated.

Materials and Methods

Study area

The Kiteezi landfill is an 8-ha site located 12 km from Kampala city center. The landfill is currently operated by the privately owned Otada Construction Company. Upon arrival at the site the waste is weighed and after dumping it is processed by waste pickers, also known as scavengers, for removal of material with a market value, for example, paper, metals, and plastics (Figure 1). Crawler trucks are used to spread and scatter the waste in an effort to stimulate decomposition. The waste is sometimes sprayed with insecticide to kill off flies before it is covered with soil (Mugagga, 2006). The landfill has a leachate treatment plant, which uses mechanical aeration to reduce the biological oxygen demand of the leachate before it is released to the adjacent wetland. The landfill receives waste from surrounding areas as well as from urban Kampala, but in this study the focus was on the latter.

Figure 1. Kiteezi landfill, Kampala.

Kampala (0°15′ N; 32°30′ E) occupies a total area of 190 km^2 (Matagi, 2002). The city is currently experiencing rapid population growth due to immigration and natural increase (Howard et al., 2003) and is estimated to have a population of 1.5 million inhabitants (KCCA, 2012). Kampala city has five divisions, with Kawempe division being the poorest and the Central division, which includes the Central Business District (CBD), being the wealthiest (Golooba, 2003). Makindye division is mainly a residential area with a mixture of very-low-income and medium- to high- income areas, in addition to being generally periurban in nature (Mugagga, 2006). Kampala's other divisions are Rubaga, which is more periurban in nature, and Nakawa, which has the highest concentration of rich neighborhoods (Katusiimeh et al., 2013).

Sampling and field measurements

Five "garbage trucks" entering Kiteezi landfill, one from each of the five different divisions of Kampala, were randomly selected on each day of the analysis using a random number table. Each selected truck emptied its contents in a preselected area for the analysis. Scavengers already working at the site were employed to manually sort the waste into organics, hard plastics, metals, papers, soft plastics (polythene), glass, textiles and leather, and others, according to Zurbrugg (2003). (The separation of plastic into hard and soft fractions is motivated by the recycling system in Kampala, where these two fractions not only have different prices but are managed as two distinct entities.) The weights of the different fractions were recorded. The organic fraction was then thoroughly mixed and spread out by hand on a 5 m × 2 m grid, from which 10 samples weighing 1 kg each were randomly collected. These samples were then thoroughly mixed before a final 1-kg sample was drawn for nutrient and energy content analysis. This procedure was repeated for the other selected trucks from the different city divisions each day for 30 consecutive days and thereafter on 2 consecutive days every 2 months. Thus, on each day, 50 samples were collected. Estimates on the total mass of material entering the landfill during the sampling days and over the whole year were taken from the logbook at the landfill site.

Laboratory analyses

Moisture content was determined by drying a 5-g subsample at 105°C for about 4 hr following the procedure specified by Sluiter et al. (2008). The drying procedure was repeated for two other subsamples and the mean moisture content of the three subsamples was taken as sample moisture content. With the moisture content of sample determined, total solids was calculated as specified by Sluiter et al. (2008). Ten samples were analyzed to determine whether there were any differences in dry moisture content at 70 and 105°C. A nonsignificant ($P = 0.8364$) average difference of 2% was found. Therefore, the analysis of moisture content performed at 105°C was used for the study.

Waste samples (1 g) were dried in an oven at 70°C to reduce the moisture content and milled. To determine total nitrogen, the milled samples were acid digested using sulfuric acid and the total nitrogen concentration was determined by a distillation–titration method. The procedure described by Okalebo et al. (2002) was followed for both the acid digestion and the distillation–titration procedure. To determine total phosphorus, the milled sample was digested using a mixture of nitric and sulfuric acid in a digester at 330°C and the total phosphorus was determined using the ascorbic acid method (Okalebo et al., 2002). To determine potassium, the milled sample was digested using sulfuric acid at 360°C for 2 hr and the total potassium concentration was determined by complete oxidation of the sample followed by spectrometric analysis. The procedure described by Okalebo et al. (2002) was followed for digestion, oxidation, and spectrometric analysis.

Energy content was determined by forming 1 g of dried sample into a pellet, which was placed in the sample pan of a bomb calorimeter (GallenKamp autobomb, United Kingdom, CAB001.ABC.C). The sample was burned with oxygen in an enclosure of constant volume. The heat liberated by the combustion of all the carbon and hydrogen in the presence of oxygen and the oxidation of other elements that are present in the sample, for example, sulfur, to form carbon dioxide and water gave a measure of the calorific value. All this followed the standard operating procedure (SOP) described by Jessup (1960).

Results

Total mass of waste entering the landfill

Waste collected by private trucks (companies) could not be assigned to particular divisions since the clients to whom they provide their services are spread across all the divisions of the city. KCCA trucks, on the other hand, collect waste from specific divisions of the city. Therefore, the analysis was limited to waste quantities delivered to the landfill by KCCA trucks. The analysis was done using two-way analysis of variance (ANOVA) in R statistical software following the procedure specified by Venables et al. (2012). It showed a significant difference ($P < 0.001$) in the waste quantities from the different divisions. Further analysis of this difference using the Tukey test revealed that the waste quantity received from the Central division was significantly greater ($P < 0.001$) from that from the other divisions. There was no significant difference between waste quantities delivered to the landfill in different months. However, two-way ANOVA indicated a significant difference ($P < 0.001$) in total solids of the waste for different months. Tukey tests confirmed that total solids content was significantly lower ($P < 0.001$) in the wet months (April, June, and October) than in the dry months (July, August, December, and February) (Table 1).

Table 1. Waste quantities (Gg) delivered to the landfill by KCCA and private trucks during the study period

		Waste delivered by KCCA trucks								
Year	Month	Kawempe	Central	Nakawa	Rubaga	Makindye	City total	Waste from private trucks	Total waste	Total solids[a]
2011	July	3.1	5.4	3.7	3.2	3.0	18.4	9.5	27.9	8.4 ± 0.9
2011	August	3.6	5.3	3.5	3.0	3.5	18.9	8.7	27.6	8.1 ± 0.1
2011	September	3.1	5.8	3.6	3.4	1.9	17.8	9.0	26.8	5.8 ± 0.8
2011	October	2.8	5.6	3.2	3.2	2.8	17.6	9.5	27.1	5.9 ± 0.8
2011	November	3.0	5.4	3.2	3.4	2.9	17.9	10.0	27.9	6.0 ± 0.9
2011	December	3.2	5.7	3.3	3.4	2.8	18.4	8.6	27.0	7.7 ± 0.7
2012	January	3.0	5.8	4.2	3.2	2.7	18.9	9.1	28.0	7.9 ± 0.7
2012	February	3.2	5.6	4.0	3.4	2.1	18.3	8.7	27.0	8.4 ± 0.4
2012	March	3.6	6.2	4.1	3.5	2.7	20.1	9.2	29.3	6.3 ± 0.2
2012	April	3.7	7.0	4.6	3.2	2.2	20.7	9.0	29.7	6.4 ± 0.2
2012	May	3.2	5.5	4.0	3.8	3.0	19.5	10.0	29.5	6.4 ± 0.2
2012	June	3.5	6.1	4.1	3.6	3.0	20.3	9.2	29.5	7.3 ± 0.7
	Monthly mean	3.3	5.6	3.8	3.4	2.7	18.8	9.2	28.0	7.7 ± 0.9

[a]Total solids ± standard deviation.

Waste composition

Physical composition of waste. The most dominant waste fractions in the waste were organics (92%), soft plastics (3%), hard plastics (2%), and paper (1%) (Tables 2 and 3). These and other fractions were analyzed further for significant differences between different months and divisions.

Two-way ANOVA showed no significant differences ($P > 0.05$) in the percentage of waste fractions for metal, glass, textile and leather, and others between the different divisions and months. However, the same test showed a significant difference ($P < 0.001$) in the percentage of paper waste between the different divisions and months. Further analysis by Tukey tests revealed that the Central division had a significantly higher ($P < 0.001$) percentage of paper waste than other divisions. The Tukey test also showed the fraction of paper waste in the months of April, June, and October to be significantly different ($P < 0.05$) from those of the other months.

Waste from Makindye division had the highest content of organics but lowest content of plastics, while that from Nakawa and Rubaga divisions had the lowest organic content but highest plastic content (Table 2). Two-way ANOVA showed a significant difference ($P < 0.001$) in the percentage of organic waste fraction between the different divisions. Further analysis by Tukey tests revealed that Makindye had a significantly higher ($P < 0.001$) percentage of organic waste than either Nakawa or Rubaga.

The highest content of organic waste was obtained during July, August, December, and February and the lowest during October, June, and April (Table 3). The highest content of plastic waste (both hard and soft) was obtained during October, June, and April. Two-way ANOVA showed a significant difference ($P < 0.001$) in the percentage of organic and plastic waste delivered to landfill between the different months. The Tukey test confirmed that the percentage of organic waste was significantly lower ($P < 0.001$) in June and October compared to other months. The organic waste fraction delivered in April was also significantly lower ($P < 0.05$) than that delivered in July and August.

During the study period, February, July, August, and December were dry and without rain and are classified as dry months (<100 mm rain per month), while April, June and October were wet, with >150 mm rain per month, and are therefore classified as wet months. The data presented in Table 3 on the composition of waste delivered to landfill in Kampala in

Table 2. Mean composition of municipal waste from Kampala by percentage weight and total waste collected from the five different divisions of Kampala city (mean ± CV)

Division	Organic	Hard plastics	Metals	Papers	Soft plastics	Glass	Textiles and leather	Other	Total/yr (Gg)[a]
Nakawa	91.0 ± 0.0	2.0 ± 0.9	0.1 ± 0.7	1.2 ± 1.2	3.9 ± 0.4	0.5 ± 0.9	0.6 ± 0.9	0.6 ± 0.8	45.5
Makindye	95.0 ± 0.0	1.1 ± 0.6	0.1 ± 0.9	0.7 ± 0.9	2.0 ± 0.5	0.3 ± 0.6	0.3 ± 0.9	0.6 ± 0.8	32.6
Kawempe	92.9 ± 0.0	1.6 ± 0.8	0.1 ± 0.9	0.7 ± 0.9	3.2 ± 0.5	0.7 ± 1.1	0.3 ± 0.8	0.5 ± 0.8	39.0
Central	91.9 ± 0.0	1.7 ± 0.7	0.2 ± 0.7	2.1± 0.9	2.4 ± 0.5	0.7 ± 0.7	0.4 ± 0.9	0.7 ± 0.9	69.4
Rubaga	89.8 ± 0.0	2.4 ± 0.8	0.2 ± 0.7	1.9 ± 0.8	3.6 ± 0.6	0.6 ± 0.9	0.7 ± 1.0	0.7 ± 1.0	40.3

Note: [a]Does not include the waste collected by private collectors, for which collection is not location specific.

Table 3. Mean composition of municipal waste from Kampala by percentage weight in seven sampling months (mean ± CV)

Month	Organics	Soft plastics	Hard plastics	Papers	Glass	Textiles and leather	Metals	Others	Total mass (Gg)
February*	93.6 ± 0.0	4.0 ± 0.5	1.0 ± 0.4	1.1 ± 1.0	0.5 ± 0.5	0.4 ± 1.3	0.1 ± 0.5	0.4 ± 0.5	27.0
April†	92.5 ± 0.0	3.3 ± 0.5	1.3 ± 0.5	1.5 ± 0.8	0.4 ± 0.2	0.5 ± 0.6	0.1 ± 0.7	0.5 ± 0.7	29.7
June†	87.2 ± 0.0	4.0 ± 0.3	3.7 ± 0.4	2.2 ± 0.5	0.9 ± 0.5	0.7 ± 0.5	0.3 ± 0.3	1.1 ± 0.5	29.5
July*	96.0 ± 0.0	1.9 ± 0.5	0.9 ± 0.5	0.3 ± 1.1	0.4 ± 0.7	0.2 ± 1.1	0.1 ± 1.0	0.3 ± 0.8	27.9
August*	94.8 ± 0.0	2.4 ± 0.6	0.9 ± 0.4	0.8 ± 1.1	0.3 ± 0.7	0.4 ± 1.2	0.1 ± 0.7	0.4 ± 0.7	27.6
October†	85.8 ± 0.1	4.1 ± 0.4	3.3 ± 0.3	2.8 ± 0.8	1.4 ± 0.5	0.8 ± 0.6	0.3 ± 0.4	1.4 ± 0.3	27.1
December*	94.6 ± 0.0	2.5 ± 0.5	1.2 ± 0.6	0.6 ± 1.0	0.2 ± 0.5	0.3 ± 0.8	0.1 ± 0.7	0.3 ± 0.4	27.0
Average wet months	88.5 ± 0.0	3.8 ± 0.1	2.8 ± 0.5	2.2 ± 0.3	0.9 ±. 0.5	0.7 ± 0.2	0.2 ± 0.4	1.0 ± 0.5	28.8
Average dry months	94.8 ± 0.0	2.4 ± 0.1	1.0 ± 0.2	0.7 ± 0.4	0.3 ± 0.3	0.3 ± 0.3	0.1 ± 0.2	0.3 ± 0.3	27.4
Annually	92.1 ± 0.0	3.0 ± 0.3	1.8 ± 0.7	1.3 ± 0.7	0.6 ± 0.7	0.5 ± 0.5	0.1 ± 0.6	0.6± 0.76	337.3
Total/yr (Gg)	310.0	10.0	6.1	4.4	2.0	1.7	0.3	2.0	

Notes: †Wet month (total rainfall >150 mm per month).
*Dry month (total rainfall <100 mm per month).

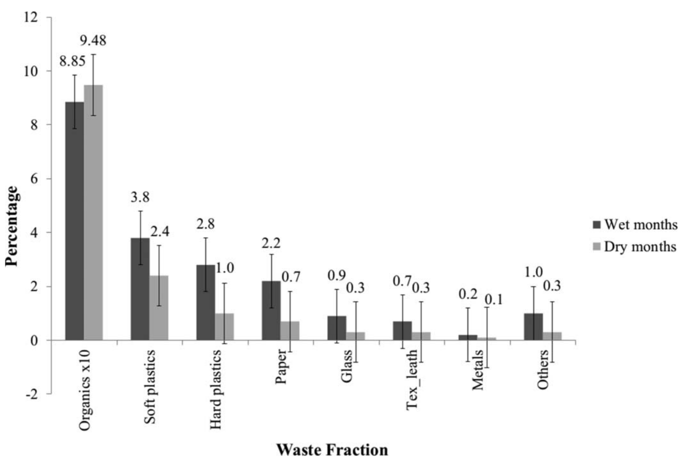

Figure 2. Composition of municipal solid waste delivered to Kampala landfill during the dry and wet months (mean with standard error).

different calendar months are summarized for the dry and wet months in Figure 2.

Chemical composition of the organic fraction in Kampala municipal waste. The mean moisture, nutrient, and energy contents of samples taken from the organic waste delivered from the five divisions of Kampala city are summarized in Table 4.

The mean moisture, nutrient, and energy contents of samples delivered in different months are summarized in Table 5.

Two-way ANOVA showed a significant difference ($P < 0.001$) in moisture content of the organic waste for the different months. According to Tukey tests, the moisture content was significantly higher ($P < 0.001$) in the wet months of April and October than in the dry months of July, August, December, and February.

Two-way ANOVA also showed a significant difference ($P < 0.001$) in the nitrogen content of the organic waste in different months. According to Tukey tests, in April and October the nitrogen content of organic waste was significantly lower than in August and December ($P < 0.001$) or July ($P < 0.05$).

Two-way ANOVA showed no significant differences ($P > 0.01$) in the chemical composition of the organic waste for the different divisions of Kampala. However, it showed a significant difference in the potassium composition for the different months ($P < 0.001$). Tukey tests confirmed that organic waste in the wetter months of June, April, and October had a significantly lower ($P < 0.001$) potassium content than that in the drier months of July, August, December, and February.

Two-way ANOVA showed no significant differences in the energy and phosphorus content of the organic waste for the different months in Kampala.

Table 4. Nutrient, energy and moisture content (mean ± CV) delivered from the five divisions of Kampala city to landfill during different months of the year

Location	Moisture content (%)	Nitrogen (g/kg DM)	Phosphorus (g/kg DM)	Potassium (g/kg DM)	Gross_EC (MJ/kg DM)
Nakawa	69.4 ± 0.1	20.8 ± 0.3	2.5 ± 0.5	18.3 ± 0.5	17.9 ± 0.4
Makindye	70.2 ± 0.1	20.0 ± 0.3	3.0 ± 0.4	25.4 ± 0.5	16.1 ± 0.2
Kawempe	69.9 ± 0.1	19.2 ± 0.3	2.7 ± 0.3	21.5 ± 0.5	17.7 ± 0.2
Central	69.4 ± 0.1	21.4 ± 0.3	2.9 ± 0.4	24.1 ± 0.5	16.9 ± 0.2
Rubaga	70.2 ± 0.1	21.2 ± 0.2	2.4 ± 0.4	21.9 ± 0.5	16.6 ± 0.2

Note: DM, dry matter.

Table 5. Nutrient, energy (mean ± CV), total waste weight (dry matter [DM]), and moisture content of organic waste delivered to landfill in Kampala during different months of the year

Month	Moisture content (%)	Nitrogen (g/kg DM)	Phosphorus (g/kg DM)	Potassium (g/kg DM)	Gross energy content (MJ/kg DM)	Total waste weight in DM (Gg)
February*	66.8 ± 0.0	18.5 ± 0.3	3.0 ± 0.3	31.4 ± 0.3	16.3 ± 0.2	8.4
April†	76.6 ± 0.0	13.5 ± 0.2	2.4 ± 0.2	6.9 ± 0.2	18.5 ± 0.3	6.4
June†	71.7 ± 0.1	18.6 ± 0.4	2.4 ± 0.3	9.5 ± 0.7	17.7 ± 0.3	7.3
July*	68.5 ± 0.1	21.8 ±0.2	3.0 ± 0.2	29.2 ± 0.3	15.6 ± 0.1	8.4
August*	69.2 ± 0.1	21.4± 0.2	2.7 ± 0.4	23.5 ± 0.4	17.0 ± 0.3	8.1
October†	74.8 ± 0.1	14.0± 0.3	2.4 ± 0.2	6.1 ± 0.3	16.7 ± 0.2	5.9
December*	70.0 ± 0.1	24.7 ± 0.2	3.3 ± 0.4	30.0 ± 0.4	19.2 ± 0.2	7.7
Average wet months	74.4 ± 0.0	15.4 ± 0.2	2.4 ± 0.0	7.5 ± 0.2	17.6 ± 0.1	6.5
Average dry months	68.6 ± 0.0	21.6 ± 0.1	3.0 ± 0.1	28.5 ± 0.1	17.0 ± 0.1	8.2
Average overall	71.1 ± 0.0	18.9 ± 0.2	2.7 ± 0.1	19.5 ± 0.1	17.3 ± 0.1	7.5

Notes: †Wet month (total rainfall >150 mm per month).
*Dry month (total rainfall <100 mm per month).

Discussion

Physical composition of the waste

This study established that on average, about 28,000 tons of municipal waste from Kampala was disposed of in the landfill every month. This waste consisted on average (by weight) of 92.1% organic material, 1.8% hard plastic, 0.1% metals, 1.3% papers, 3.0% soft plastic, 0.6% glass, 0.5% textile and leather, and 0.6% others (Table 3). These figures are quite different from those reported for other Sub-Saharan African (SSA) cities like Abuja (Imam et al., 2008), Accra (Fobil et al., 2008,) and Gaborone (Bolaane and Ali, 2004), showing that studies that assume average values for SSA cities may result in erroneous results.

Both Henry et al. (2006) and Parrot et al. (2009) reported a reduction in the amount of waste delivered to landfill in Nairobi and Yaoundé, respectively, during the wet season compared with the dry season. However, in the present study there was no significant difference in the total quantities of waste delivered to landfill in the different months, although there was a significant difference in the quantity of total solids in the waste delivered during the wet and dry months. This was expected, since the waste had higher moisture content during the wet months than in the dry months. Both Henry et al. (2006) and Parrot et al. (2009) cite impassable roads during the wet season as being the major reason for the reduction in total waste quantity delivered to landfill. Although there are also several impassable roads in Kampala during the wet months, the results of this study indicate that this factor has a minimal effect on the total waste collection. It appears that areas with poor roads are avoided during the wet months, with waste collectors concentrating their services to areas with better roads. In most cases, such areas are more affluent and are most likely to generate less organic waste than less affluent areas. This could explain the difference observed in waste composition between the different months, with more plastics and paper and less organics in the wet months. It also indicates that the limiting factor in collection is actually transport capacity and not waste generation. Furthermore, the collection of waste in selected areas during the wet months could be responsible for the practice of dumping waste into drainage channels during rain/storm events, which can lead to blockage of the channels and subsequent flooding in low-lying areas (Lwasa, 2004). In addition, the dry months normally coincide with the harvest season for many food crops in the city's hinterland and periurban areas (Komakech et al., 2013). As such, the city markets are flooded with an abundance of various foods crops at cheaper price (Haggblade and Dewina, 2010). This process of increased availability and consumption of these food crops by the city's inhabitants could also be responsible for the high prevalence of organic waste during the dry months than during the wet months.

The condition of the road network in lower income areas had a bearing on the amount of organics collected. Comparing the organic content of the waste collected from the different divisions of Kampala, Makindye division, which at the time of the study had a better road network in the lower income areas than the other divisions, had the highest organic content. It is likely that the good road network in Makindye facilitated better waste collection in lower income areas, which mainly generate organic waste. A similar finding was reported for Nairobi and other Kenyan cities (Henry et al., 2006).

More waste is collected from the Central division (Table 1) because of its political importance. As such, more resources for waste management are provided to it. For example, it is allocated about twice the number of waste collection trucks compared to the other divisions and waste collection is performed 24 hours a day, while in the other divisions it is done for 12 hours a day. A similar trend was reported for Nairobi city (Henry et al., 2006). Furthermore, the Central division, which contains the CBD, generates more paper waste than other divisions, as expected. It could also have been expected to generate a significantly lower amount of organic waste, but the data showed that this was not the case (Figure 3). This could be due to the large number of scavengers in the Central division, who retrieve material that can be reused or recycled, leaving behind the organic fraction, which they regard as low value (Dangi et al., 2011). There are also several large markets in the Central division, which significantly increase the amount of organic material generated in that division.

A study in 1989 reported that the waste in Kampala consisted of (by weight): vegetable matter 73.8%, paper 5.4%, sawdust 1.7%, plastics 1.6%, metals 3.1%, glass 0.9%, tree cuttings 8.0%, and street debris 5.5% (MLHUD, 1993). This reflected a time when Kampala was entering economic growth after the devastating wars of the mid 1980s. This is shown by the unusually high amount of tree cuttings in the waste, generated as a result of virgin land being cleared to set up various structures

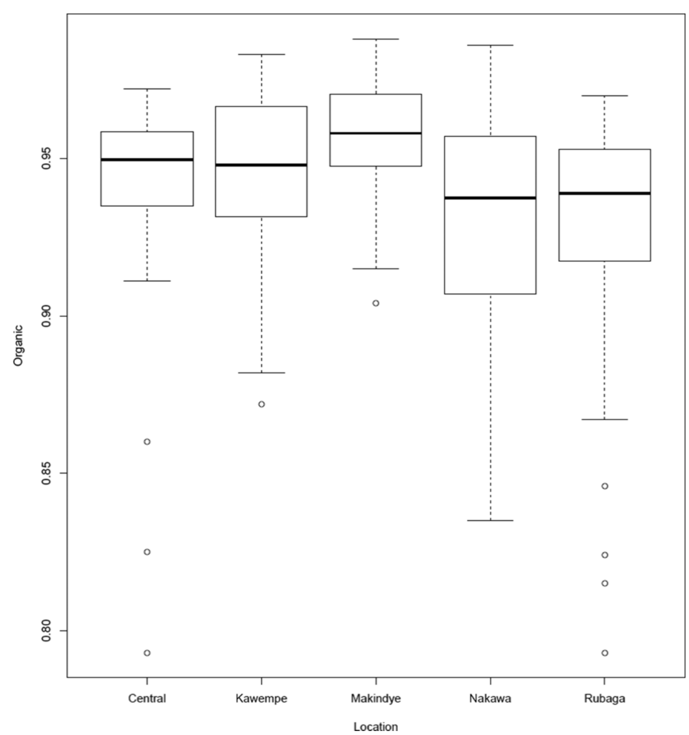

Figure 3. Box plot of the fraction of organic waste in the five different divisions of Kampala City.

such as buildings and roads. In addition, during that period many industries had not yet been revived, a factor that explains the higher metal quantity and lower plastic quantity in the waste. In the present study, vegetable matter, sawdust, and tree cuttings were considered organic waste. Applying the same principle to the study by MLHUD (1993) would give an organic waste fraction of 87.9%, which is close to what this study established. Although some studies report a reduction in the organic fraction of the waste with the increased economic status of an SSA city (NEMA, 2007; Oteng-Ababio et al., 2013), this finding is not necessarily true, as shown by this study. Other factors such as population growth (Chang and Davila, 2008), consumption behavior, and awareness of material recycling (Cox et al., 2010) could also play a critical role in determining the sizes of the different fractions of a city's waste. There were also great discrepancies in the amounts of metals, plastic, and street debris between the two studies. The most likely reason for this is the absence of metal recycling industries in 1989. However, the metal recycling industry, and by implication trade in scrap metal, is now a highly lucrative venture as a result of the great increases in metal prices on the world market. The demand for scrap metal is extremely high, a factor that has contributed to the increase in the incidence of thefts of metal objects such as manhole covers, road signs, railway sleepers, fences, guard rails, and streetlights (Nyapendi, 2011). This also explains the low fraction of metals in the municipal waste at present. The large fraction of plastic waste currently entering the landfill can be attributed to the increased number of supermarkets and shops that provide their customers with free plastic carrier bags, as well as the increased use of plastic mineral-water bottles compared with 1989. The reduced amount of street debris is probably a result of street debris being collected from nearly the same length of streets as in 1989, yet the population generating other types of wastes has increased tremendously.

It is worth noting that a number of scavengers work at the landfill. Although they are interested in salvaging anything of value from the waste, according to Mugagga (2006) their main interest is in paper, scrap metal, cardboard, and plastics. These they sell mainly to traders and some plastic recycling industries. Scavengers play a vital role in reduction of the waste volumes at the landfill, as according to Mugagga (2006) they remove an estimated 1 ton of waste per day.

An important finding of the present study is that hazardous wastes (represented by dry-cell batteries) were hardly found at all in the municipal waste analyzed. This is probably because they are mainly disposed of in pit latrines, owing to a widespread myth that this increases the service lives of the latrines through lowering the sludge levels. This has major implications for the chemical quality of the fecal sludge found in the latrines, which is a large potential source of plant nutrients in Uganda. Medical wastes were also not found in the municipal waste analyzed, reflecting the success of programs to educate waste collectors about the types of waste they should bring to the landfill.

Chemical composition of the waste

The average nutrient composition of the organic fraction in Kampala municipal waste during the dry months was 2.16% nitrogen, 0.30% phosphorus, and 2.85% potassium (Table 5). During the wet months, it was 1.54% nitrogen, 0.24% phosphorus, and 0.75% potassium. This translates into an average of 5900, 900 and 6000 Mg of nitrogen, phosphorus, and potassium in the organic fraction of the waste delivered to landfill annually in Kampala. An explanation for the larger amount of nutrients during the dry months is that the time, as discussed in the previous section, normally coincides with the harvest period for many crops (Haggblade and Dewina, 2010). Therefore, it is possible that crop wastes (and their constituent nutrients) could be present in significantly higher amounts in the organic waste during the dry months than in the wet months. One of the most widely eaten foods in Kampala is bananas, locally known as *matooke*, and their harvest time coincides with the dry months (Haggblade and Dewina, 2010). This would also explain the unusually high amount of potassium in the organic waste during the dry months as opposed to the wet months. Furthermore, according to Table 5, the nitrogen concentration in the organic fraction was highest in December. This could probably be explained by a wider variety of foodstuffs being consumed during the festive season, including food with high protein content such as meat.

Amoding (2007) established that market wastes in Kampala city contain on average 1.57% nitrogen, 0.21% phosphorus, and 2.95% potassium. Comparing the present results with those, it can be seen that results of this study for the dry months were fairly similar, confirming our assumption that crop waste dominated the organic waste fraction generated in the dry months. Cofie et al. (2009) reported the quality of co-compost from a pilot plant using fecal sludge and organic waste in Kumasi, Ghana, to be 1.19% nitrogen, 1.6% phosphorus, and 1.7% potassium. Comparing the results of Kampala with those from Kumasi, it can be concluded that it is possible to get a superior quality of co-compost from municipal waste in Kampala.

The average gross energy content of the organic factions was 17.3MJ/kg DM (Table 5). This figure is quite similar to the 18.0 MJ/kg DM reported by Bingh (2004), showing that the organic waste has a potential for energy recovery through incineration. However, its high average moisture content of 71% is likely to make incineration an uneconomical option (Kathirvale et al., 2004).

The annual landfilling of plant nutrients from organic waste in Kampala corresponded to 92, 110, and 680%, respectively, of the amounts of mineral nitrogen, phosphorus, and potassium fertilizer imported to Uganda annually (FAO., 2010). The plant availability of the nitrogen in organic material is lower than that in mineral fertilizer, but anaerobic treatment would increase the availability of the nitrogen in the organic material. The availability of phosphorus and potassium is more similar to that in mineral fertilizer. In addition, the organic material contains other micronutrients required by plants, as well as organic material that improve the soil structure considerably. This indicates the high potential of reusing this fraction, which could even have a great impact on the national economy, as it would increase the self-sufficiency considerably.

The energy content in the material collected annually corresponded to 1.6×10^9 MJ. If this material were processed in a biogas plant and 50% were converted into biogas, 8.0×10^8 MJ of biogas could be expected to be produced. This could be used for electricity production or as vehicle fuel. Thus, diverting organic waste from landfill into recycling of energy and plant nutrients could provide great opportunities for the future.

Conclusion

Analysis of the physical composition of the municipal waste generated in Kampala city revealed that it consisted mainly of organic material (92.1%), soft plastic (3.0%), hard plastic (1.8%), and paper (1.1%). The average chemical composition of its organic fraction was 71% moisture, 1.89% nitrogen, 0.27% phosphorus, and 1.73% potassium. The plant nutrients in landfilled organic waste from Kampala corresponded to 92, 110, and 680% of imported fertilizer nitrogen, phosphorus, and potassium, respectively. The waste also had a gross energy content of 17.3 MJ/kg. Both the physical composition and the chemical composition of the waste varied depending on whether the month was dry or wet, while the physical composition also varied depending on the city division generating the waste. Recycling of some fractions of the waste is being successfully carried out in some divisions already. The organic waste, although suitable for production of compost, is not suitable for energy recovery through incineration owing to its high moisture content. Further studies are needed to further classify the organic waste into its physical components and other chemical components not tested in this study.

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