View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Elsevier - Publisher Connector

Waste Management 46 (2015) 15–27

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

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, Lynbgy, Denmark

ARTICLE INFO

Article history:
Received 26 May 2015
Revised 4 August 2015
Accepted 6 September 2015
Available online 28 September 2015

Keywords:
Waste sorting
Biodegradables
Generation rate
Compliance level
Nationwide
Household waste
Municipal solid waste

ABSTRACT

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 0.096 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. Metropolises 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 separating into the bin marked biodegradables, 84% effectiveness was obtained whiles 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/).

1. Introduction

Reliable waste management data provides an all-inclusive resource for a comprehensive, critical and informative evaluation of waste management options in all waste management programmes (Chang and Davila, 2008; Hancs et al., 2011; Qdais et al., 1997). Unfortunately, these required fundamental statistics are lacking in many developing countries (Buenrostro et al., 2001) and where they are available, they are inconsistent because they come from many sources which cannot be validated and are sometimes based on assumptions but not scientific measurements (Couth and Trois, 2011; IPCC, 2006; Ranjith, 2012). The net effect of these misleading data are often a source of confusion and doubt in the minds of investors who may want to do business or services in the waste management sector. Ghana is no exception of this data deficit problem. Data on municipal solid waste generation and composition are available in only few selected cities, most of which are over a decade old. A nationwide waste statistics in general is lacking; field study on household waste composition and generation has not been conducted holistically in the ten regions of the country, hence lack of reliable data which could provide information to

Abbreviations: AMA, Accra Metropolitan Assembly; ASTM, America Society of Testing Materials; BMSW, Biodegradable Municipal Solid Waste; EPA, Environmental protection Agency; HDPE, High Density Polyethylene; IPCC, Intergovernmental Panel on Climate Change; KMA, Kumasi Metropolitan Assembly; LDPE, Low Density Polyethylene; MMDAs, Metropolitan, Municipal and District Assemblies; MMDs, Metropolitan, Municipals and Districts; MSW, Municipal Solid waste; OECD, Organization for Economic Cooperation and Development; PET, Polyethylene Terephthalate; PP, Polypropylene; PS, Polystyrene; PVC, Polyvinyl Chloride.

* Corresponding author.
E-mail address: zska@kt.dtu.dk (Z. Kádár).

http://dx.doi.org/10.1016/j.wasman.2015.09.009
0956-053X/© 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 "biodegradables, 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), 49 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 Distrct) and also one municipal area in Greater Accra region (Anya in the Ga Central Municipal) (Fig. 2). Thus 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

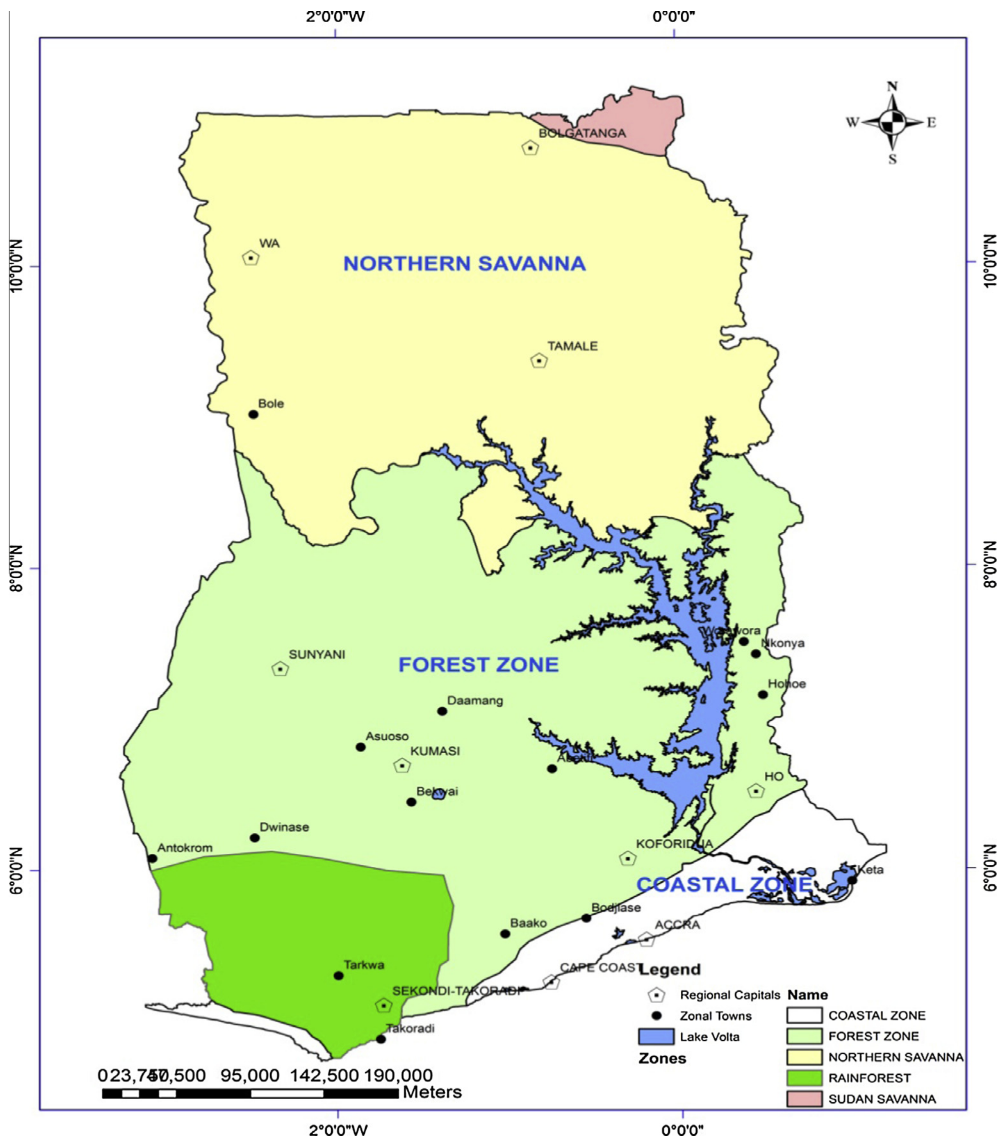

Fig. 1. Map of Ghana showing the Geographical Regions and vegetative cover. Source: Map developed by Ahianyo Cornelius using QGIS Software with Transverse Mercator.

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.

S/N	Regions	City	MMDA Status	Specific study locality	Population in the study areas	Estimated sample size at 5% margin of Error using Eq. (1)	Number of samples collected	Total waste analyzed/kg	Total houses/households surveyed	Total people generating the waste	Sampling duration/week
1	Western	Takoradi	Metropolitan	Beach Road, Essikafoambantem No.1 and Adakope	97352	383	1395	11760.7	93	563	4
2	Ashanti	Kumasi (Oforikrom)	Metropolitan	KNUST campus, Oforikrom and Ayigya	303016	384	900	7986.5	90	517	4
3	Eastern	Koforidua	Municipal	Adweso, Old Estate, Effiduase, Oyoko, Srodae and Akwadum	183727	384	1200	10610.3	80	515	4
4	Greater Accra	Anya	Municipal	Agape, Palace Town, Nsunfa, Abease and Ablekuma Newtown	24306	383	720	5159.3	60	335	3
		Accra	Metropolitan	East Legon, Adenta and Kotobabi	1848614	385	810	10035.6	81	468	5
5	Upper West	Wa	Municipal	Danko, Nakori and Kpongu	107214	383	900	4905.2	90	674	4
6	Upper East	Bolgatanga	Municipal	SNNIT Resident, Estate Area and Class Soe	131550	384	900	3918.6	90	545	5
7	Brong Ahafo	Sunyani	Municipal	Estate, Penkwa and Newtown	123224	383	720	3833.9	60	374	3
8	Northern	Bole	District	Hospital area, Mempeasem and Balpe	61593	382	600	3188.5	60	308	5
		Tamale	Metropolitan	Tamale South: Tuutingli, Kalariga and Lamashegu	142450	384	900	4530.7	90	605	3
9	Volta	Ho	Municipal	Alayi, Ahoe and SNNIT Flat	271881	384	800	3309.5	80	335	5
		Worawora (Biakoye)	District	Dwamenakrom, Mission, Zongo, Kotomase and Ricemill	65901	383	750	2035.4	50	339	4
10	Central	Cape Coast	Metropolitan	Ramlers, Apewosika and Ola Estates	169894	384	1080	10827.4	90	505	5

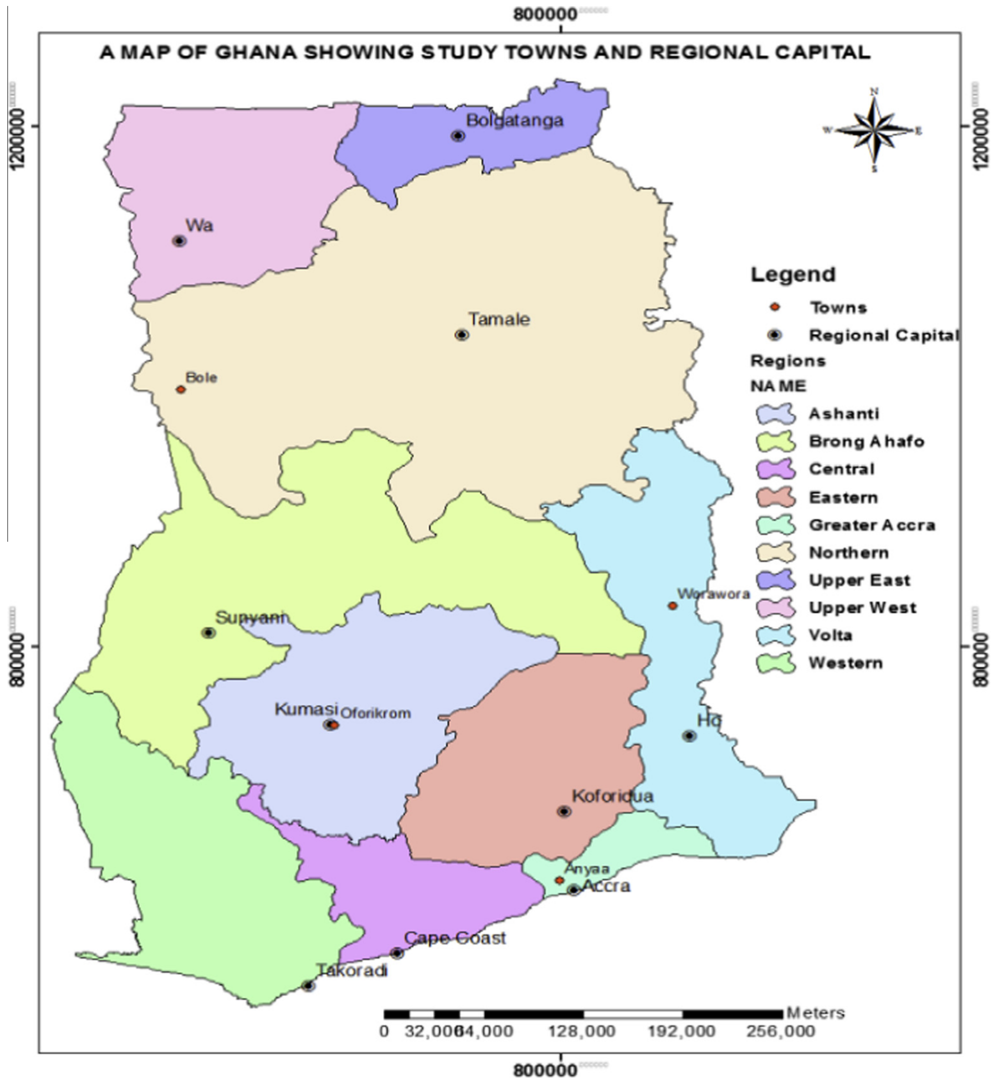

Fig. 2. The map of Ghana showing the study areas in the regions of Ghana; Map developed by Ahianyo Cornelius using QGIS Software with Transverse Mercator.

(2012) and Gomez et al. (2008) as in Eq. (1), was used to estimate the representative waste sample for analysis.

$$n = Z * Z[P * P)/(D * D)] \quad (1)$$

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 Pan balance (China P090008, Hot pan) of various capacity: 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

$$Percentage\ composition\ of\ waste\ fraction = \frac{Weight\ of\ separated\ waste}{The\ total\ of\ mixed\ waste\ sampled} \times 100 \quad (2)$$

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:

$$Per\ capita\ waste\ generation = \frac{Weight\ of\ MSW\ generated\ at\ household}{Total\ number\ of\ persons\ in\ the\ household \times Total\ number\ of\ generation\ days} \quad (3)$$

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.

$$Compliance\ Level = \frac{Weight\ of\ sorted\ waste\ in\ the\ right\ bin}{The\ total\ weight\ of\ all\ waste\ separated\ into\ the\ bin} \times 100 \quad (4)$$

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 socioeconomic 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 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 metropolises 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 socioeconomic 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

Table 2
Generation of household waste from households in the Regional capitals of Ghana.

Regional capital	2014 Population estimate based on inter-census growth rate from 2010 census	High class income area/ kg/p/day	Middle class income area/kg/ p/day	Low class income area/ kg/p/day	Average generation rate kg/p/day	Total waste generation based on population/tonnes	*P*-value
Takoradi	605673	0.76	0.68	0.65	0.70	424	0.7299
Cape coast	191961	0.74	0.69	0.58	0.67	128	0.3690
Accra	2088723	0.86	0.73	0.62	0.74	1552	0.2666
Ho	300106	0.34	0.33	0.27	0.31	94	0.6412
Koforidua	199653	0.80	0.54	0.48	0.61	122	0.0004
Kumasi	2263914	0.63	0.73	0.86	0.75	1689	0.3189
Sunyani	134958	0.52	0.49	0.47	0.49	66	0.6967
Tamale	416338	0.38	0.27	0.36	0.33	137	0.2178
Bolgatanta	137979	0.31	0.20	0.20	0.21	29	0.0024
Wa	115627	0.30	0.23	0.21	0.25	29	0.0075
Average Regional Capitals	645493	0.56	0.49	0.47	0.51	427	0.3788
Non-regional capitals							
Anya	30345	0.57	0.44	0.48	0.53	16	0.0789
Bole	65695	0.42	0.26	0.22	0.3	20	0.00007
Worawora	67950	0.26	nd	nd	0.26	18	
Average Overall	509148	0.53	0.46	0.45	0.474		
Std		0.30	0.20	0.21	0.22	669	
Max.		0.86	0.73	0.86	0.746	1689	
Min.		0.26	0.20	0.20	0.209	29	

nd means not done.

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

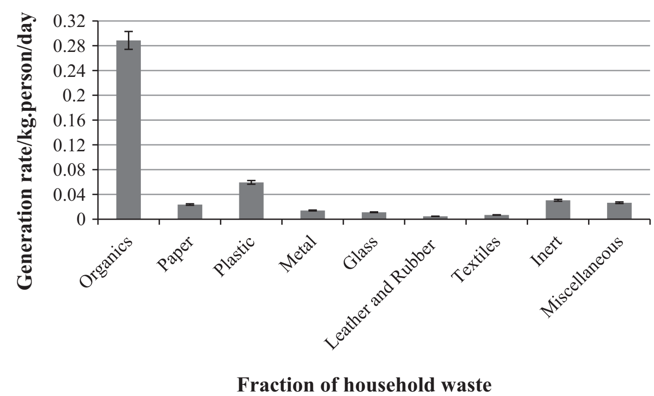

Fig. 3. Average generation rate of fractions of household waste per capita per day in Ghana.

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 metropolis. 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 municipals 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 0.25 kg for the municipals and 0.17 kg for the districts. These were all close to the national average of 0.29 kg.

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/perso/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.

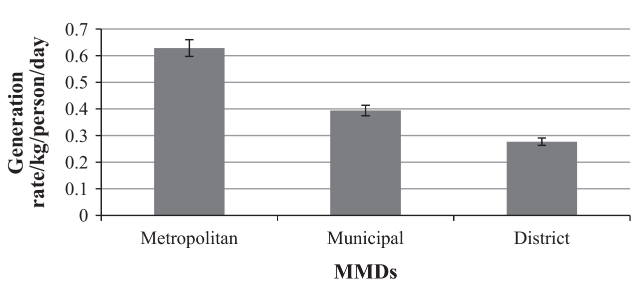

Fig. 4. Per capita household waste generation based on the MMDs in Ghana.

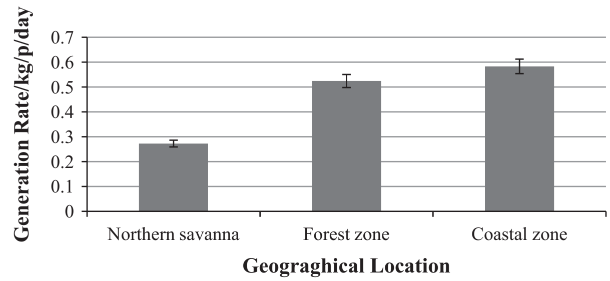

Fig. 5. Per capita household waste generation based on geographical locations of Ghana.

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 zone, 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 Zaafi, 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
Generation rate, kg/person/day, of the various fractions of household waste from the MMDs and geographical zones of Ghana.

MMDAs	Organic	Paper	Plastic	Metal	Glass	Leather and Rubber	Textile	Inert	Miscellaneous
Metropolitan	0.376	0.036	0.079	0.020	0.017	0.007	0.012	0.048	0.033
Municipal	0.249	0.019	0.041	0.011	0.009	0.004	0.005	0.027	0.028
District	0.172	0.011	0.063	0.009	0.007	0.002	0.002	0.004	0.007
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
Regression analysis of household income and household size each, against the per capita waste generation of MSW in Ghana.

Relationship	Correlation	Multiple R^2	Adjusted R^2	*P*-value	*F*-value	df
Household income	0.0199	0.00039	0.00039	0.5719	0.3198	862
Household size	−0.4171	0.174	0.173	2.2×10^{-16}	168.9	862

Table 5
Household waste composition from some selected cities in the various regions of Ghana compared to the average composition of household waste from this survey.

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

(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, miscellaneous, 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 development has seen the setting 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 cardboards 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 Atwima-Nwabiagya District (Osei-Mensah et al., 2014) and 22% inert waste from Kumasi by Asase (2011).

The high biodegradables (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
MSW composition and generation rate in some selected cities in Africa.

City	Country	Per capita GDP/US$ (1)	Population of city/million (2)	Generation rate kg/p/day	Organics (%)	Papers (%)	Plastics (%)	Metals (%)	Glass (%)	Textiles (%)	Leather & Rubber (%)	Inert (%)	Miscellaneous (%)	Sources
Accra	Ghana	1458.7	1.96	0.74	65.8	5.3	10.4	3.1	2.8	2.0	2.1	5.2	4.1	This survey
Kumasi	Ghana		1.47	0.75	48.4	6.5	17.6	4.5	2.9	0.1	1.6	10.7	7.8	This survey
Takoradi	Ghana		0.23	0.70	60.0	7.3	11.5	2.4	1.5	1.2	2.9	8.0	5.0	This survey
Tamale	Ghana		0.36	0.33	58.6	3.2	10.9	2.8	4.9	0.9	1.0	4.5	3.4	This survey
Cape Coast	Ghana		0.14	0.67	63.2	4.1	10.6	2.1	1.9	1.1	1.2	10.2	5.6	This survey
Kano	Nigeria	2884.0	3.60	0.52–0.80	53.6	2.1	11.3	2.2	2.8	3.8	-	22.5	1.7	Nabegu (2010)
Abuja	Nigeria		0.59	0.59–0.79	52	12.46	2.85	0.71	1.42	1.42	3.56	25.6		Ternenge et al. (2014)
Lagos	Nigeria		9.00	0.5	53	10	15	5	5	4	–	8		Oluwafemi and Bowen (2014)
Freetown	Sierra Leone	696.4	0.80	0.56	59.2		0.9	6.2	1.2	1.9	-	19.9		Sankoh et al. (2012)
Gaborone	Botswana	7407.1	0.21	0.5–0.9	35	30	15	6	5	3	-	6		Nagabooshnam (2011)
Nairobi	Kenya	1495.1	2.75	0.6	65	6	12	1	2	-	-	14		Okot-Okumu (2012)
Kampala	Uganda	684.2	1.35	0.59	77.2	8.3	9.5	0.3	1.3	-	-	3.4		Okot-Okumu (2012)
Cape Town	South Africa	5902.4	3.43	0.7–1.3	47	7	6	14	4	1	-	21		DEA (2012)
Cairo	Egypt	3303.8	7.73	1.3	56	19.5	3.8	7.2	3	1.1	-	9.4		Plan Bleu (2000)
Juba	South Sudan	1029.3	0.30	1.11	31	12	20	7	5	4	2	12	7	UNEP (2013)

(1) International Monetary Fund (2015).
(2) United Nation Population Division (2015).

61% is 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 fractions of 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 municipals. The high inert materials in the household waste from metropolis 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

Table 7
Generation and composition of sub-fractions of household wastes from Ghana.

Components	High class income areas			Middle class income areas			Low class income areas		
	Total waste/kg	% Composition	Per capita/kg/p/day	Total waste/kg	% Composition	Per capita/kg/p/day	Total waste/kg	% Composition	Per capita/kg/p/day
Food waste	12110.1	44.201	0.235	13777.2	50.595	0.236	13752.5	49.358	0.220
Yard waste	4749.3	17.334	0.092	2059.2	7.562	0.035	2484.1	8.915	0.040
Wood	356.3	1.301	0.007	366.5	1.346	0.006	357.1	1.282	0.006
Animal droppings/manure	48.3	0.176	0.001	103.1	0.379	0.002	81.2	0.291	0.001
Paper and cardboard	0.000			0.000			0.000		
News paper	184.6	0.674	0.004	105.7	0.388	0.002	115.4	0.414	0.002
Office print	165.8	0.605	0.003	121.2	0.445	0.002	150.6	0.541	0.002
Tissue paper	314.6	1.148	0.006	413.8	1.520	0.007	467.3	1.677	0.007
Cardboard/packaging paper	883.0	3.223	0.017	875.5	3.215	0.015	622.2	2.233	0.010
Non-biodegradables									
Plastics									
Plastic Film/LDPE	567.4	2.071	0.011	988.0	3.628	0.017	1492.9	5.358	0.024
PET	908.2	3.315	0.018	897.9	3.297	0.015	586.1	2.104	0.009
HDPE	842.5	3.075	0.016	749.2	2.751	0.013	952.2	3.418	0.015
PP Rigid	425.8	1.554	0.008	414.1	1.521	0.007	313.6	1.126	0.005
PS	166.1	0.606	0.003	146.6	0.538	0.003	162.4	0.583	0.003
PVC	151.7	0.554	0.003	168.4	0.618	0.003	68.7	0.247	0.001
Other plastics	658.0	2.402	0.013	539.9	1.983	0.009	599.9	2.153	0.010
Metals									
Scrap metals	290.4	1.060	0.006	428.9	1.575	0.007	147.7	0.530	0.002
Can/tins	471.6	1.721	0.009	359.3	1.319	0.006	587.4	2.108	0.009
Glass/bottles									
Coloured	784.7	2.864	0.015	542.2	1.991	0.009	396.5		0.006
Plain	231.8	0.846	0.004	292.0	1.072	0.005	163.8	0.588	0.003
Leather & rubber	277.3	1.012	0.005	318.9	1.171	0.005	288.5	1.035	0.005
Textiles	144.6	0.528	0.003	312.8	1.149	0.005	501.3	1.799	0.008
Inert (Sand, ash, fine organics) Material	1021.6	3.729	0.020	1584.1	5.817	0.027	2473.3	8.877	0.040
Miscellaneous or other waste	1644.1	6.001	0.032	1665.8	6.117	0.028	1098.1	3.941	0.018
Total	27397.8	100.000	0.531	27230.1	100.000	0.466	27862.8	100.000	0.446

Table 8
Chemical composition of household wastes from Ghana.

	Kuleape et al. (2014)	Fobil et al. (2005)	Adu and Lohmueller (2012)
Calorific value/kJ/kg	$1.39 \times 10^4 - 2.99 \times 10^4$	$1.4 \times 10^4 - 2.0 \times 10^4$	1.69×10^4
Moisture%	25–76	40–60	50
Ash Content%	2.2–19	nd	nd
Volatile Solid%	31–88	nd	nd
Density. kg/m^3	nd	$5.3 \times 10^2 - 5.4 \times 10^2$	nd
Carbon: Nitrogen	nd	37:1 – 100: 1	nd

nd: not determined.

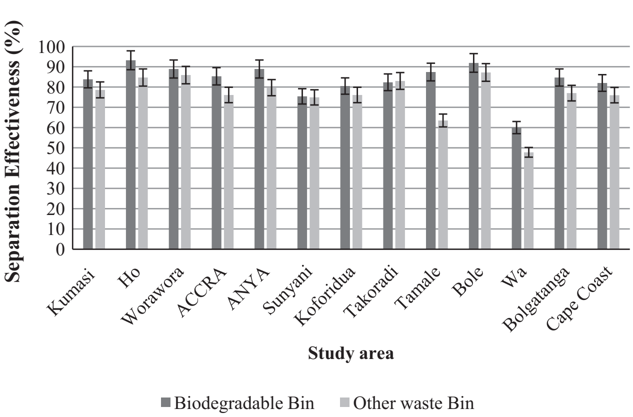

Fig. 6. Average Separation Effectiveness of the various households in the cities/-towns in the regions of Ghana.

ideal for use as feedstock in biological conversions. Also the calorific 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 system 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 willingness 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 separation 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 however all the sorting and separation were below 60% (Fig. 6). A 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 biodegradables and available for bioconversion processes and 2754 tons for recycling.

National sorting and separation efficiency was 84% for biodegradables 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. 10-018RISØ. 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

Adu, O.R., Lohmueller, R., 2012. The use of organic waste as an eco-efficient energy source in Ghana. J. Environ. Protect. 3, 553–562.
Adjei, S.M., 2013. Municipal solid waste minimization through household waste segregation in Bantama, Kumasi. A thesis submitted to the Department of Environmental Science, Kwame Nkrumah University of Science and Technology, Kumasi, in partial fulfillment of the requirement for the award of Master degree in Environmental Scienc.
American Society for Testing and Materials, 2008. Standard test method for determination of the composition of unprocessed municipal solid waste, In: ASTM D5231-92-2008, US.
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.
Ansah, B., 2014. Characterization of municipal solid waste in three selected communities in the Tarkwa Township of Tarkwa-Nsuaem Municipality in Ghana, A thesis submitted to the Department of Environmental Science, Kwame Nkrumah University of Science and Technology, Kumasi, in partial fulfillment of the requirement for the award of Master degree in Environmental Science.
Asamoah-Okyere, E., 2011. Characterization and composting of solid waste generated in the Aburi Township, A thesis submitted to the Department of Environmental Science, Kwame Nkrumah University of Science and Technology, Kumasi, in partial fulfillment of the requirement for the award of Master degree in 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 Department, 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.
Bartlett, J.E., Kotrlik, J.W., Higgins, C.C., 2001. Organizational research: determining appropriate sample size in survey research. Inform. Techno. Learning, Perform. J. 19 (1), 43–50.
Bensah, E.C., Kemausuor, F., Miezah, K., Kádár, Z., Mensah, M., 2015. African perspective on cellulosic ethanol production. Renew. Sustainable Energy Rev. 49, 1–11. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1364032115003299.
Bolaane, B., Ali, M., 2004. Sampling household waste at source: lessons learnt in Gaborone. Waste Manage. Res. 22, 142–148.
Buenrostro, O., Bocco, G., Vence, J., 2001. Forecasting generation of urban solid waste in developing countries-A case study in Mexico. J. Air Waste Manage. Assoc. 51, 86–93.
Chang, N.B., Davila, E., 2008. Municipal solid waste characterization and management strategies for the Lower Rio Grande Valley, Texas. Waste Manage. 28, 776–794.
Cochran, W., 1977. Survey Sampling. John Wiley, ES 2332.
Couth, R., Trois, C., 2011. Waste management activities and carbon emissions in Africa. Waste Manage. 31 (1), 131–137.
Dagadu, P.K., 2005. Municipal solid waste source separation at the household level: A case study of the Accra Metropolitan Area. MPhil. Thesis, Environmental Science, University of Ghana.
DEA, 2012. National waste information baseline report, Department of Environmental Affairs, Pretoria, South Africa.
Essumang, D.K., 2000. Effect of leachate from solid waste disposal site on Cape Coast Municipal environment, a thesis submitted to the Department of Chemistry, University of Cape Coast, Cape Coast, in partial fulfillment of the requirement for the award of Master degree in philosophy (Chemistry).
Fobil, J.N., Hogarh, J.N., 2006. The Dilemmas of plastic wastes in a developing economy: proposals for a sustainable management approach for Ghana. West African J. App. Ecol. 10 (1), 221–229.
Fobil, J.N., Carboo, D., Armah, N.A., 2005. Evaluation of municipal solid wastes (MSW) for utilisation in energy production in developing countries. Int. J. Environ. Technol. Manage. 5 (1), 76–86.
Friedrich, E., Trois, C., 2011. Quantification of GHG emission from waste management processes for municipalities – a comparative review focusing on Africa. Waste Manage. 31 (7), 1585–1596.
Gallardo, A., Bovea, M.D., Colomer, F.J., Prades, M., 2012. Analysis of collection systems for sorted household waste in Spain. Waste Manage 32, 1623–1633.
Ghana Statistical Service, 2014. 2010 population and housing census, summary report of final results, Accra, Ghana.
Ghana Statistical Service, 2014. Estimation of population of Ghana in 2014, Ghana Statistical Service, Accra, Ghana.
Gomez, G., Meneses, M., Ballinas, L., Castells, F., 2008. Characterization of urban solid waste in Chihuahua, Mexico. Waste Manage. 28 (12), 2465–2471.
Hancs, A., Novak, P., Dvorak, M., Habart, J., Svehla, P., 2011. Composition and parameters of household bio-waste in four seasons. Waste Manage. 31, 1450–1460.
International Monetary Fund, 2015. World Economic Outlook (WEO) Database April edition, <www.imf.org/external/pubs/ft/weo/2015/01/weodata/index.aspx> (assessed 30.07.15).
IPCC, 2006. 2006 IPCC Guidelines for Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change (IPCC), <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html> (Retrieved 23.03.15).
Kanat, G., 2010. Municipal solid-waste management in Istanbul. Waste Manage. 30, 1737–1742.
Ketibuah, E., Asase, M., Yussif, S., Mensah, M. Y., Fischer, K., 2004. Comparative analysis of household waste in the cities of Stuttgart and Kumasi – Options of waste recycling and treatment in Kumasi. In: Proceedings of the 19th International CODATA Conference Berlin, Germany, 7–10 November.
Kotoka, P., 2001. Physical Analysis of Solid Waste in Selected High Income communities in Kumasi. MSc. Thesis, Water Supply and Environmental Sanitation, Department of Civil Engineering, Kwame Nkrumah University of Science and Technology.
Kuleape, R., Cobbinah, S.J., Dampare, S.B., Duwiejuah, A.B., Amoako, E.E., Asare, W., 2014. Assessment of Energy recovery potential of solid waste generated in Akosombo, Ghana, African. Environ. Sci. Technol. 8 (5), 297–308.
Local Government Bulletin, January 2002. Ministry of Local Government and Rural Development, Accra, Ghana.

Mensah, A., Larbi, E., 2005. Solid Waste Disposal in Ghana. WELL Factsheet November 2005. <www.trend.watsan.net>.

MLGRD, 2010b. National Environmental Sanitation Strategy and Action Plan (NESSAP) 2010-2015, Ministry of Local Government and Rural Development, Government of Ghana.

Monney, I., Makimula, T., Bagah, H.C., 2013. Characterization and management of household solid waste in Urban areas in Ghana: the case of Wa. Civ. Environ. Res. 3 (9).

Nabegu, A.B., 2010. An analysis of municipal solid waste in Kano metropolis, Nigeria. J. Hum. Ecolo. 31 (2), 111–119.

Nagabooshnam, J.K., 2011. Solid waste generation and composition in Gaborone, Botswana, Potential for resource recovery, Master thesis, Energy and environmental engineering, Department of Management Engineering, Linkoping University, Sweden.

Nguyen, T.T.T., 2005. Audit and separation of compostable solid wastes at households in Danang, Vietnam. Master of Engineering Thesis, Graduate Department of Civil Engineering, University of Toronto.

Nordtest, 1995. Solid waste, municipal: sampling and characterization. Nordtest method NT ENVIR 001, Finland.

OECD, 2010. Municipal waste, OECD factbook 2010: Economic, environmental and social statistics OECD publishing 2010, pp. 172–173.

Okot-Okumu, J., 2012. Solid waste management in African cities – East Africa, Waste Management – An Integrated Vision, ISBN: 978-953-51-0795-8, InTech, http://dx.doi.org/10.5772/50241. <http://www.intechopen.com/books/waste-management-an-integrated-vision/solid-waste-management-in-african-cities-east-africa>.

Oluwafemi, O., Bowen, D.M., 2014. Environmental and economic analysis of solid waste management alternatives for Lagos municipalities, Nigeria. J. Sustain. Develop. Africa 16 (1), 1520–1526.

Opoku, G.A., 1999. A Pilot Study of Domestic Solid Waste Disposal–Sorting at the Source of Generation. University of Science and Technology, Department of Mineral Processing and Extractive Metallurgy, Kumasi, Ghana.

Osei-Mensah, P., Adjaottor, A.A., Owusu-Boateng, G., 2014. Characterization of solid waste in the Atwima-Nwabiagya District of the Ashanti Region, Kumasi-Ghana. Int. J. Waste Manage. Technol. 2 (1), 1–14.

Owusu-Ansah, K., 2008. Evaluation of household solid waste processing options in Accra, Ghana. MSc. Thesis, UNESCO-IHE Institute for Water Education, Delft, the Netherlands.

Pichtel, J., 2005. Waste Management Practices-Municipal, Hazardous, and Industrial. Taylor and Francis Group, LLC, New York.

Plan Bleu, 2000. Regional Study on Policies and Institutional Assessment of Solid Waste Management in Egypt. Retrieved 18thJanuary, 2015, from Plan Bleu – Regional Activity Centre-Enviroment and Development in the Mediterranean. <http://www.planbleu.org/publications/wasteEGY.pdf>.

Puopiel, F., 2010. Solid waste management in Ghana; the case of Tamale Metropolitan Area, MSc Thesis, Kwame Nkrumah University of Science and Technology, Ghana.

Qdais, H.A., Hamonda, M.F., Newham, J., 1997. Analysis of residential solid waste at generation sites, Waste Manage. Res. 15, 395–406.

Ranjith, K.A., 2012. Sustainable solid waste management in India, A thesis submitted to the Department of Earth and Environmental Engineering, in partial fulfillment of the requirement for the degree of MSc in Earth Resource Engineering, Fu Foundation School of Engineering and Applied Science, Columbia University.

Ranninger, B., Bidlingmaier, W., Li, R., 2006. Pilot research on source separation and utilization of bioorganic municipal solid waste in China. In: proceedings of the International Conference ORBIT (Organic Recovery and Biological Treatment), Part 4, Weimar, Germany, 13th–15th September, pp. 1307–1316.

Rigamonti, L., Moller, J., Grosso, M., Christensen, T.H., 2012. Environmental evaluation of plastic waste management scenarios. In: 1st International EIMPack Congress, Recycling of plastic waste considering all the cost and all the benefit, Lisbon, Portugal, 29–30th November.

Sankoh, F.P., Yan, X., Conteh, A.M.H., 2012. A situation assessment of socioeconomic factors affecting solid waste generation and composition in Freetown, Sierra Leone. J. Environ. Prot. 3, 562–568.

Tai, J., Zhang, W., Che, Y., Feng, D., 2011. Municipal solid waste source-separated collection in China: A comparative analysis. Waste Manage. 31, 1673–1682.

Ternenge, A.B., Enomena, E.O., Ayuba, D.G., 2014. Characterization of municipal solid waste in the Federal capital, Abuja, Nigeria. Global J. Sci. Frontier Res., Hum. Environ. Earth Sci. 14 (2).

UNEP, 2013. Municipal solid waste comparative analysis study in Jubah, South Sudan, United Nations Environmental Programme. Retrieved 28th January, 2015 at <http://unep.org/SouthSudan/>.

United Nation Population Division (2015). World population prospect, UN department of economics and Social Affairs, UN Secretariat.

Valkenburg, C, Walton, C.W., Thompson, B.L., Gerber, M.A., Jones, S., Stevens, D.J., 2008. Municipal solid waste (MSW) to liquid fuels synthesis, Volume 1: Availability of feedstock and Technol. PNNL 18144, Pacific Northwest National Laboratory, Richland, WA.