Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana

Miezah, Kodwo; Obiri-Danso, Kwasi; Kádár, Zsófia; Fei-Baffoe, Bernard; Mensah, Moses Y

Published in:
Waste Management

Link to article, DOI:
10.1016/j.wasman.2015.09.009

Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana

Kodwo Miezah\(^a\), Kwasi Obiri-Danso\(^a\), Zsófia Kádár\(^c\)*, Bernard Fei-Baffoe\(^a\), Moses Y. Mensah\(^b\)

\(^a\)Department of Theoretical and Applied Biology, College of Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
\(^b\)Department of Chemical Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
\(^c\)Department of Chemical and Biochemical Engineering, Technical University of Denmark (DTU) DK 2800, Kgs. Lyngby, Denmark

1. Introduction

Reliable national data on waste generation and composition that will inform effective planning on waste management in Ghana is absent. To help obtain this data on a regional basis, selected households in each region were recruited to obtain data on rate of waste generation, physical composition of waste, sorting and separation efficiency and per capita of waste. Results show that rate of waste generation in Ghana was 0.47 kg/person/day, which translates into about 12,710 tons of waste per day per the current population of 27,043,093. Nationally, biodegradable waste (organics and papers) was 0.318 kg/person/day and non-biodegradable or recyclables (metals, glass, textiles, leather and rubbers) was 0.266 kg/person/day. Inert and miscellaneous waste was 0.055 kg/person/day. The average household waste generation rate among the metropolitan cities, except Tamale, was high, 0.72 kg/person/day. Metropolitan areas generated higher waste (average 0.63 kg/person/day) than the municipalities (0.40 kg/person/day) and the least in the districts (0.28 kg/person/day) which are less developed. The waste generation rate also varied across geographical locations, the coastal and forest zones generated higher waste than the northern savanna zone. Waste composition was 61% organics, 14% plastics, 6% inert, 5% miscellaneous, 5% paper, 3% metals, 3% glass, 1% leather and rubber, and 1% textiles. However, organics and plastics, the two major fractions of the household waste varied considerably across the geographical areas. In the coastal zone, the organic waste fraction was highest but decreased through the forest zone towards the northern savanna. However, through the same zones towards the north, plastic waste rather increased in percentage fraction. Households did separate their waste effectively averaging 80%. However, in terms of sorting the waste into the bin marked biodegradables, 84% effectiveness was obtained whereas 76% effectiveness for sorting into the bin labeled other waste was achieved.

© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
the local and national waste management authorities for decision making. Human and resource capacity to carry out these studies which involves the collection of informative data on waste composition and quantity that is hauled to treatment sites or recycling centers or disposal sites is lacking (Kanat, 2010; Pichtel, 2005).

Municipal or household wastes are often generated from several sources where variable human activities are encountered. Several studies indicate that much of the municipal solid waste from developing countries are generated from households (55–80%), followed by commercial or market areas (10–30%) with varying quantities from streets, industries, institutions among others (Nabegu, 2010; Nagabooshnam, 2011; Okot-Okumu, 2012). Waste from these sources are highly heterogeneous in nature (Valkenburg et al., 2008) and have variable physical characteristics depending on their sources; notably in their composition are food waste, yard waste, wood, plastics, papers, metals, leather, rubbers, inert materials, batteries, paint containers, textiles, construction and demolishing materials and many others which would be difficult to classify. The heterogeneity of the generated waste is a major setback in its utilization as a raw material. There is therefore the need for fractionation of the waste before they can be subjected to any meaningful treatment process. Source sorting and separation of waste is one of the traditional fractionation methods and fundamental steps in an integrated waste management system with the potential to provide data on waste generation and the quality of the fractions. However, the success of any designed waste segregation system will depend largely on the active participation of the waste generators in the various communities and how they comply with the principles of sorting and separation of the waste. Generation of waste from commercial outfits in Ghana is difficult to quantify on per capita basis since all the generators are not known. Assessment is mostly done on bulk of the waste collected. The composition may depend on the business activities; hence the household is the right source to obtain correct data for managing waste.

The aim of this study was to generate a comprehensive data at the regional and national level for use in planning and implementation of relevant waste management activities in Ghana. The study will also assess how well households in three different socioeconomic areas are able to separate their wastes into organic and non-organic wastes labeled on the bins as “biodegradable, except papers (food waste, yard waste, wood and manure)” and “other wastes (paper, plastics, metals, textiles, rubber and leather and any other waste)”.

2. Materials and methods

A pilot source sorting and separation was conducted at the household level in selected cities and towns of Ghana from November 2013 to April, 2014 for collection of data on composition, generation rate and compliance level of separation of the waste.

2.1. Study area

Ghana is located in West Africa and has a total area of 238,533 sq. km with a coastal line of 550 km. It has a tropical climate with two major seasons; rainy season (May–October) and dry season (November–April). The average temperature is 30 °C and annual rainfall is between 1100 mm in the north and 2100 mm in the south.

Ghana has three major geographic regions; coastal, forest and northern savanna with no clearly defined boundaries (Fig. 1). The Coastal area is the smallest region, but has more than 25% of the population of Ghana (Ghana Statistical Service, 2014a). The seaboard makes the region an important commercial hub that has resulted in the growth of major cities and many urban centers compared to the other two geographical regions. Four out of the six metropolitan cities of Ghana (Accra; Cape Coast, Tema and Takoradi) are located here. The major economic activities in the region are fishing, small scale farming and trading. The Coastal zone of Ghana has four different vegetative or ecological zones comprising coastal scrub and grassland, strand and mangrove, rain forest and lastly semi deciduous forest which extend into the forest zone.

The Forest region covers close to one-third of the country with rich agricultural lands. The main economic activity is farming and most of the cash and food crops in Ghana are produced here. Compared to the coastal region, the only large urban centers are Kumasi, Sunyani, Koforidua and Ho. The Northern Savanna, which can be divided into Guinea and Sudan savannah (Fig. 1), covers nearly two-thirds of the country. The Guinea savanna has a larger vegetative cover, longer and heavier rainfall regime which averages around 600–1200 mm per annum. The Sudan savanna has a shorter rainfall period reaching 300–600 mm annually. Economically, this region is the least developed due to reduced rainfall and unfertile lands suitable for only yam and cereal cultivation. However, the vegetation allows for considerable animal breeding. The main urban centers are Tamale, Wa and Bolgatanga.

Administratively, Ghana is divided into ten regions (Table 1) which are further divided into metropolitan, municipal and district assemblies (MMDAs), all of them having governing authorities. There are 216 MMDAs in Ghana: 6 metropolitan areas (Accra, Tema, Sekondi-Takoradi, Cape Coast, Kumasi and Tamale), 45 municipalities and 161 districts. The research survey was conducted in the capital cities of all the ten regions of Ghana; including two selected districts one each in Northern (Bole in Bole District) and Volta regions (Worawora in the Biakoye District) and also one municipal area in Greater Accra region (Anya in the Ga Municipal District) (Fig. 2). The survey covered Metropolitan, Municipal and Districts (MMDs) areas of Ghana as outlined in Table 1. This was necessary because waste management is supervised by the MMDAs who will require the information for policy decisions, planning and adoption.

In each of the regions or areas for the study, three socioeconomic areas (high, middle and low class areas) were identified and selected based on an already stratified settlements plan made by the city authorities. This stratification was adopted because ability to pay for waste collection services was based on the type of socioeconomic area that has been specified by the city authorities.

Based on the number of households and population size in each regional capital, specific numbers of households were sampled randomly from each of these classes of settlement.

2.2. Basis of the classification by the MMDAs

The settlement classification in the various MMDAs was developed by the Local Government Authorities of the Assemblies. The Local Government Bulletin (January 2002), outlined settlement pattern classifications in the MMDAs which are constantly reviewed to suit determinants employed. A scalogram analysis on settlement systems and spatial linkages was applied to score variety and level of services alongside varying social and economic facilities of residents upon which each settlement area was assigned a level of settlement. The scalogram is primarily a presentation or graphic device that illustrates in the form of a matrix chart, the spatial distribution of services or functions of all selected settlements in a locality or municipality by their frequency of presence or absence. This technique enables the determination of the hierarchy of settlements in the MMDAs and hence the nature of spatial integration. Based on the number and type of service and
facilities available in the scalogram, the centrality indices of selected settlements are analyzed, which eventually leads to the ranking of the Settlements. Some of the social and economic facilities considered were quality of road network, housing facilities, water and sanitation facilities, and access to quality services such as health, education, communication, security, transportation, commerce, etc. One of the drawbacks in this system of classification has to do with measurement of affluence since many high income earners are also found in supposedly low income areas. However, this classification was adopted for the study because decisions on services delivery, payments and supply of waste management facilities are based on these proposed classifications.

The main features of the settlement hierarchy with this system of classification are summarized here:

2.2.1. High Income class area
These are residential areas which have relatively good roads, enjoy reliable social amenities and services such as water, electricity supply, security, well planned houses, supermarkets and schools. The houses are often detached single or storey buildings with large compound either paved or grassed. They are mostly occupied by single household or family normally with small household size. Though it is perceived that those in this class are high income earners, there has not been any scientific study on income stratification to really assign the socioeconomic status of the settlers.

2.2.2. Middle income class area
These residential areas are characterized by flats or bungalows. The buildings are often occupied by more than one household. The buildings are either semi-detached or detached with paved compounds and occasionally with back yard gardens. They may have some level of improved social amenities and services.

2.2.3. Low income class area
These are areas with poor social services and amenities. They are mostly located in the slum areas of the cities. The buildings range from storey or detached to squatting shacks.

2.3. Sampling technique and determination of sample size of waste
The formula of sampling for continuous variable measurements reported by Cochran (1977) which has been widely applied by other researchers including Bartlett et al. (2001), Gallardo et al.
Table 1
Sample size and amount of waste collected for analysis.

<table>
<thead>
<tr>
<th>S/ N</th>
<th>Regions</th>
<th>City</th>
<th>MMDA Status</th>
<th>Specific study locality</th>
<th>Population in the study areas</th>
<th>Estimated sample size at 5% margin of Error using Eq. (1)</th>
<th>Number of samples collected</th>
<th>Total waste analyzed/kg</th>
<th>Total houses/households surveyed</th>
<th>Total people generating the waste</th>
<th>Sampling duration/week</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Western</td>
<td>Takoradi Metropolitan</td>
<td>Beach Road, Essikafoamberem No.1 and Adakoぺ</td>
<td>97352</td>
<td>383</td>
<td>1395</td>
<td>11760.7</td>
<td>93</td>
<td>563</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Ashanti</td>
<td>Kumasi Metropolitan</td>
<td>KNUST campus, Oforikrom and Ayigya</td>
<td>303016</td>
<td>384</td>
<td>900</td>
<td>7986.5</td>
<td>90</td>
<td>517</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Eastern</td>
<td>Koforidua Municipal</td>
<td>Adweso, Old Estate, Effiduase, Oyoko, Srodae and Akwedum</td>
<td>183727</td>
<td>384</td>
<td>1200</td>
<td>10610.3</td>
<td>80</td>
<td>515</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Greater</td>
<td>Accra</td>
<td>Agape, Palace Town, Nsunfa, Acbease and Ablekuma Newtown</td>
<td>24306</td>
<td>383</td>
<td>720</td>
<td>5159.3</td>
<td>60</td>
<td>335</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Upper</td>
<td>Wa Municipal</td>
<td>Danks, Nakori and Kpogu</td>
<td>107214</td>
<td>383</td>
<td>900</td>
<td>4905.2</td>
<td>90</td>
<td>674</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Upper</td>
<td>Bolgatanga Municipal</td>
<td>SNNIT Resident, Estate Area and Class Soe</td>
<td>131550</td>
<td>384</td>
<td>900</td>
<td>3918.6</td>
<td>90</td>
<td>545</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>Eastern</td>
<td>Sunyani Municipal</td>
<td>Estate, Penkwa and Newtown</td>
<td>123224</td>
<td>383</td>
<td>720</td>
<td>3833.9</td>
<td>60</td>
<td>374</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>Northern</td>
<td>Ahafo District</td>
<td>Hospital area, Mempeaseam and Balpe</td>
<td>61593</td>
<td>382</td>
<td>600</td>
<td>3188.5</td>
<td>60</td>
<td>308</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>Central</td>
<td>Tamale Metropolitan</td>
<td>Tamale South: Tuutingli, Kalariga and Lamashegu</td>
<td>142450</td>
<td>384</td>
<td>900</td>
<td>4530.7</td>
<td>90</td>
<td>605</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>Central</td>
<td>Ho Municipal District</td>
<td>Alavi, Aho and SNNIT Flat Dwamenakrom, Mission, Zongo, Kotomase and Ricemill Ramiers, Apeiwosika and Ola Estates</td>
<td>271881</td>
<td>384</td>
<td>800</td>
<td>3309.5</td>
<td>80</td>
<td>335</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cape Coast Metropolitan</td>
<td></td>
<td>65901</td>
<td>383</td>
<td>750</td>
<td>2035.4</td>
<td>50</td>
<td>339</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>169894</td>
<td>384</td>
<td>1080</td>
<td>10827.4</td>
<td>90</td>
<td>505</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
(2012) and Gomez et al. (2008) as in Eq. (1), was used to estimate the representative waste sample for analysis.

\[ n = \frac{Z \cdot Z \cdot (P + P)}{(D - D)} \]  

(1)

where \( n \) = the sample size, \( Z \) = value for selected alpha level of each tail = 1.96 (the alpha level of .05 indicates the level of risk the researcher is willing to take that true margin of error may exceed the acceptable margin of error), \( P \) = estimate of standard deviation in the population and \( D \) = acceptable margin of error for mean being estimated.

The estimated number of waste samples using the equation 1 is presented in Table 1. It could be referred from the table that the actual sample of waste collected from households for the analysis far exceeded the required sample size. The larger sample size obtained was necessary in getting a more accurate and precise data which is true of the nature and amount of waste generated in the localities.

Having determined the sample size of waste to be analyzed, the number of households selected in each class of settlement was between 20 and 40 as recommended by Nordtest (1995) and Gomez et al. (2008).

Stratified, purposive and direct sampling technique was employed in each study area to select the number of households.

2.4. Collection of household data/information

Randomly selected households from the study location as shown in Table 1 were visited to inform occupants about the survey and to receive feedback on their willingness to participate in the study. Using University students that had earlier been trained on how to solicit responses on the designed questionnaire, questionnaires were administered to obtain data on socio-economic, demographics, educational level, knowledge on waste management and reasons for willingness to participate. The selected households were earlier educated over a two day period on waste sorting and separation using designed flyers and personal contacts.

2.5. Sorting procedure

Initial sorting of the waste was carried out by members of the households and further sorting was done by the research team. Two bins or polythene bags were supplied to each household for the sorting and separation, to organic wastes and all other waste. The organic waste bin was labeled “Biodegradables except paper” which included food/kitchen waste, leaves, tree branches, wood waste, and agricultural waste) while the “Other wastes” comprised plastics, papers, textiles, metals, glass, rubber, leather and any waste which could not be classified.
In order to avoid significant undesired changes in the composition of the waste separated by households, especially the organic fraction, further sorting was done every two days and or at least twice a week for a period of 3–5 weeks. The Sorters, Supervisors and Recorders were trained in theory and practice on all aspects of the sorting, measurement and recordings on excel sheet. Number of Sorters per household per sorting day was of ratio 1 Sorter to 5 households, but for the sake of efficiency, the Sorters worked in a group of 6. Thus the 6 Sorters worked on 30 households per day. A total of 18 Sorters were used in all the three settlement areas per a region; complimented with 6 Supervisors who coordinated the collection as well as the transportation of the waste to the sorting venue and 3 Recorders for data entry. Personal protective equipment was provided for each person involved in the study.

2.6. Weighing of sorted waste

The sorted waste was collected using either a truck, a pick up or a bicycle from the household to the main sorting center. The sorted wastes were weighed using a Labe spring balance (100–200 kg) and a Top Bal pan balance (China P090008, Hot pan) of various capacities: 1 kg, 5 kg, 10 kg and 20 kg, (Labotrix Group Limited, China). Plastic sheets were placed on the floor to ease sorting, segregation and weighing. The fine particles were sieved from the waste to help ease the sorting and also reduce the fractions which could otherwise be identified as inerts.

The wastes sorted by households were further segregated into 23 various sub-fractions and analyzed by their weight as well as the percentage composition as described by Pichtel (2005) and ASTM D5231-92 (2008).

These include:

a. Organics – a. Food waste, b. Yard waste (grass trimmings),
   c. wood, d. animal droppings,

b. Paper – a. cardboards, b. newsprints, c. office papers,
   d. tissue papers,

c. Plastics – a. Polyethylene terephthalate (PET), b. High density polyethylene (HDPE), c. Polyvinyl chloride (PVC),
   d. Low density polyethylene (LDPE), e. Polypropylene (PP),
   f. Polystyrene (PS), g. other plastics,

d. Metals – a. Scrap b. Cans/Tins,

e. Glass – a. Coloured b. Plain

f. Rubber and leather
g. Textiles

h. Inert (sand, fine organics, ash).
i. Miscellaneous (construction and demolishing waste, batteries, paints, any other waste fraction not fit in the categories)

The percentage composition of each of the components was calculated by the formula

\[
\text{Percentage composition of waste fraction} = \frac{\text{Weight of separated waste}}{\text{The total of mixed waste sampled}} \times 100 \tag{2}
\]

The per capita generation was also determined as per the mixed or the total waste collected in a day and also the separated fractions using this formula:

\[
\text{Per capita generation} = \frac{\text{Weight of MSW generated at household}}{\text{Total number of persons in the household} \times \text{Total number of generation days}} \tag{3}
\]

2.7. Level of compliance in the separation

Source sorting and separation of waste by households requires the input of the generators. The ability of household participants to sort and separate their waste well serves as a yardstick for authorities to consider introducing source sorting and separation of household waste. Initially, there was questionnaire administration to assess the willingness of selected households to participate in the survey. Afterwards they were made sort and separate their waste by the one-way sorting and separation system which involved the two categories of the waste, organics and non-organics. The compliance level of the sorting and separation was measured by taking the weight of waste rightly sorted into the appropriate bin provided as a percentage over the total weight of waste in the same bin.

\[
\text{Compliance Level} = \frac{\text{Weight of sorted waste in the right bin}}{\text{The total weight of all waste separated into the bin}} \times 100 \tag{4}
\]

2.8. Statistical analysis

Relationship between waste generation rate and household income as well as waste generation and household size was performed using regression analysis with the statistical software called R. The add-on packages used were leaps and gplots. The difference in waste composition and generation rate among the socio-economic classes, the various MMDs and geographical locations were analyzed by excel packages using one-way and two factor Anova.

3. Results and discussion

3.1. Waste generation rate

On the average, rate of waste generation was 0.51 kg/person/day for all the ten regional capitals and that for the other study areas aside the regional capitals was 0.47 kg/person/day (Table 2). The Kumasi metropolitan area recorded the highest waste generation rate of 0.75 kg/person/day which was slightly above that of the capital city Accra, 0.74 kg/person/day. Waste generation within the four of the five metropolitan areas studied; Accra, Kumasi, Takoradi, and Cape Coast had on the average 0.72 kg/person/day compared to Tamale which was lower 0.34 kg/person/day (Table 2). The much lower waste generation rate in Tamale could be attributed to the low economic activities in the area compared to the other four metropolitan cities and other municipalities in the Coastal and Forest zones. The least was recorded in Bolgatanga municipality, 0.209 kg/person/day. The average per capita household waste generation obtained for the metropolitan cities, except Tamale, was comparable to the 0.75 kg/person/day generation rate reported for all metropolitan cities in Ghana by the Ministry of Local Government and Rural Development (MLGRD, 2010) in a forecast of National Environmental Sanitation Strategy and Action Plan (NESSAP) 2010–2015. Again the 0.45 kg/person/day predicted by the same source and also by Mensah and Larbi (2005) for all other cities and towns in the districts and municipalities is below the average generation rate for regional capitals (0.51 kg/person/day), but closer to the average generation rate (0.47 kg/person/day) for the whole of Ghana as reported in this research.

Waste generation rates across Ghana irrespective of the socio-economic considerations ranged from 0.2 to 0.8 kg/person/day. This is also the range for most of the cities in Sub-Saharan Africa (Friedrich and Trois, 2011; UNEP, 2013). However, higher generation

Please cite this article in press as: Miezah, K., et al. Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. Waste Management (2015), http://dx.doi.org/10.1016/j.wasman.2015.09.009
rates have been reported for OECD countries, 1.39 kg/person/day (OECD, 2010). Considering the average waste generation rate from the regional capitals, a daily total amount of 4270 tons of household waste were generated from the regional capitals based on an estimated national population projection for 2014 calculated using the growth rates from the 2010 Housing and Population Census (Table 2) (Ghana Statistical Service, 2014b).

The high socioeconomic class areas generated the highest quantity of waste in the study areas; 0.56 kg/person/day followed by the middle class areas, 0.49 kg/person/day and the low class areas 0.47 kg/person/day for the regional capitals. Similar findings regarding waste generation differences among socioeconomic areas where the higher socioeconomic classes generated higher waste have been reported by Asase (2011) as; 0.63 kg/person/day for Asokwa a high class area, 0.52 kg/person/day for Atonsu, a Middle class area and 0.27 kg/person/day for Ahinsan, a low class socioeconomic area all in the Kumasi metropolis. Fobil et al. (2005) and Owusu-Ansah (2008) obtained similar generation rates data among the different socioeconomic class areas in Accra. However, this trend was different for Tamale and Kumasi where the low class areas generated more than the middle class. This was probably due to the high inert particles (0.2 kg/person/day) of the waste generated from the low class areas. Additionally, the high class areas in Kumasi included the residential quarters of the lecturers in second largest university in Ghana who tend to produced less waste as most of them spend more time outside their homes. Many of the lecturers also burned their yard waste on site. A separate study by Asase (2011) on waste generation from the campus of KNUST, reported a generation rate of 0.39–0.49 kg/person/day which is below the generation rate for residents of lecturers on the same campus which was also the first class socioeconomic settlement for the study area in Kumasi.

The research did not find significant differences in the average regional waste generation rate for the different socioeconomic settlements, though there were differences (p < 0.05) between the high socioeconomic areas and the other settlement hierarchies.

The various fractions of the MSW and their average generation rate for all the areas studied are shown in Fig. 3 whereas the sub-fractions and their generation rates have been elaborated in Table 7. The average per capita per day generation were 0.29 kg organic, 0.02 kg paper, 0.06 kg plastic and 0.004–0.01 kg for metal, glass, textile or leather and rubber. Inert and other items that could not be classified were also high, 0.03 kg/person/day and 0.026 kg/person/day, respectively.

In this study, the effect of seasonal variation on generation and composition of household waste was not considered since this is believed to have no effect on change in waste composition and generation in Ghana proved by separate surveys. For instance, separate studies conducted in Kumasi (Ashanti Region of Ghana) by Adjei (2013), Asase (2011), Ketibuah et al. (2004), Kotoka (2001), Opoku (1999) within the wet and dry seasons did not show any trend in variation of the composition and generation of waste. Similarly, studies on household waste quantity and composition by Anomanyo (2004), Dagadu (2005), Fobil et al. (2005) could not establish any seasonal trend. Seasonal variation normally affects generation of outdoor waste such as yard waste and the amount depends on the trimming rate (Hancs et al., 2011). In Ghana...
trimming of yard waste is done any time in the seasons and also no variety of food crops grown is limited to a season in Ghana.

3.1.1. Household waste generation from MMDs in Ghana

Average waste generation rate from the MMDs in Ghana is shown in Fig. 4. The average household waste generation rate from the metropolitan areas was 0.63 kg/capita, municipal 0.40 kg/capita and the district 0.28 kg/capita. The higher values for the metropolitan areas could be because of the more vibrant economic activities and affluent lifestyles compared to the municipal and districts. However, some selected municipalities also enjoyed equally high economically active areas, hence the high per capita comparable to some metropolises. The geographical location, culture, occupation, economic activity could also influence waste generation. In the northern parts of Ghana, the use of household waste in feeding animals, the activity of itinerant buyers at the household level, staple foods prepared from mainly cereals which generate less waste compared to the use of tubers and suckers all have a positive effect on the reduction of the per capita waste generation in these areas. The low waste generation at the district level could be attributed to lower level of affluence compared to the metropolises. Again the use of waste as fuel, animal feed and recycling of bottles, gallons and many others may contribute to waste reduction.

The generation rate of the various fractions also followed the same trend from the MMDs; the metropolises generated the highest in each fraction of the waste, followed by the municipalities and the least from the districts, except for plastics which had the districts generating more compared to the municipals. Nationally, the major fractions were organic, paper and plastic wastes, though the inert materials and miscellaneous items were also substantial. The highest fraction of the waste from the MMDs was still organic with a per capita per day generation rate of 0.38 kg for the metropolitan areas which was above the national average followed by the organic from municipals (Table 3). The forest zone on the other hand generated 0.31 kg/person/day organic waste compared to 0.16 kg/person/day from the northern savanna. Paper waste followed the same trend. Plastic waste however was highest in the forest zone, 0.07 kg/person/day followed by the northern savanna, 0.06 kg/person/day and coastal zone, 0.05 kg/person/day. The generation rates of the fractions can be explained on the basis of booming economic activities in the coastal zones compared to the forest zone and northern savanna. However, due to high patronage of plastics in the northern savanna especially for food packaging (Tuo Zaafii, Kooko, among others), plastic waste generation is even higher than in the coast.

3.1.2. Effect of geographic locations on household waste generation

Based on the geographical areas, the Forest and Coastal zones had similar generation rates of 0.52 kg/person/day and 0.58 kg/person/day, respectively which were far higher than the 0.27 kg/person/day generated in the Northern zone (Fig. 5). Location of businesses and industries in the Forest and Coastal zones of the country meant economic goods for these areas, a disadvantage which resulted in many economic downturns in the north. The three northern regions of Ghana are the poorest regions and are known for lower economic output which could mean low level of life style compared to the forest and coastal regions. However some households from the northern savanna geographical areas generated far more than some households in the forest and coastal zones. The per capita generation of household waste in this study from the northern savanna zone of Ghana ranged from 0.24 to 0.66 kg/person/day. Similar results were reported by Monney et al. (2013) in his study in Wa, the regional capital of Upper West Region which is part of the northern savanna zone. Additionally, the per capita generation from both the forest and coastal zones were comparably to studies by Ketibuah et al. (2004) who reported 0.6 kg/person/day in Kumasi, 0.40 kg/person/day by Fobil et al. (2005) in Accra and 0.46 kg/person/day by Mensah and Larbi (2005) also in Accra. However, a higher generation rate of 0.96 kg/per/day has been reported by Kotoka (2001) for high class areas in Kumasi.

Household waste fractions were dominated by organics, plastics and paper in all the geographical areas of Ghana just as it was for the MMDs and Ghana in general. The organic fraction remained the most prominent fraction in the household waste followed by plastics and paper. The coastal zone generated 0.36 kg/person/day organic waste, the highest among the geographical areas, but this was lower compared to the metropolitan average, but higher than the organic from municipals (Table 3). The forest zone on the other hand generated 0.31 kg/person/day organic waste compared to 0.16 kg/person/day from the northern savanna. Paper waste followed the same trend. Plastic waste however was highest in the forest zone, 0.07 kg/person/day followed by the northern savanna, 0.06 kg/person/day and coastal zone, 0.05 kg/person/day. The generation rates of the fractions can be explained on the basis of booming economic activities in the coastal zones compared to the forest zone and northern savanna. However, due to high patronage of plastics in the northern savanna especially for food packaging (Tuo Zaafii, Kooko, among others), plastic waste generation is even higher than in the coast.

3.1.3. Effect of income and household size on waste generation

The relationship between the per capita waste generation and household income as well as waste generation and household size are shown in Table 4. Qdais et al. (1997) have shown a positive correlation between waste generation and high income levels, but this study recorded no correlation between household income and waste generation. Our study agrees with a study in Mexico by Gomez et al. (2008) and in Gaborone, Botswana by Bolaane and Ali (2004). There are some high income earners who reside in low class areas and these among other factors could have been the reason why no correlation was found between household income and waste generation in this study. Furthermore, this study recorded that individuals in larger households generated less waste compared to their counterparts in smaller households. This could be due to the fact that larger households always buy items in bigger packages which are shared by all members of the household thus limiting the amount of waste which could have been generated if each person was to buy the package alone as observed by Pichtel (2005) in a study in the United States.

3.2. Physical composition of household waste from Ghana

Household wastes further sorted into 23 sub-fractions, analyzed in 9 major fractions and averaged for the ten regions of Ghana are
Table 3

<table>
<thead>
<tr>
<th>MMDAs</th>
<th>Organic</th>
<th>Paper</th>
<th>Plastic</th>
<th>Metal</th>
<th>Glass</th>
<th>Leather and Rubber</th>
<th>Textile</th>
<th>Inert</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metropolitan</td>
<td>0.376</td>
<td>0.036</td>
<td>0.079</td>
<td>0.020</td>
<td>0.017</td>
<td>0.007</td>
<td>0.012</td>
<td>0.048</td>
<td>0.033</td>
</tr>
<tr>
<td>Municipal</td>
<td>0.249</td>
<td>0.019</td>
<td>0.041</td>
<td>0.011</td>
<td>0.009</td>
<td>0.004</td>
<td>0.005</td>
<td>0.027</td>
<td>0.028</td>
</tr>
<tr>
<td>District</td>
<td>0.172</td>
<td>0.011</td>
<td>0.063</td>
<td>0.009</td>
<td>0.007</td>
<td>0.002</td>
<td>0.002</td>
<td>0.004</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Geographical areas

| Northern Savanna | 0.164   | 0.011     | 0.061   | 0.007 | 0.009 | 0.004              | 0.004   | 0.017     | 0.010         |
| Forest zone     | 0.311   | 0.027     | 0.067   | 0.019 | 0.013 | 0.003              | 0.005   | 0.039     | 0.041         |
| Coastal zone    | 0.360   | 0.031     | 0.048   | 0.015 | 0.013 | 0.007              | 0.011   | 0.042     | 0.031         |

Table 4

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Correlation</th>
<th>Multiple $R^2$</th>
<th>Adjusted $R^2$</th>
<th>$P$-value</th>
<th>$F$-value</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household income</td>
<td>0.0199</td>
<td>0.00039</td>
<td>0.00039</td>
<td>0.5719</td>
<td>0.3198</td>
<td>862</td>
</tr>
<tr>
<td>Household size</td>
<td>-0.4171</td>
<td>0.174</td>
<td>0.173</td>
<td>2.2 x 10^-16</td>
<td>168.9</td>
<td>862</td>
</tr>
</tbody>
</table>

Table 5

<table>
<thead>
<tr>
<th>Percentage fraction of household wastes</th>
<th>GreaterAccra (Newtown) (1)</th>
<th>Ashanti region (Asokwa) (2)</th>
<th>Northern region (Tamale) (3)</th>
<th>Upper West region (Wa) (4)</th>
<th>Central region (Cape Coast) (5)</th>
<th>Western region (Tarkwa) (6)</th>
<th>Eastern region (Aburi) (7)</th>
<th>This survey (all ten regions in Ghana)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic</td>
<td>63</td>
<td>54.4</td>
<td>57.5</td>
<td>48</td>
<td>63</td>
<td>68.6</td>
<td>70</td>
<td>61</td>
</tr>
<tr>
<td>Paper</td>
<td>2.8</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>4.9</td>
<td>6</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Plastic</td>
<td>10</td>
<td>6.8</td>
<td>20</td>
<td>5</td>
<td>2</td>
<td>16.0</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Metal</td>
<td>2</td>
<td>1.7</td>
<td>10</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Glass</td>
<td>2</td>
<td>1.1</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>0.9</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Leather &amp; Rubber</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Textile</td>
<td>5</td>
<td>1.8</td>
<td>–</td>
<td>4</td>
<td>1</td>
<td>3.23</td>
<td>–</td>
<td>2</td>
</tr>
<tr>
<td>Inert</td>
<td>12</td>
<td>31.4</td>
<td>2.5</td>
<td>33</td>
<td>26</td>
<td>4.2</td>
<td>–</td>
<td>6</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>2</td>
<td>3</td>
<td>0.3</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>5</td>
</tr>
</tbody>
</table>

(1) Owusu-Ansah (2008); (2) Asase (2011); (3) Puopiel (2010); (4) Monney et al. (2013); (5) Essumang (2000); (6) Ansah (2014) and (7) Asamoah-Okyere (2011).

presented in Table 5. The sub-fractions categorization helped identified the waste fraction which could be targeted for the purpose of recycling. The major fractions were organics, plastics, papers, metals, glasses, textiles, leather and rubber, inert materials and miscellaneous items. Over 61% of the waste stream from all the regions was organic followed by plastics, inert, paper, miscellane- neous, metals, glass, textiles and leather and rubber in that order. The high organic waste in Ghana's waste stream could be due to her high dependency on agricultural products. Food waste formed the major sub-fraction of the organic waste analyzed followed by yard waste. Plastic waste was the second largest fraction in terms of weight. This could be because of the increasing use of plastic products in packaging. Plastics are also being used as stretched HDPEs in sachet water packaging, PET bottles for bottling drinks and water, LDPEs and PS as bags. This survey has seen the development up of many plastic industries in Ghana. Fobil and Hogarh (2006) outlined the different plastic composition in the waste stream of Accra; it’s moved from 1.4% in 1979, 4% in 1993, 5% in 1997 to 8% in 2000. In this study, the average plastic in the waste stream was 14% and were mainly PET, LDPE, HDPE and PS (Table 7). This is lower than the 20% plastic reported by Puopiel (2010) in Tamale but close to 16% in Aburi in the Eastern Region (Asamoah-Okyere, 2011) and Tarkwa in Western Region (Ansah, 2014). Paper waste on the other hand, averaged 5% but ranged from 1.5% to 7.3% in the regions. The main fractions of paper waste obtained in the survey were cardboard and other packaging papers. Some other fractions such as metals, glass and textiles ranged between 1% and 3% which compares with other studies (Table 5), except Tamale where 10% metals was obtained (Puopiel, 2010). The sieving method employed in this study to separate the inert materials led to a high recovery of the waste fractions, especially the fine organics which reduced the inert to 6%, although some regions still recorded as high as 10–13%. The 6% fraction of inert material in the waste stream was lowest compared with other studies including 33% from Wa (Monney et al., 2013), 26% from Cape Coast (Essumang, 2000) 39% inert waste from Awaiwa-Nwabiga District (Osei-Mensah et al., 2014) and 22% inert waste from Kumasi by Asase (2011). The high biodegradable (organics and papers) recorded in this study, 67%, could serve as a guide for bioconversion programmes such as biofuel production and composting. A careful segregation of this fraction can serve as raw material base for value addition of waste and a safe haven for disposal of this problematic waste. The recyclables including plastics, textiles, metals, glass, rubber and leather on the other hand formed about 22% of the waste stream which is high enough for utilization in any recycling activity.

In comparison, waste fractions from the three different socioeconomic areas did not show significant variation in their composition. The organic was the highest fraction in all the socioeconomic areas with the low class areas generating the highest percentage and the high class areas the least. Except for paper, the middle class areas had the highest volumes of all the other waste fractions and the high class areas had the highest percentage in the various recyclable fractions. The low class areas had the highest fraction of inert and miscellaneous materials. The per capita per day household wastes generation and percentage composition of the various fractions from selected cities in Africa has been compared with the metropolitan cities of Ghana where the study was conducted. The average organic fraction of...
Table 6

<table>
<thead>
<tr>
<th>City</th>
<th>Country</th>
<th>Per capita GDP/ US$ (1)</th>
<th>Population of city/municipal (2)</th>
<th>Generation rate kg/person/day</th>
<th>Percentage composition (% of waste stream)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accra</td>
<td>Ghana</td>
<td>1458.7</td>
<td>1.36</td>
<td>63.2</td>
<td>0.74</td>
<td>This survey 2015</td>
</tr>
<tr>
<td>Kumasi</td>
<td>Ghana</td>
<td>1.47</td>
<td>0.75</td>
<td>60.0</td>
<td>0.70</td>
<td>This survey 2015</td>
</tr>
<tr>
<td>Takoradi</td>
<td>Ghana</td>
<td>0.23</td>
<td>0.70</td>
<td>58.6</td>
<td>0.84</td>
<td>This survey 2015</td>
</tr>
<tr>
<td>Tamale</td>
<td>Ghana</td>
<td>0.36</td>
<td>0.67</td>
<td>63.2</td>
<td>0.75</td>
<td>This survey 2015</td>
</tr>
<tr>
<td>Kano</td>
<td>Nigeria</td>
<td>2884.0</td>
<td>0.52–0.80</td>
<td>53.6</td>
<td>0.59</td>
<td>Nabegue (2010)</td>
</tr>
<tr>
<td>Abuja</td>
<td>Nigeria</td>
<td>0.59</td>
<td>0.59–0.79</td>
<td>52.0</td>
<td>0.59</td>
<td>Ternenge et al. (2014)</td>
</tr>
<tr>
<td>Lagos</td>
<td>Nigeria</td>
<td>9.00</td>
<td>0.59</td>
<td>53</td>
<td>0.59</td>
<td>Okor-Osumi (2012)</td>
</tr>
<tr>
<td>Freetown</td>
<td>Sierra  Leone</td>
<td>696.4</td>
<td>0.56</td>
<td>35</td>
<td>0.59</td>
<td>DEA (2012)</td>
</tr>
<tr>
<td>Cairo</td>
<td>Egypt</td>
<td>3303.8</td>
<td>0.74</td>
<td>15</td>
<td>0.59</td>
<td>Plan Bleu (2000)</td>
</tr>
<tr>
<td>Juba</td>
<td>Sudan</td>
<td>619.6</td>
<td>0.59</td>
<td>52</td>
<td>0.59</td>
<td>UN (1983)</td>
</tr>
</tbody>
</table>

1. International Monetary Fund (2015).

The sub-fractions of wastes analyzed in the survey are shown in Table 7. Food waste formed bulk of organic waste, averaging 48% of the entire municipal solid waste analyzed and 79% of the organic waste fraction. The huge fraction of food waste generated, 0.23 kg/person/day provides an opportunity to divert much of the waste in anaerobic digestion suggested as the best means of treating this type of waste. Yard waste is the next higher fraction of organic waste in as much as 11% of the MSW stream. Organic waste is commonly used in Ghana for composting and it is practiced by few groups and individuals, however only few commercialized projects on composting utilizing MSW are available in Ghana as has been reported by Bensah et al. (2015). Cardboards formed the highest fraction, 60% of papers wastes and 3% of the entire waste stream. Paper recycling has not been initiated on a larger scale, though few individuals have been recycling smaller portion as sanitary tissues. Plastic waste which is the largest fraction of the waste in terms of volume mainly consisted of LDPE, HDPE, PET and PP with percentages of 4, 3, 3 and 1.4, respectively in the MSW. LDPEs are used mostly in food packaging and are often contaminated with food waste, hence the highest fraction as per weight. Plastic recycling has not received the needed attention; it is believed that less than 2% of plastics are recycled in Ghana; the rest form major pollutants in public places and environmental receptacles in Ghana. Scrap metal is one fraction of MSW that has a great market in Ghana and beyond. This reason makes them attractive to scrap collector and itinerant buyers therefore reducing their composition in the waste stream to about 1%. They are utilized in local steel industries and are even exported.

Chemical composition of household waste from Ghana has been outlined by different researchers (Table 8). It follows that the high moisture content of the waste, above 50% on average, makes it 61% comparable to the percentage organic fraction of waste from other African countries where similar studies have been done (Table 6). There were similarities in the various waste streams although few variations were also seen with some of the fractions. The organic fraction was the highest and compares to the range reported for some developing countries such as 50–74% in some cities of China by Tai et al. (2011) and 51–58% in India by Ranjith (2012).

3.2.1. Percentage composition of household waste from MMDs and geographic locations of Ghana

Similarly, organic waste was highest in all the MMDs and geographical locations followed by plastics and paper. The metropolitan areas had the least fraction of organic waste, 59%, whereas averages for the municipal and district areas were 62% each. However, paper waste was 5% in the metropolitan areas and 4% in the municipalities and the districts. Contrastingly, plastic waste was highest in the districts, 23%, followed by 12% in the metropolis and 11.5% in the municipalities. Metals, textiles, leather and rubber percentage fractions were minimal in all the MMDs and also across the geographical zones. Inert also formed about 8% of all the waste in the metropolises and municipalities. The high inert materials in the household waste from metropolitan and municipal areas could be from soil particles originating from dredged storm drains in the houses. Geographically, the Coastal region generated the highest fraction of organics and paper, but least plastics. In the Northern Savanna however, plastics and glass were highest. In general, organic waste fraction decreased from the Coastal region (65%) through the Forest (61%) to the Northern Savanna (58%). In contrast, plastic waste showed an increase from the Coastal zone (10%) through the Forest (14%) to the Northern Savanna zone (18%).

3.2.2. Sub-fractions of household wastes and their availability for recycling

The sub-fractions of wastes analyzed in the survey are shown in Table 7. Food waste formed bulk of organic waste, averaging 48% of the entire municipal solid waste analyzed and 79% of the organic waste fraction. The huge fraction of food waste generated, 0.23 kg/person/day provides an opportunity to divert much of the waste in anaerobic digestion suggested as the best means of treating this type of waste. Yard waste is the next higher fraction of organic waste in as much as 11% of the MSW stream. Organic waste is commonly used in Ghana for composting and it is practiced by few groups and individuals, however only few commercialized projects on composting utilizing MSW are available in Ghana as has been reported by Bensah et al. (2015). Cardboards formed the highest fraction, 60% of papers wastes and 3% of the entire waste stream. Paper recycling has not been initiated on a larger scale, though few individuals have been recycling smaller portion as sanitary tissues. Plastic waste which is the largest fraction of the waste in terms of volume mainly consisted of LDPE, HDPE, PET and PP with percentages of 4, 3, 3 and 1.4, respectively in the MSW. LDPEs are used mostly in food packaging and are often contaminated with food waste, hence the highest fraction as per weight. Plastic recycling has not received the needed attention; it is believed that less than 2% of plastics are recycled in Ghana; the rest form major pollutants in public places and environmental receptacles in Ghana. Scrap metal is one fraction of MSW that has a great market in Ghana and beyond. This reason makes them attractive to scrap collector and itinerant buyers therefore reducing their composition in the waste stream to about 1%. They are utilized in local steel industries and are even exported.

Chemical composition of household waste from Ghana has been outlined by different researchers (Table 8). It follows that the high moisture content of the waste, above 50% on average, makes it
ideal for use as feedstock in biological conversions. Also the calori-
fic value is high enough for energy conversion; however a barrier
to this is the high moisture content (Fobil et al., 2005) suggesting
that source separation of waste should be undertaken before waste
could be utilized for waste to energy.

3.3. Compliance level of sorting and separation of household wastes

Sorting and separation of waste using a one way separation sys-
tem which basically sorted into ‘biodegradable (except papers)’
and all ‘other wastes’ was tested in this study and the outcome
averaged for each study area (Fig. 6). From the questionnaire
administration results, out of 1000 respondents from all the study
areas, 924 (92.4%) were willing to separate their waste while 4.8%
were unwilling and 2.3% did not respond. The reason for their will-
ingness to separate waste was because it had the potential for a
cleaner environment, it was a good waste management practice
and good for recycling but for those not willing to separate waste
it was because there was no motivation to do it. Sorting and sepa-
ration into the correct bins was effective in most of the areas as it
averaged above 80% for the “biodegradables except paper waste”
and above 75% for the “other waste”. In the Wa municipality how-
ever all the sorting and separation were below 60% (Fig. 6). A

<table>
<thead>
<tr>
<th>Components</th>
<th>High class income areas</th>
<th>Middle class income areas</th>
<th>Low class income areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total waste/kg %</td>
<td>Per capita/kg/ p/day</td>
<td>Total waste/kg %</td>
</tr>
<tr>
<td>Food waste</td>
<td>12110.1 44.201 0.235</td>
<td></td>
<td>13777.2 50.595 0.236</td>
</tr>
<tr>
<td>Yard waste</td>
<td>4749.3 17.334 0.092</td>
<td></td>
<td>2059.2 7.562 0.035</td>
</tr>
<tr>
<td>Wood</td>
<td>356.3 1.301 0.007</td>
<td></td>
<td>366.5 1.346 0.006</td>
</tr>
<tr>
<td>Animal droppings/manure</td>
<td>48.3 0.176 0.001</td>
<td></td>
<td>103.1 0.379 0.002</td>
</tr>
<tr>
<td>Paper and cardboard</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Newspaper</td>
<td>1846.6 0.674 0.004</td>
<td></td>
<td>105.7 0.388 0.002</td>
</tr>
<tr>
<td>Office print</td>
<td>165.8 0.060 0.003</td>
<td></td>
<td>121.2 0.445 0.002</td>
</tr>
<tr>
<td>Tissue paper</td>
<td>314.6 1.148 0.006</td>
<td></td>
<td>413.8 1.520 0.007</td>
</tr>
<tr>
<td>Cardboard/packaging paper</td>
<td>883.0 3.223 0.017</td>
<td></td>
<td>875.5 3.215 0.015</td>
</tr>
</tbody>
</table>

Table 8
Chemical composition of household wastes from Ghana.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Calorific value/kJ/kg</td>
<td>1.39 × 10^4 – 2.99 × 10^4</td>
<td>1.4 × 10^4 – 2.0 × 10^4</td>
</tr>
<tr>
<td>Moisture%</td>
<td>25–76</td>
<td>40–60</td>
</tr>
<tr>
<td>Ash Content%</td>
<td>2.2–19</td>
<td>nd</td>
</tr>
<tr>
<td>Volatile Solid%</td>
<td>31–88</td>
<td>nd</td>
</tr>
<tr>
<td>Density, kg/m³</td>
<td>nd</td>
<td>5.3 × 10^2 – 5.4 × 10^3</td>
</tr>
<tr>
<td>Carbon: Nitrogen</td>
<td>nd</td>
<td>37:1 – 100: 1</td>
</tr>
</tbody>
</table>

nd: not determined.

Please cite this article in press as: Miezah, K., et al. Municipal solid waste characterization and quantification as a measure towards effective waste man-
agement in Ghana. Waste Management (2015), http://dx.doi.org/10.1016/j.wasman.2015.09.009
nationwide average of 84% was obtained for separation into the biodegradable waste bin/bag and 76% for the other waste bin/bag. The high separation efficiency is an indication that the one way separation system employed was convenient for the participating households. This simple sorting and separation system could be recommended for communities learning to separate waste. It is therefore imperative for the MMDAs or city authorities or planners to start rolling out a source sorting process in the various cities.

The pilot study was successful because all the needed logistics were provided. There is also the need for regular collection of the sorted waste to avoid lack of trust from the community. Fee reduction could also be employed as an incentive for those who are effective in sorting and separation. Commitment of the household to the exercise was a major factor that accounted for the sorting and separation efficiency. The 84% efficiency from this study was higher than the 65% obtained from a study in Kumasi by Asase (2011). However, this was less than that reported by Ranninger et al. (2006) 96% in China, Nguyen (2005) 98% in Vietnam and Rigamonti et al. (2012) 80% in Denmark.

4. Conclusion

The organic fraction in the waste was the highest in the waste stream and ranged from 48% to 69%. Paper increased the percentage of biodegradables to 58–76% which could be used as raw material for biological conversion processes like composting, biogas and bioethanol refinery process. The organic composition varied among the various socioeconomic areas but these differences were not significant (p < 0.05). The geographical locations recorded decreases in organic waste from the Coastal regions through the Forest to the Northern savanna. Plastic waste was the second highest fraction and decreased from the Northern savanna through the Forest regions to the Coastal regions. Paper waste as a percentage of the total waste stream was less in the Northern savanna but almost the same for the Coastal and Forest regions. Nationally, waste generation rate was 0.47 kg/person/day. A total of 12,710 tons of household wastes was generated from households in Ghana. 8389 tons of the waste are biodegradable and available for bioconversion processes and 2754 tons for recycling.

National sorting and separation efficiency was 84% for biodegradable and 76% for other waste. The one way separation system was effective.

Acknowledgements

This work was supported with a Grant from Danida Fellowship Centre (DFC) of the Danish Ministry of Foreign Affairs, as part of the project “Biofuel production from Lignocellulosic Materials, 2GBIONRG”, DFC Journal no. 10-0188R50. Furthermore, the authors would like to thank Zoomlion Ghana Limited for supporting the field work and also thank the MSc student researchers who assisted in conducting the fieldwork in all the Regions of Ghana.

References


Anomanyo, E.D., 2004. Integration of municipal solid waste management in Accra (Ghana) Bioreactor treatment technology as an integral part of the management process. A thesis submitted to the Lund University in partial fulfillment of the requirements for the award of the Master of Science (MSc) degree in International Environmental Science.


Asase, M.A.D., 2011. Solid waste separation at source: A case study of the Kumasi Metropolitan Area, A thesis submitted to the Chemical Engineering School, Kwame Nkrumah University of Science and Technology, Kumasi, in partial fulfillment of the requirements for the Degree of Doctor of Philosophy, Faculty of Chemical and Materials Engineering, College of Engineering.


Please cite this article in press as: Miezah, K., et al. Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. Waste Management (2015), http://dx.doi.org/10.1016/j.wasman.2015.09.009