Kwame Nkrumah University of Science and Technology

Kumasi, Ghana.

Physico-chemical characteristics of solid waste for treatment options

A case study of Kumasi, Ghana.

Abel Acquah Mensah

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Physico-chemical characteristics of solid waste and treatment options

A case study of Kumasi, Ghana.

By

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CERTIFICATION

I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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THIS THESIS IS DEDICATED TO MY BELOVED MOTHER, MAD. MARY MARKSON

Abstract

The existing landfill in Kumasi is reaching full capacity, and all components of our environment, air, water, as well as open spaces are increasingly threatened. In addressing the task of properly disposing solid waste, it has become eminent to look for alternative treatment options beyond landfilling to reduce the increasing volume of waste generated. The rejection of landfill sitting by individuals and communities has led to a difficulty in getting land for landfilling. This together with the large investment cost in landfill construction has therefore necessitated the need for this research to divert part of the increasing volume of waste generated from going to landfill to prolong its lifespan. To establish the basis for waste diversion from landfill, this survey was conducted. The objective of the study was to determine the physical and chemical characteristics of solid waste for treatment and disposal options. Ninety households were conveniently selected comprising all the three categories of income levels (low, middle and high) in Kumasi. Solid wastes from these households were separated into its components with the weight and volume of each component measured. Subsequently sub-samples from the composite samples were then taken to the laboratory for the chemical analysis. The solid waste generated per capita/day was 0.542 kg, 0.608kg and 0.728 kg for the low, middle and high income respectively. Thus, an estimated volume of 1227 tonnes of domestic solid waste is generated daily based on the city's population of 2,089,842. In relation to the waste composition, the wastes were sorted into nine fractions of which the organic waste accounted for the highest proportion; 61% on the average. Since the high fraction of organic waste had moisture of approximately 55% and a favourable C/N ratio that ranged from 24.8:1-27.0:1, the treatment options that best suits the organic waste are composting and anaerobic digestion. This will divert 61% of the waste from going to the landfill site, representing 747 tonnes per day of domestic waste. Almost all the combustible components of the wastes gave appreciably high calorific values that ranged from 12-41 MJ/kg, which makes incineration a feasible treatment option. The aforementioned treatment options in addition to the possibility of reuse/recycling (plastics, glasses, paper and the metals/cans) that amounts to

15.6% of the daily waste will further reduce the waste, leaving only 19.3% of the waste to be sent to the landfill. From the study, large proportion of waste can be composted, recycled/reused and incinerated. The municipality can reduce the increasing volume of waste that goes to the landfill site through composting, recycling/reuse and incineration techniques.

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List of Abbreviations and Acronyms

WHO	World Health Organization
ISWM	Integrated Solid Waste Management
UNECE	United Nations Economic Commission for Europe
E.P.A	Environmental Protection Agency
KMA	Kumasi Metropolitan Assembly
AMA	Accra Metropolitan Assembly
WB	World Bank
CV	Calorific Value.
UK	United Kingdom.
MSW	Municipal Solid Waste.
KNUST	Kwame Nkrumah University of Science and Technology.
HHW	Household waste
IWM	Integrated Waste Management
A.D	Anaerobic digestion
MSWM	Municipal Solid Waste Management

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1 INTRODUCTION

1.1 Background

The concept of waste management in the world is one of the most actual targets of humanity. In recent years, management of solid waste has become an issue of increasing concern, becoming one of the primary environmental concerns of public debate (Rahman, 2007).

Open dumps were the means of solid waste disposal in the three major cities of Ghana (Accra, Kumasi, and Takoradi) (Johannessen et al, 1999). In an attempt to address the escalating problems of solid waste management due to urbanization and rapid economic growth, Ghana under the World Bank's Urban Environmental Sanitation Project developed plans to build its first sanitary landfills in these three major cities (Government of Ghana 2003). The waste management system so far in Ghana has not properly integrated other solutions as collection, treatment, and supply for re-use, reprocessing and final disposal. There are different kinds of waste based on their origin, compositions and characteristics: physical, chemical and biological. Based on their origin, characteristics and compositions, household wastes should be sorted and handle in different ways to achieve the development of ecologically and healthy management of waste (Falu Kommun, 1999 as cited by Anomanyo, 2004).

The built landfill may be crammed even before its estimated lifetime and may revert to open dump if proper management system is not put in place. It is time therefore to establish a paradigm shift of waste management with a necessity of an integrated waste management system whereby collection/sorting, composting, incineration, recycling / reuse of the municipal solid waste are incorporated.

In integrating the appropriate waste treatment and disposal options into the management of waste to divert waste from going to landfill, the physical and chemical characteristics of solid waste are imperative to achieving this. It is against this background that the relevance of the study cannot be underestimated.

1.2 Problem statement

In many developing countries most of the municipal solid waste is land filled. As a result of rapid rate of urbanization and economic growth, increasing amount of solid waste is being generated. This presents greater difficulty for solid waste disposal. In Kumasi, Ghana, only one sanitary landfill exists to accommodate the increasing amount of solid waste generated. There is no form of waste treatment to reduce the increasing volume of waste that ends up at the landfill. Over the years, individuals and communities have rejected landfill sitting and have encroached on land designated for landfilling. This has therefore led to a difficulty in getting land for land filling. The short lifespan of landfill coupled with the large investment cost involved in constructing new landfill as well as getting public approval, has therefore made it prudent to look for alternative treatment options beyond the landfilling to conserve space and maximize the use of the existing landfill.

The problem this study seeks to address is which treatment and disposal options are appropriate for handling the different waste fractions to reduce the volume of waste to the landfill.

1.3 Objective of study

To determine the physical and chemical characteristics of solid waste for the assessment of potential treatment and disposal options within the three income groups (low, middle and high).

Specific objectives include the following:

a. To determine the physical characteristics of solid waste.
b. To determine the chemical characteristics of solid waste.
c. To assess possible alternatives of waste treatment and disposal options based on the characteristics and the material balances of the waste streams.

1.4 Justification of study

As there are several possible recycle, reuse and treatment options, one of the first steps in identifying the most suitable treatment option is to determine the chemical characteristics of solid waste. The physical and chemical characteristics of solid waste are important for designing appropriate waste treatment and disposal options. The appropriate waste treatment and disposal options once identified could form the basis on which waste is diverted to the landfill. As the waste is diverted for other purposes, volume of waste going to the landfill reduces and the entire lifespan of the landfill is maximized.

1.5 Scope of study

The area selected for the study is Kumasi. Due to the lack of logistics and funds, the study was limited to three out of the ten sub-metropolitan areas of Kumasi. The research involved the determination of the physical and chemical characteristics of solid waste. The physical characteristics comprised: the composition, the per capita generation rate, moisture content and the density of the solid waste. The chemical characteristics also comprised: the total organic carbon, total organic nitrogen, C/N ratio, calorific values.

1.6 Limitation

The following are the limitations encountered during the study.

I. The unwillingness of some selected households to give reliable information and participate in the survey was a difficulty.

II. Lack of adequate logistics and funds.

1.7 Organization of report

This report is made up of five chapters. Chapter one begins with an introduction which consists of the background, the objectives, the problem statement, the justification and the scope of the study. Chapter two presents a review of available literature. Chapter three describes the study area and the research methodology. Chapter four presents the results and discussions whiles the fifth chapter outlines the conclusions and recommendations of the study.

2 LITERATURE REVIEW

2.1 Definition of solid waste

2.1.1 Solid Waste

Waste is an inevitable product of society (white et al, 1995). Waste according to Basel Convention of 1997 is defined as "substance or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provision of the national law". Solid waste is all the waste arising from human and animal activities that are normally solid and that are discarded as useless or unwanted (Tchobanoglous et al, 1993). Solid waste is defined in accordance with the U.S Environmental Protection Agency as any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility, and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial or commercial operations or from community activities.

In this study, solid waste is defined as discarded materials and objects which originate from domestic, business, and industrial sources, which are typically disposed of in landfills, but does not include industrial hazardous or special wastes. (W.H.O, 1996).

2.2 Sources of solid waste

Solid waste streams should be characterized by their source, type of waste produced as well as by generation rates and composition.

Knowledge of the sources and types of waste in an area is required in order to design and operate solid waste management systems appropriately. There are eight major classifications of solid waste generators and these are linked to zoning and land use. They are; Residential, Industrial, Commercial, Institutional, Construction and demolition, Municipal services, Process, Agriculture. The term solid waste is all inclusive and encompasses all the source, types of classification, composition and properties (Peavy et al, 1985).

2.2.1 Residential and Commercial

Residential and commercial solid wastes, consist of the organic (combustible) and inorganic (non combustible) solid wastes from residential and commercial establishments. Typically the organic fraction of residential and commercial solid waste consists of materials such as food waste (also called garbage), paper of all types, corrugated cardboard (also known as paperboard and corrugated paper), plastics of all types, textiles, rubber, leather, wood and yard wastes. The inorganic fraction consists of items such as glass, crockery, tin cans, aluminum, ferrous metals and dirt. If the waste components are not separated when discarded, then the mixture of these wastes is also known as commingled residential and commercial MSW. Wastes that will decompose rapidly, especially in warm weather, are also known as putrescible waste. The principal source of putrescible wastes is the handling, preparation, cooking and eating of foods.

2.2.2 Institutional

Institutional sources of solid waste include government centers, schools, prisons, and hospitals. Excluding manufacturing wastes from prisons and medical wastes from hospitals, the solid wastes generated at these facilities are quite similar to commingled MSW. In most hospitals, medical wastes are handled and processed separately from other solid wastes.

2.2.3 Construction and Demolition

Wastes from the construction, remodelling, and repairing of individual residences, commercial buildings, and other structures are classified as construction wastes. The quantities produced are difficult to estimate. The composition is variable but may include dirt, stones, concrete, bricks, plaster, lumber, shingles and plumbing, heating and electrical parts. Wastes from razed buildings, broken-out streets, sidewalks, bridges, and other structures are classified as demolition wastes. The composition of demolition wastes is similar to construction wastes, but may include broken glass, plastics and reinforcing steel.

2.2.4 Municipal Services

Other community wastes, resulting from the operation and maintenance of municipal facilities and the provision of other municipal services, include street sweepings, road side litter, wastes from municipal litter containers, landscape and tree trimmings, catch-basin debris, dead animals and abandoned vehicles. Because it is impossible to predict where dead animals and abandoned automobiles will be found, these wastes are often identified as originating from nonspecific diffuse sources.

2.2.5 Treatment Plant Wastes and other Residues

The solid and semisolid wastes from water, wastewater, and industrial waste treatment facilities are termed treatment plant wastes.

The specific characteristics of these materials vary, depending on the nature of the treatment process. Materials remaining from the combustion of wood, coal, coke and other combustible wastes are categorized as ashes and residues. (Residues from power plants normally are not included in this category because they are handled and processed separately). These residues are normally composed of fine, powdery materials, cinders, clinkers and small amounts of burned and partially burned materials. Glass, crockery and various metals are also found in the residues from municipal incinerators.

2.2.6 Industrial solid waste and Process

The type of solid waste classified as industrial waste originates from industry and their characteristics depend on the industrial activities taking place within the industry. These, typically include rubbish, ashes, demolition and construction wastes, special wastes, and hazardous wastes.

The type of solid waste classified as process waste comprises industrial process wastes, scrap materials, off-specification products, slag and tailings. The specific characteristics of the waste vary depending on the nature of the treatment process. Wastewater treatment plant sludges are commonly co-disposed with MSW in a municipal landfill. In the future the disposal of such waste should be done separately.

2.2.7 Agricultural Wastes

Wastes and residues resulting from diverse agricultural activities – such as the planting and harvesting of row field, tree and vine crops; the production of milk; the production of animals for slaughter and the operation of feedlots – are collectively called agricultural wastes.

Even thought a vast number of classifications exist as outlined above, in this thesis work emphasis is restricted to only the domestic source of waste. For this purpose, households are the best place to collect samples, as this makes the identification of waste materials easier and eliminates any uncertainty as to their origins.

2.3 Characteristics of solid wastes

Information on the characteristics of solid waste is important in evaluating alternative equipment needs, systems, management programs and plans especially with respect to the implementation of disposal, resource and energy recovery options. To effectively plan solid waste management, information and data on the expected future composition of solid wastes are important.

2.3.1 Physical characteristics

Different sources express physical property of municipal solid waste by its density, particle size, moisture content, etc. (Holmes, 1981). According to these sources, density-specific weight (weight per unit volume) is managed by assessing total weight and volume of waste.

Solid waste composition

This is the term used to describe the individual elements that make up the solid waste stream and their relative distribution, usually based on percent by weight. The individual components of solid waste as indicated in Tables 2.1- 2.5 are organics, plastics, paper/cardboard, metals/cans, glass, wood, textile/fabrics, miscellaneous. Table 2.1 establishes a range of values for the various components of solid waste as a guide for the low, middle and high income countries. Table 2.2 compares studies done in developing countries (Ghana) to the developed countries (India, Britain, and U.S.A). Table 2.4 and 2.5 illustrates how the compositions of solid waste have changed over the years. Tables 2.3, 2.4, 2.5 depict the differences in the waste composition across cities within the same country.

Information about the nature of waste is critical for assessing the effects on the environment if specific composition is found in MSW. Moreover, knowledge on the composition of waste is essential for implementing the most appropriate treatment and disposal process (McDougal et al, 2002; Zeng et al, 2005).

Table 2. 1: Global perspective on solid waste characteristics for low, middle and high income countries.

Range of Composition	Low	Middle	High
Paper	1-10	15-40	15-50
Glass/ceramics	1-10	1-10	4-12
Metals	1-5	1-5	3-13
Plastics	1-5	2-6	2-10
Leather/rubber	1-5	-	-
Wood/bones/straw	1-5		
Textile	1-5	2-10	2-10
Vegetables/putrescible	40-85	20-65	20-50
Misc. inert	1-40	1-30	1-20

Source: Cointreau et al, 1987.

Table 2. 2: Comparison of solid waste composition in Ghana, India, Britain and USA.

Components	Ghana	India	Britain	U S A
Garbage	89.5	67	13	5
Paper	2.4	8.75	30	54.4
Glass	0.8	1	6	9.1
Plastic	0.3	7.3	3	2.6
Rags	1.3	0.7	-	1.7
Stones	2.5	-	-	-
Bones	0.1	-	-	-
Tins/cans etc	3.6	15.3	28	27

Source: T. Agyapong 1974 as cited in Kotoka .P, 2001.

Table 2. 3: Solid waste Properties in Accra.

ITEM	COMPONENT	WEIGHT (%)
1	Organic	65
2	Paper	4.2
3	Plastic	3.5
4	Metal	1.8
5	Inert material	22.5
6	Glass	1.9
7	Miscellaneous	1.1
	TOTAL	100
	Solid Waste Density = 500kg/m3	
	Solid waste generation rate = 0.5kg/capita/day	

Source: Waste Management Department- AMA.

Table 2. 4: Comparison of solid waste characteristics in Kumasi.

Solid waste characterization by various group and individual.	Solid waste characterization by KMA.	Physical analysis of solid waste in some selected high income areas in Kumasi by Kotoka.
Components	**% by weight**	**% by weight**
Greens/Vegetable/Fruits	44	43.87
Plastics	3.52	1.145
Fabrics/Textiles	3.2	0.505
Paper/Cardboard	3.1	2.275
Bottles	0.64	1.165
Metals	0.64	0.565
Rubber	0.3	0.32
Miscellaneous (including ash, **food waste,** sand etc)	44.6	50.31
Total	100	100

Source: Kotoka, 2001.

Table 2. 5: Solid waste characteristics for three income groups in Kumasi.

	Low income group	Middle income group	High income group
Components	**% by weight**	**% by weight**	**% by weight**
Organic	48	56	71
Plastic	8	5	6
Paper	2	2	4
Metals	2	1	2
Glass	1	2	2
Wood	2	1	1
Textile	3	6	2
Miscellaneous	34	27	12
Total	100	100	100

Source: Ketibuah et al, 2004.

Bulk density of waste

Density is a critical criterion for the estimation of storage, collection, transportation as well as landfilling of waste. The weight-volume analysis is mostly used in determining the density of solid waste materials. This involves the measurement of the weight and volume of waste generated over a period. Because the densities of solid wastes vary markedly with geographic location, season of the year and the length of time in storage, great care should be exercised in selecting typical values.

Moisture content

Moisture content indicates water contents of the waste, which is percentage of the wet weight material to dry material. Moisture content of solid wastes is usually expressed as the mass of moisture per unit mass of wet or dry materials. The wet-mass moisture content is expressed as follows: Moisture content (%) = ((w-d) /w) x 100; where w = initial mass of sample as delivered and d = mass of sample after drying. A moisture content of 50–60% of the total weight of waste is considered ideal for the developing countries (Diaz et al, 1993; Yousuf, 2005). Higher moisture content indicates the possibility of the development of anaerobic conditions in the disposal site that causes obnoxious odours and quicker rotting. It has major role in determining compaction, decomposition and incineration.

Solid waste generation

Waste generation is the first element of waste management. It is a prerequisite to any waste management plan to have adequate knowledge of the generators of waste, its physical and chemical characteristics. Table 2.6 outlines how the quantities of solid waste generated vary within the three income countries (low, middle and high). As indicated in Table 2.6, a range of values are established for the three income countries to serve as a guide for subsequent studies on waste generation, waste densities and moisture content. Waste generation embodies activities in which materials are identified as no longer of value and either thrown away or gathered together for disposal of which reliable estimate of solid waste generation is very important for proper waste management planning.

Table 2. 6: Pattern of waste characteristics for low, middle and high income countries.

	Low income countries	Middle income countries	High income countries
Waste generation(kg/c/d)	0.4-0.6	0.5-0.9	0.7-1.8
Waste densities (kg/m^3)	250-500	170-330	100-200
Moisture content(%)	40-80	40-60	20-40

(Source: Cointreau et al, 1987)

2.3.2 Chemical characteristics

Typically, solid wastes can be thought of as a combination of semi moist combustible and non-combustible materials. The most important chemical properties of solid wastes are proximate analysis (moisture content, volatile matter , fixed solids) and the ultimate analysis(percent of carbon, hydrogen, oxygen , nitrogen, sulphur , ash) as well as the calorific value (energy value).

Carbon to nitrogen (C: N) ratio

Carbon and nitrogen are essential to microorganisms that break down organic material. In the process of breaking down the organic material, microorganisms utilize the carbon as a source of energy and the nitrogen as the building block for protein synthesis. A nutritional requirement for microorganisms is that the C: N ratio of organic matter must be at a level for optimum decomposition efficiency. The limiting C: N ratio for most microbial organisms ranges from 25:1 to 30:1 (i.e., 25–30 parts carbon to 1 part nitrogen). When the C: N ratio of the compost exceeds 30:1, the organisms become deficient in nitrogen and the process of decomposition is slowed (Mamo et al, 2002).

Calorific value

The feasibility of combustion depends on moisture content, volatile combustible matter, fixed carbon and ash (Tchobanoglous et al, 1993). The combustion is expressed by the term calorific value of waste, which is a quantitative estimation of heat energy released by burning. Higher calorific value indicates the combustion of waste with a lesser amount of auxiliary fuel support. To facilitate self combustion of waste, the calorific value of the waste should be at least 5MJ/kg and approximately 6MJ/kg for power generation.

2.4 Solid waste management

Municipal Solid Waste Management (MSWM) is the generation, separation, collection, transfer, transportation and disposal of waste in a way that takes into account public health, economics, conservation, aesthetics, the environment, and is responsive to public demands (Wakjira, 2007).

It is most common for municipalities in developing countries to spend 20-50 percent of their available recurrent budget on solid waste management (Onibokun and Kumuyi, 2003). Open dumping with open burning has always been the practice in most developing countries. The uncollected or illegally dumped wastes constitute a disaster for human health and environmental degradation (Wakjira, 2007).

2.5 Design of Appropriate Waste Management System

An approach to design sustainable waste management system and operating guidelines are outlined below.

2.5.1 Quantity and Characteristics

Quantity and characteristics of the waste are the major factors, for assessing magnitude of waste management problems. It is necessary to carry out weight measurement exercise regularly to assess the quantity of waste. Future per capita quantity can be estimated with the help of projected population and annual increase of per capita quantity. On the basis of the waste quantity, infrastructure requirement can be estimated. It is also necessary to carry out characterization studies frequently in order to assess the changes in waste characteristics due to ever-changing scenario. This data will also serve as a basis for selection of disposal and treatment options.

Methods used to estimate solid waste quantities.

Methods commonly used to estimate solid waste quantities include

a. Load count analysis
b. Weight volume analysis
c. Material balance analysis

Load count analysis:

This is one of the methods of estimating solid waste quantities. Analyzing the estimation method using the load count takes into consideration the individual loads and the corresponding waste characteristics (the type of waste, estimated volume) over a specified period of time. Weight data are also recorded. The challenge in this method is whether the data derived represents truly what needs to be measured.

Weight volume analysis:

In this method, both volume and weight are used for the measurement of solid waste quantities. Unfortunately, the use of volume as a measure of the quantity can be misleading. For example a cubic yard of loose wastes is different from a cubic yard of wastes that has been compacted in a collection vehicle, and each of these is different from a cubic yard of waste that has been compacted further in a landfill. Accordingly, if volume measurements are to be used, measured volumes must be related to either the degree of compaction of the wastes or specific weight of the waste under conditions of storage. This estimation method weighs and measure each load collected. It gives better information on the specific weight of the various forms of solid waste at given location.

Material balance analysis:

The only way to determine the generation and movement of solid waste with any degree of reliability is to perform a detailed material balance analysis for each generation source, such as the individual home or commercial or industrial activity. In some cases, the material balance method of analysis will be required to obtain the data needed to verify compliance with state-mandated recycling programs.

2.5.2 Collection and Transportation of Waste

Properly designed collection bins and implements should be used for collection and storage of waste. Wastes should be collected frequently in order to avoid accumulation, which leads to the degradation of the environment and aesthetic quality. Suggestion from citizen as well as workers for improvement in the design of bins and implements will be useful. Spacing and location of the bins should be fixed on the basis of the waste load and public opinion. House to house collection system can be introduced gradually to ensure environmental friendly collection practices. Selection of properly designed vehicles is important. Various factors like width of the road, transport volume, road conditions, etc. play important role in selection of vehicles. Proper garage should be provided to save the vehicles from wear and tear due to heat and rain. Preventive maintenance system should be introduced, which is useful for longer life of the vehicles. Vehicle route should be properly planned for proper utilization of manpower, saving of fuel and reduction of time. Time and motion study should be conducted to reduce the non productive idle time of the vehicles and increase productivity.

2.6 Material Recovery

Waste prevention is given the highest priority in integrated waste management (Tchobanoglous et al, 1993). This is a preventive action whose objective aims at reducing the amount of waste that individuals, businesses and other organizations generate (Zurbrugg, 2003 as cited by Wakjiar, 2007). Source reduction can be a successful method of reducing waste generation. Source reduction has many environmental benefits. It prevents emissions of many greenhouse gases, reduces pollutants, saves energy, conserves resources, and reduces the need for new landfills and combustors (Medina, 1999).

2.6.1 Reuse

Reuse comprises the recovery of items to be used again, perhaps after some cleaning and refurbishing (Tchobanoglous et al, 1993). Reusing materials and products saves energy and water, reduces pollution, and minimizes society's consumption of natural resources. Reuse of materials and products is regarded as more socially desirable than recycling the same materials (Hui et al, 2006).

2.6.2 Recycle

Recycling is the material recovery option after the reuse of materials and products (Medina, 1999). Recycling is the recovery of materials for melting, repulping and reincorporating them as raw materials (Onibokun and Kumuyi, 2003).

It is technically feasible to recycle a large amount of materials, such as plastics, wood, metals, glass, textiles, paper, cardboard, rubber, ceramics, and leather (Holmes, 1981). In many African countries, artisans also constitute a significant source of demand for waste materials (Onibokun and Kumuyi, 2003). Recycling can render social, economic, and environmental benefits. It provides an income to the scavengers who recover recyclable materials (Kofoworola, 2006 as cited by Wakjiar, 2007). Recycling can result in a more competitive economy and a cleaner environment, and can contribute to a more sustainable development (Onibokun and Kumuyi, 2003). Informal recycling is common throughout Africa, Asia and Latin America (Medina, 1999).

2.6.3 Compost

Composting municipal solid waste involves managing conditions to accelerate the biological decomposition of some of its organic components. The conditions for efficient biological decomposition of organic waste depend on optimum temperatures (130–150° F), moisture (46–56%), oxygen (15–21%), pH (6.0–7.5) levels, and carbon to nitrogen (25:1–30:1) ratios of the feedstock (Mamo et al, 2002). If conditions deviate from these optimum levels, the composting process is slowed and chemically unstable compost may be produced. When microorganisms degrade the organic materials under optimum oxygen levels, the process is called aerobic composting. In contrast, a different group of microorganisms can degrade the organic material under limited oxygen levels, where the process is called anaerobic composting (Bilitewski et al, 1997). Aerobic composting is usually preferred over anaerobic composting because it is faster in biological oxidation and does not generate as many foul odours (i.e., ammonia, sulphur compounds and organic acids).

Municipal solid waste is mixed waste from residential, commercial, institutional, and industrial sources. Municipal solid waste has a composting potential of 60–90% (Holmes, 1981). Non-composting waste (glass, metals, and plastics) contaminates the municipal solid waste to varying degrees. In general, the fewer non-composting materials in the feedstock, the better the finished compost will be for agricultural use (Holmes, 1981; Tchobanoglous et al, 1977).

2.6.4 Waste incineration

In an Integrated Waste Management approach, incineration occupies the next to last priority, after waste prevention, reuse, recycling and composting have been undertaken (Tchobanoglous et al, 1993). Incineration is the burning of wastes under controlled conditions, usually carried out in an enclosed structure. Incineration may include energy recovery. Wastes generated in developing countries, however, usually do not allow energy recovery, due to their high moisture and high content of organic matter (Akankeng, 2003; Hui et al, 2006).

2.6.5 Sanitary Landfilling

Sanitary landfill as the final disposal site for solid waste is given the least priority in an Integrated Waste Management approach (Tchobanoglous et al, 1993). A sanitary landfill is a facility designed specifically for the final disposal of wastes, which minimizes the risks to human health and the environment associated with solid wastes (Medina, 1999). Waste arriving at landfill is compacted and then covered with a layer of earth, usually every day. This prevents animals from having access to the organic matter to feed.

Sanitary landfills may also include other pollution control measures, such as collection and treatment of leachate, and venting or flaring of methane. It is possible to produce electricity by burning the methane that landfills generate (Kirov, 1972 as cited by Wakjira, 2007). Proper management of landfill site is of a major concern because landfill might cause environmental impacts, such as bad odour in the neighbourhood, leachate leakage, and ground water contamination (Jones et al, 2006 as cited by Wakjira, 2007).

2.6.6 Anaerobic digestion of solid waste

Anaerobic digestion (A.D) which is a series of processes in which micro - organisms break down biodegradable material in the absence of oxygen is one of the few natural processes that have not been fully exploited until recent. The production of biogas by anaerobic digestion can be designed around several biodegradable feedstocks. The technology is not suitable for unsorted MSW. There are 3 main process stages in anaerobic digestion which involves a number of bacteria including acetic acid forming bacteria (acetogens) and methane forming bacteria (methanogens). These bacteria feed upon initial feedstock, which undergoes a number of different processes, converting it to intermediate molecules including sugars, hydrogen and acetic acid before finally being converted to biogas. When the oxygen source in an anaerobic system is derived from the organic material itself, then the intermediate end products are primarily alcohols, aldehydes and organic acids plus carbon dioxide. In the presence of specialized methanogens, the intermediates are converted to final end products of methane, carbon dioxide with trace levels of hydrogen sulphide. In an anaerobic digester, majority of the chemical energy contained within the starting material is released by methanogenic bacteria as methane. The carbon: nitrogen ratio of the organic waste material being fed into the tank determines the amount of gas that will be produced. A C/N ratio ranging from 20-30 is considered the optimum for anaerobic digestion. A higher C/N ratio results in a lower amount of gas being produced and vice versa.

3 RESEARCH APPROACH AND METHODOLOGY

3.1 Study Area

The Kumasi metropolis is the second largest city in Ghana. It is the capital of the Ashanti Region and commercial capital of Ghana. Kumasi is bounded by the Kwabre District to the north, Nkawie District to the west, Ejisu-Juaben District to the east and Bosomtwi-Atwima Kwanwom District to the south. Most of the people in Kumasi are traders, artisans, office worker, and factory workers.

The Kumasi metropolis is divided into ten (10) sub-metropolitan areas. Figure 3.1 depicts the sub-metropolitan areas of Kumasi. The areas dotted red as indicated in Figure 3.1 were the areas selected for the study. These are the Asokwa, Oforikrom and Nhyiaso sub-metropolitan areas.

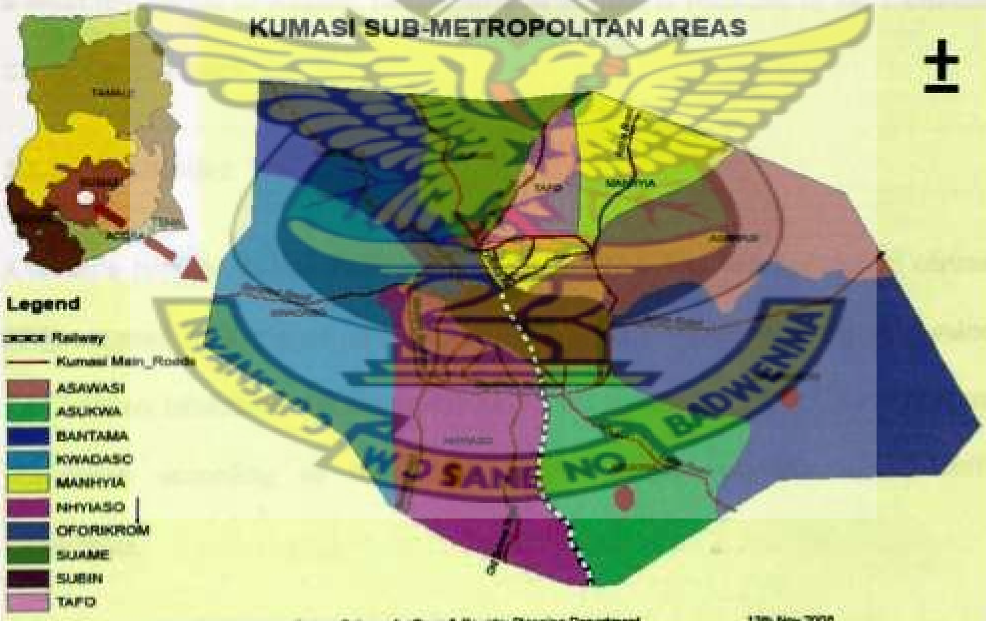

Figure 3.1: Map of Ghana indicating the study area, Kumasi with its sub-metros.

3.1.1 Location and climate

The Kumasi Metropolis is located at a vantage point that makes it accessible to every part of the country. It lies within latitudes $6^0 35^1$ and $6^0 40^1$, longitudes of $1^0 30^1$ and $1^0 35^1$. Its area is about 254 km^2 and approximately 10 km in radius. The metropolis has a concentric road system of structure and a centrally located commercial area from which radiates its major arterial roads, some of which serve as a trunk road linking it to other parts of the country. Its ecological zone is moist semi-deciduous forest and the climate of the area is wet, semi-equatorial with a mean annual rainfall of 1350mm (1967-2006). Minimum and maximum temperatures are 21^0C and 30^0C, respectively, with only little variability throughout the year. Mean minimum and maximum annual humidity are 59% and 94%, respectively. It is generally less humid in the dry season between November and February. Rainfall is slightly bimodal with a short dry period in August. Nearly 90% of rainfall is recorded in the 7 months of the two wet seasons.

3.1.2 Population

Kumasi's population has doubled twice since 1970. The last population census in 2000 counted 1.17 million inhabitants. KMA (2006) estimated a projected value of 1.61 million inhabitants for the year 2006 (5.4% annual growth). Currently Kumasi population according to the KMA projections is approximately 2.1million inhabitants.

3.1.3 Housing

Kumasi has been categorized into four housing units. These are tenement housing, indigenous housing, New Government housing and the high cost housing (Strategic sanitation plan-Kumasi, 1993 as cited by Kotoka, 2001). The necessity for the housing units is strictly for planning purposes. The respective characteristics of the four categories are presented in the table below.

Table 3. 1: Characteristics of categories of housing in Kumasi.

Parameter	Tenement	Indigenous	New government	High cost
Population (%)	22	60	8	10
Population density(per ha)	300-600 persons	80-250 persons	50persons	10-15person
Population density(per house)	4-10families/40-100persons	4-10 families/20-50persons	1-2 families	1.2 families
Description of house.	2-3 storey buildings with 20-30 rooms.	Single storey buildings with 5-10 rooms and interior compound.	Rows of detached single storey buildings in walled compounds with 2-3 rooms.	Detached single family building on large plots with 5-8 rooms and outhouse

Source: Strategic Sanitation Plan-Kumasi, 1993.

3.2 Sample size selection

The sample size selection depends on the error permitted in the data, the standard deviation (σ) of the data available and the confidence interval, but when the σ is unknown (as is also the case), n is large (say $n \geq 30$), the value of the σ can be approximated by the sample standard deviation. However due to cost constraint and inadequate logistics, a sample size of 90 households, 30 each for the three income groups, low, middle, high was selected.

3.3 Identification of households

The number of households selected for the study covered households from the three income groups; low, middle and high income. To identify these households for the study, the criteria used by the Waste Department of the Kumasi Metropolitan Assembly for the classification of income groups was adopted. These criteria are based on the resident's living standards; housing and other facilities in the households. The table below list all the criteria looked at.

Table 3. 2: Criteria to distinguish high income from low income communities.

High Income Communities	Low Income Communities
Ownership of House by Occupants	Do not own House themselves (tenants).
Household toilet within premises	No good toilet facilities
Decent livelihood	Indecent livelihood
Can afford portable water	No good water sources
High social status	Has little money and may beg
Have access to luxury and expensive things	Wear poor clothing
Keep surroundings very neat	Lives in a poor and dirty communities
Good community layout	Poor community layout
Good road and drains	Bad roads and drains if any
Very good buildings	Old and dilapidated crowded houses
Access to good education	Can generally afford only public school education if any
Low population density.	Over population.
Access to good solid waste collection methods.	Poor solid waste collection methods.
Access to good electricity supply.	Poor electricity supply.
Access to telephone.	Poor or no telephone service.

Source: Modified from Charles Abugre et al, 1998.

Note: A combination of these two could be classified as middle income.

3.4 Collection, sorting and sampling of solid waste.

The weight volume analysis method was adopted. This involved the measurement of the weight and volume of solid waste generated over a period. Each household was assigned a number and given seven plastic bags, one for each day. The purpose of the survey was explained during the distribution of the plastic bags, with the number of persons in the household noted. The waste generated was collected from the selected households every day at a fixed time for seven consecutive days to allow for variation in waste generation over the week.

Sorting procedures

The plastic bags collected were weighed and recorded against their allocated household numbers. Then, one after the other the bags content were poured into a standard bucket and the volume of each bag noted and recorded. The content of each bucket was then spread over a plastic sheet for manual sorting into the 9 different categories, and each component was weighed and recorded on data sheet. The 9 different categories involved are organic, paper/cardboard, plastic, faeces, glass, metals and cans, miscellaneous, wood and textile and clothes. Plate 3.1 depicts waste collection and the sorting.

Plate 3.1: Collection of waste from households and subsequently the sorting.

Sampling procedures

Within each zone, refuse was pooled together from each of the households to produce a huge waste composite sample. Subsamples, each weighing 5kg were taken from the composite samples and oven-heated at 105°C to constant weight for determination of moisture content. Clean polyethylene sheets were spread on the floor on which the contents of the sub samples were placed and manually separated to determine the proportions of the various waste components in the mixed waste. The procedure allowed for the determination of the amounts of combustible portions in the mixed sub-samples. All combustible materials were pulled out manually and the remaining materials were quantified as non-combustible materials. Combustible materials included the organic, plastic, paper, textile and wood. The different components were separately milled using an electrical miller.

3.5 Laboratory analyses

These comprised of the proximate analysis, the calorific value and the total nitrogen determination.

3.5.1 Proximate analyses

For proximate (moisture content, fixed solids, organic matter) analyses, one waste component was collected every other day after the sorting. Triplicate samples of the organic waste of which each weighed approximately 630g were brought to the Water Resource and Environmental sanitation Programme (KNUST) laboratory for analysis. For moisture content analyses, samples of organic waste was first weighed and put in an oven at 105° C for 24 hrs. It was kept in a desicator for about 30 minutes and then weighed and recorded. Ash content was determined after burning the dry solids(105°C for 24hours) in a furnace for 8 hrs at 550°C.The samples were again sent to a desicator for about 30minutes and weighed.

Plate 3.2: Waste being removed from the oven to be kept in a desicator.

3.5.2 Determination of calorific value

A known weight of 0.7 grams of the sample was taken and transferred into an empty crucible. The crucible with the sample was then positioned in the sitting of the bomb cover and a suitable piece of ignition wire was connected to the terminal, but touching the sample's surface. 15 mls of distilled water was added to the base of the bomb and assembled. It was then charged with oxygen to 25 bars and tested under water for leaks. *Note*: Dry the bomb if there are no leaks. The weight of 2400mls of water that was poured into the calorimeter vessel was noted. The calorimeter vessel was positioned in a water filled jacket to determine a sensibly constant temperature environment. The bomb was placed in the calorimeter vessel and the electrical lead was connected with the stirrer and the Beckmann thermometer. The stirrer gear was set in motion. The samples were then ignited in excess oxygen where the rise in temperature due to the combustion of the sample was noted and the calorific value of the HHW calculated.

$$W_f \times Q = (W_w + W_a) \times (\textit{rise in temperature})°\text{C} \times 4.2$$

Where W_f Kg is the weight of fuel,

QKJ/Kg is the calorific value.

W_w Kg is the weight of water in the bomb vessel.

W_a Kg is the water equivalent of the apparatus (0.482Kg).

Plate 3.3: Samples to be milled and weighed for calorific value determination.

Plate 3.4: The charged bomb to be fitted into the calorimeter vessel.

3.5.3 Determination of total nitrogen

The kjeldhal procedure was used for the percentage total nitrogen determination. It involves two steps, digestion, distillation and titration.

Digestion

Ten grams of milled organic was weighed into a 500ml kjeldhal flask moistened with distil water. Selenium powder and sodium sulphate was added as a catalyst and 30ml of concentrated sulphuric acid was also added and then digested for 2hours using the

Bunsen burner flame. The solution was then cooled and decanted into a 100ml volumetric flask and made up to the mark.

Distillation and Titration

An aliquot of 10ml of the digested sample was taken into a distillation unit and 20ml of 40% NaOH was taken and 10ml of 4% boric acid was added to it resulting in a pink colour, the distillate was then collected over NaOH solution and boric acid for about 5minutes.The presence of nitrogen gave a blue colour. The solution was the titrated with 0.1MHCL until the blue colour changed to pink signifying the end point.

Using the recorded titre value and the relation below the % of nitrogen was then calculated.

$$\%\,Total\ Nitrogen = {}^{14 \times (A - B) \times N \times 100}/_{1000 \times 1}$$

Where;

A is the volume of standard HCL used in the sample titration.

B is the volume of the standard solution used in the blank titration.

N is the normality of standard HCL.

4 RESULTS AND DISCUSSIONS

This section presents the results of the study and discusses the implications of the results in relation to the objectives of the study.

4.1 Field observations

In all, a total of 90 households from the three income groups were involved in the survey. There were some differences in the number of households sampled in the three income groups. Whiles some residents wholeheartedly welcomed the idea of the research work and were ever ready to cooperate, others on the other hand were reluctant to participate. In the execution of the work, a number of challenges were encountered at the various income levels and these are explained below.

4.1.1 Low income level

Some difficulties were encountered at the low income group level during the survey: Some of residents were of the view that it is a research aimed at increasing the amount to be paid at disposal sites hence did not want to participate. Some of the residents claimed they visit the dump site as late as 2:00 a.m and as such did not show interest in the exercise. Few of the residents also indicated that they were not comfortable with individuals having access to their waste content for fear of taboos such as witchcraft or for fear of being laughed at. Because of the absence of in-house toilet facilities at such homes at the low income level, faeces forms part of the waste. This made some of the residents to resist for fear that we might find faeces in their waste, which to them was a disgrace. On the whole the participation at the low income group level was appreciably better owing to the fact that to them it was a big relieve for them going to the dump site to pay for disposal. Only five residents objected during the dialoguing process.

4.1.2 Middle income level

At the middle income level, 30 households were visited. Most of the residents at the middle income group level bury their waste in their backyard garden. Below is a typical picture captured during the field work showing a dugout pit in which waste is buried.

Plate 4.1: A dugout pit where solid waste is dumped.

Five households at the middle income group level claimed they were so used to taking the waste to the dugout pit immediately after sweeping and might forget to keep it in the plastic bag provided for collection and therefore did not participate. About 3 of the residents at the middle income group level also argued from the fact that they have been disposing their waste at their work place and did not just agree to participate after several efforts in trying to explain to them what the exercise was about. About 2 of the residents objected to participate because they claim to apply the organic part of the waste as manure to their flowers and did not just want to give out the waste. These and others were the reasons why the middle income group level could not cover a wide range of households as anticipated. On the whole 20 out of the 30 households cooperated at the middle income group level.

4.1.3 High income level

About 30 households were contacted at the high income group level out of which only 20 households agreed to participate in the exercise. Below were some of the reasons why the targeted number of households was not achieved. The tight security and wild dogs in the premises of some households were some of the reasons why the high income group could not cover larger number of households as anticipated. In some of the households visited, we had to call them on their cellular phone before we could get the plastic bag provided for the solid waste collection after the dialogue and the purpose of the study was explained to them. Security personnel were reluctant to allow anybody to their bosses, this can seen in the remark one of them made "*As for me my duty here as a security is to prevent people from getting into the house*". In about 6 of the households, the landlords were not the real occupants themselves and these households were occupied by care takers they had employed because they do not often stay in Kumasi, but once a while visit the place. Since among the criteria for high income group, ownership of house is a key criterion, there was no way such houses could have been included. Some of the houses had faulty door bells. This could have added some number to the household size but because of the non functionability of the door bells, we could not meet them for dialogue especially places without security personnel. Below is a picture depicting a wild giant dog in front of a household we intended to visit at a high income residential area which scared us from visiting the house.

Plate 4.2: A wild giant dog in front of a house.

4.2 Physical characteristics of solid waste

Some of the physical characteristics of solid waste considered are the per capita generation rate, moisture content, bulk density and waste composition.

4.2.1 Per capita generation rate.

Figure 4.1 shows the results of the generation rate in kg/capita/day for the three income groups.

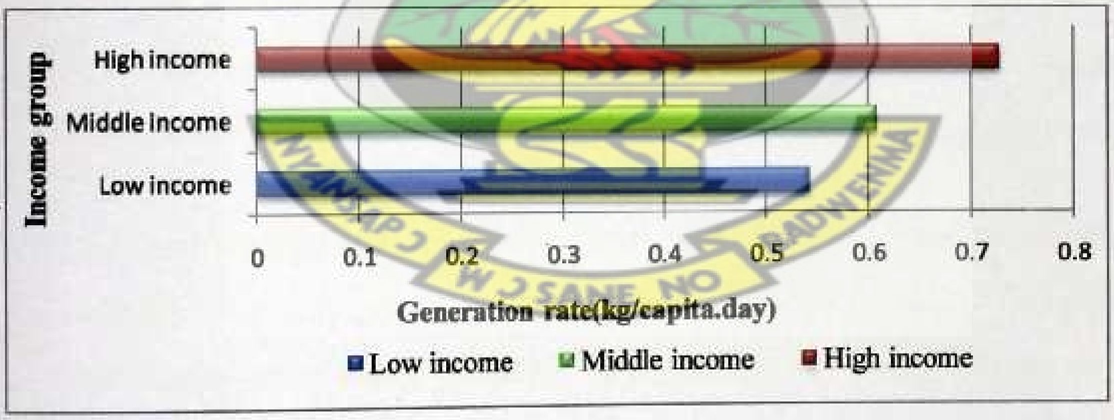

Figure 4.1: The per capita generation rate at the three income group levels.

The study analysis revealed significant variations in the per capita generation rates for the three income groups. This is in agreement with the common understanding that waste quantities generated are directly proportional to the household income levels (Diaz et al, 1993; Abu Qdais et al, 1997). The trend observed could be attributed to the differences in the purchasing power at the three income groups. The WHO expert committee report (1982) establishes generation rate of 0.2kg/capita/day to 3kg/capita/day for developing countries. The results obtained falls within the WHO expert committee report (1982). This could help in making informed decision as the values obtained are specific from the WHO varied range. Kotoka, 2001 established a generation rate of 0.94kg/capital/day for high income communities in Kumasi. The 0.728kg/capita/day obtained for the high income communities in this study is slightly lower. This largely may be due to the fact that residents lately spend much more time outside and as a result consumes less leaving little to be collected.

4.2.2 Waste composition and variations

The results of waste composition by household income levels are shown in Fig.4.2 below. The figure depicts the percentages of the 9 main fractions.

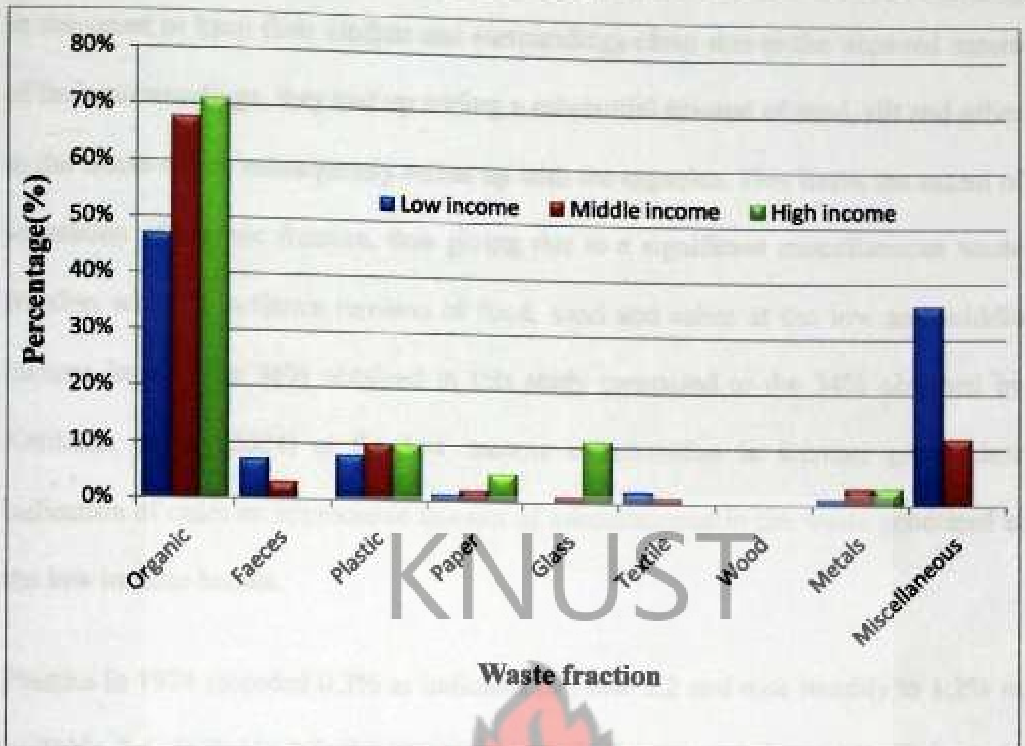

Figure 4.2: Average waste composition in the three income group levels.

The principal components are organic (45%, 69%, 71%), miscellaneous (36%, 12%, 0%), plastics (8%, 10%, 10%), for low, middle and high income groups respectively. Looking at the waste composition as shown in Figure 4.2, the organic waste dominates the bulk of HHW. The percentage of organic waste obtained at the high income level in the study confirms that obtained by Ketibuah et al, (2004).

The low income group recorded the least percentage of organic waste in comparison with the other income groups. This could be due to the dependence of livestock in such homes on the organic waste. The 36% of miscellaneous recorded at the low income could be due to the fact that the residents within the low income group make use of local clay stove and coal pots for cooking purposes and as a result generate some amount of ashes.

In the quest to keep their kitchen and surroundings clean due to the unpaved nature of their surroundings, they end up adding a substantial amount of sand, silt and ashes to the waste which subsequently mixes up with the organics. This limits the extent of separation of organic fraction, thus giving rise to a significant miscellaneous waste fraction which constitutes remains of food, sand and ashes at the low and middle income levels. The 36% obtained in this study compared to the 34% obtained by Ketibuah et al, (2004) at the low income communities in Kumasi gives clear indication of quiet an appreciable amount of miscellaneous in the waste generated at the low income homes.

Plastics in 1974 recorded 0.3% as indicated in Table 2.2 and rose steadily to 1.2% as in Table 2.4. In Table 2.5, the percentage of plastics increased to 6.3%. This study revealed an additional increase in plastic generation to about 10% hence indicating a growing trend in plastics generation.

Glasses generation were very similar for both the low and middle income levels with a significant increase of approximately 10% at the high income level. This could be attributed to the fact that residents within the high income group have greater purchasing power to buy a greater variety of products packaged in glass containers.

It is also worth mentioning the inclusion of faeces in the waste. This could be due to the absence of in- house toilet facility at such places, which make children and aged adults who are unable to visit the public toilet provided in the community to defecate into plastic bags and added to the refuse generated at the home. The 3% faeces at middle income level is mainly pampers and this is coming from babies from such homes. The inclusion of faeces in the waste poses health hazards for those directly involved in the manual sorting. Plates 4.3: A, B below are pictures of how faeces get into our homely generated waste. These are typical situations captured during the field work especially at the low income level.

A

B

Plate 4.3 : A, B: Faeces being packaged in plastic bags.

4.2.3 Bulk density of solid waste

The densities vary from 250 to 600 Kg/m^3 for low income countries like Ghana. The WHO expert report (1982) quotes density as (100-500) Kg/m^3 and typical values obtained from high income community-KNUST ranged between 366.7Kg/m^3 and 392Kg/m^3 and that by Kotoka, (2001) was 235 Kg/m^3. The densities obtained in the study of the three income groups (low, middle and high) in Kumasi are **381, 237, 306Kg/m^3** respectively. The density for the high income communities in Kumasi in this study is comparable to that obtained by Kotoka,(2001) except that the value obtained in this study is on the high side which probably could be due to the higher amount of wet waste (71%) and glasses(about 12%) in the waste as at the time of the sampling.

4.2.4 Moisture content

Moisture content is one of the major physical characteristics of solid waste that could give room for the consideration of certain solid waste treatment options. The moisture content of the waste for the three income groups according to this study increased from the low income group through the middle to the high income group.

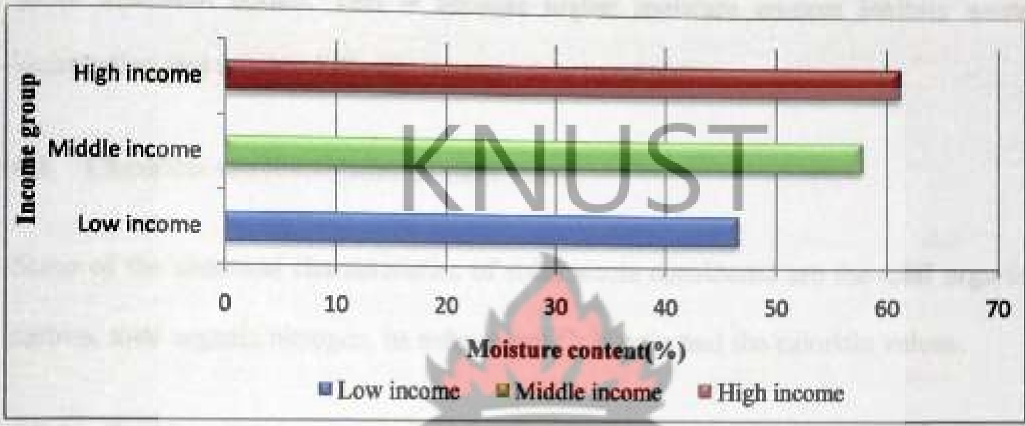

Figure 4.3: Moisture content of the waste in the three income groups.

The trend observed could be attributed to the fact that significant proportion of the waste from the low, middle income groups constituted the miscellaneous waste fraction. The low income group had 36% of the waste to be the miscellaneous with a corresponding lower organic waste fraction (45%) whiles the middle income on the other hand had 12% of the miscellaneous with a corresponding higher organic waste fraction (69%). But since the organic waste fraction contributes greatly to the moisture content of the waste, this in a blend with the miscellaneous waste fraction accounted for the trend in Figure 4.3. The miscellaneous is the inseparable mixture of food, sand, ash, and silt in the waste. The trend observed agrees with that of

Cointreau's estimation of moisture content for developing countries, 40-80% by weight.

The higher the level of moisture, the longer it takes for the material to burn. It will also affect the useful calorific value obtainable from the waste. The moisture content indicates that, the waste in Kumasi is wet and might not favour waste to energy as a waste treatment option. This is because higher moisture content inhibits waste incineration and creates difficulty during waste handling.

4.3 Chemical characteristics of solid waste

Some of the chemical characteristics of solid waste considered are the total organic carbon, total organic nitrogen, its subsequent C: N ratio and the calorific values.

4.3.1 Carbon : Nitrogen ratio

The composting potential apart from the fraction of the organic wastes depends on the chemical characteristics such as the concentration of organic carbon (C) and total nitrogen (N) and the consequent Carbon/Nitrogen (C/N) ratio. In the event when the C/N ratio of the compost exceeds 30:1, the organisms become deficient in nitrogen and the process of decomposition is slowed (Mamo et al, 2002).

In the data on the carbon : nitrogen ratios of waste as indicated in Table 4.1, it was shown that the C/N ratio for low, middle, high income groups were 26.6:1, 24.7:1 and 25.0:1 respectively.

Table 4. 1: Carbon: Nitrogen ratios of waste for the three income groups.

Component	Low income group	Middle income group	High income group
Moisture content (%)	45.587 ± 3.064	57.542 ± 6.663	60.672 ± 2.393
Total solids (TS, %)	54.413 ± 3.064	42.458 ± 6.663	39.328 ± 2.393
Fixed solids (%, TS)	40.546 ± 5.849	31.978 ± 3.856	20.144 ± 3.982
Organic matter(%,TS)	59.454 ± 5.849	68.022 ± 3.856	79.856 ± 3.982
Organic Carbon (%)	33.294 ± 3.275	38.092 ± 2.159	44.719 ± 2.229
Total nitrogen (%)	1.25 ± 0.100	1.54 ± 0.070	1.79 ± 0.070
C/N ratio	26.6	24.7	25.0

Even though differences existed between the C/N ratios obtained for the three income groups, that for the middle and high income groups were very similar (24.7, 25.0), with the one for the low income group slightly higher (26.6:1) than those obtained for the other two income groups. In comparison to the ideal C/N ratio, it was observed that all the three C/N ratios obtained were within the ideal C/N ratio of 25:1 to 30:1 a range that is considered favourable for composting without any further balancing of the carbon to nitrogen ratio before the execution of the composting itself.

The C/N ratio could also be used in determining the potential viability of anaerobic digestion of the organic waste. The relationship between the amount of carbon and nitrogen present in organic fraction is expressed in terms of the C/N ratio. A C/N ratio ranging from 20:1-30:1 is considered optimum for anaerobic digestion. If the C/N ratio is very high, then nitrogen will be consumed rapidly by the methane forming bacteria (methanogens) before meeting their protein requirement and will no longer react on the left over carbon content of the material. As a result, gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of Ammonia (NH4). Ammonia will increase the pH value of the content in the digester. A pH higher than 8.5, ammonia will start showing toxic effect on methanogen population. This will then subsequently give rise to a high amount of gas been produced. The C/N ratios obtained in relation to what is considered the optimum for anaerobic digestion makes this option of handling organic waste fraction a viable one. Materials with high C/N ratio could be mixed with those of low C/N ratio to bring the average ratio of the composite sample to a desirable level.

4.3.2 Calorific value

As shown in Table 4.2, all the analyzed wastes in three income groups had high calorific values (high heat energy contents).

Table4. 2: Calorific value of waste from urban waste zones in Kumasi, Ghana.

	Calorific values		
Component	Low income group	Middle income group	High income group
Organic (kJ/kg)	12680.8 ± 1129.78	14986.4± 1129.78	16715.6 ± 1129.78
Paper (kJ/kg)	14410 ± 1129.78	14986.4 ± 1129.78	14986 ± 1129.78
Plastic (kJ/kg)	37466 ± 2259.54	40348± 1129.78	40348 ± 1129.78
Cloth(kJ/kg)	13833 ± 0.00	17292 ± 0.00	-
Simulate(kJ/kg)	16139 ± 1129.78	23056± 1956.80	27667. 2 ± 2989.11

There were some differences in the gross calorific values per mass of waste from the three income groups and also among the various sample types both within and between the three income groups investigated. This therefore suggests a close association between gross calorific values and material composition in waste stream. The calorific values decreased from the very high income group through the middle to the low income group. This trend could be attributable to the fact that solid waste from a high income group is rich in compounds containing high energy bonds than those of middle and low income groups.

As indicated in Table 4.2, plastic had the highest calorific value in all the three income groups. This was followed by the simulate sample which in this case referred to the natural waste as it was as collected using the percentages for the various fractions obtained during the characterization stage. It is also interesting to note that the organic waste had reasonably good calorific values in the three income groups. The values involved are 16715.6 kJ/kg, 14986.4kJ/kg and 12680.8 kJ/kg respectively for the high, middle and low income groups. But because the organic waste contributes greatly to the higher moisture content in the waste, part of the calorific values obtained for the organic waste will have to be used as an additional fuel in order offset the energy requirement to evaporate the moisture in the waste, which to some extent will leave a net less calorific value. However the minimum calorific value of a sample for power generation is 6280kJ/kg.

4.4 Material balances and quantities of solid waste

The only way to determine the generation and movement of solid wastes with any degree of reliability is to perform a detailed materials balance analysis for each generation source, such as an individual home or commercial or industrial activity. There could be several treatment and disposal options for solid waste, but for a waste treatment option to achieve its long term objective of sustainability there is the need to perform the material balances of the various waste streams that is generated in order to ascertain the availability of inflow of materials for whatever treatment option under consideration. The material balances this study performed went beyond the single waste stream collection system to look at it in terms of the individual components that makes up the solid waste (see Figures 4.4, 4.5, 4.6, 4.7). The material balances for the various waste streams could contribute immensely to the diversion of waste from landfill and guarantee that the appropriate waste treatment and disposal options are adopted in the handling of the various waste streams. The material balances for the three income groups using the estimated population as indicated in Table 4.3 and the percentages obtained in the characterization of the waste gives the quantities of the various fractions readily available.

Table4. 3: Estimation of population for the three socio-economic groups.

Income group	Number of properties	Number of persons/properties	Total number of population	% of total properties
Low	23421	30	702630	43.5
Middle	27238	50	1361900	50.6
High	3164	8	25312	5.9
Total	53823		2089842	100

Source: Strategic Sanitation Plan-Kumasi, 1995 as cited by Kotoka, 2001.

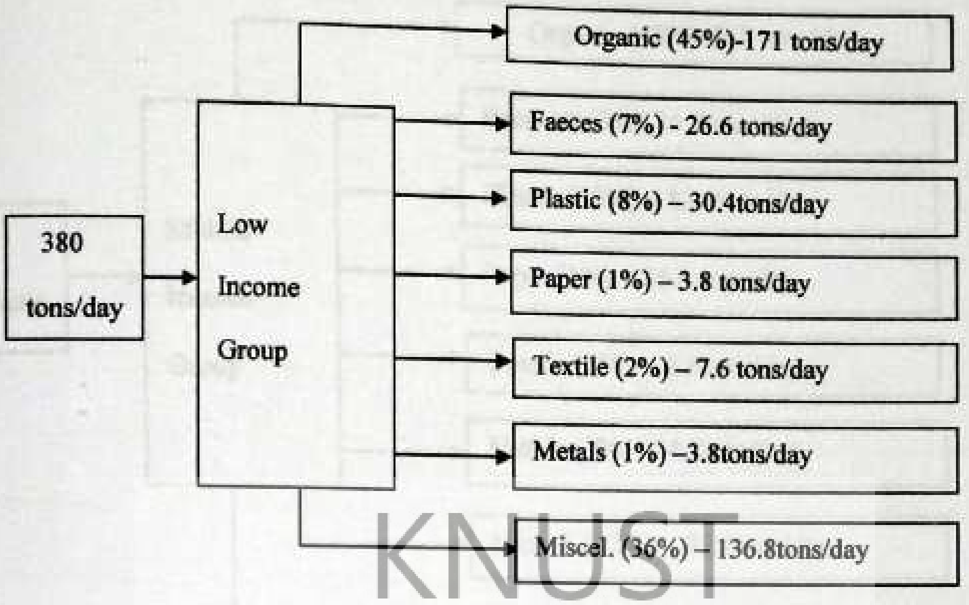

Figure 4.4: Materials flow balance in waste stream for the low income group.

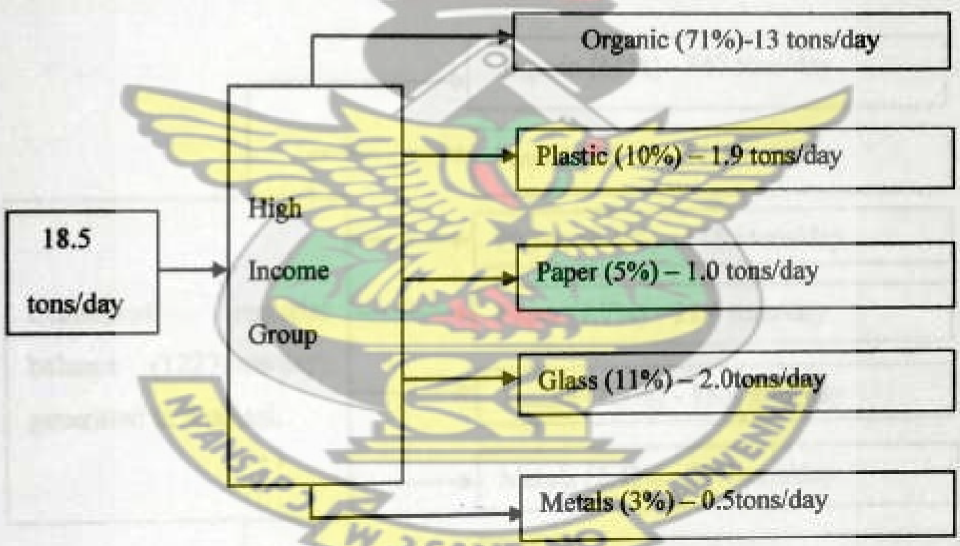

Figure 4.5: Materials flow balance in waste stream for the high income group.

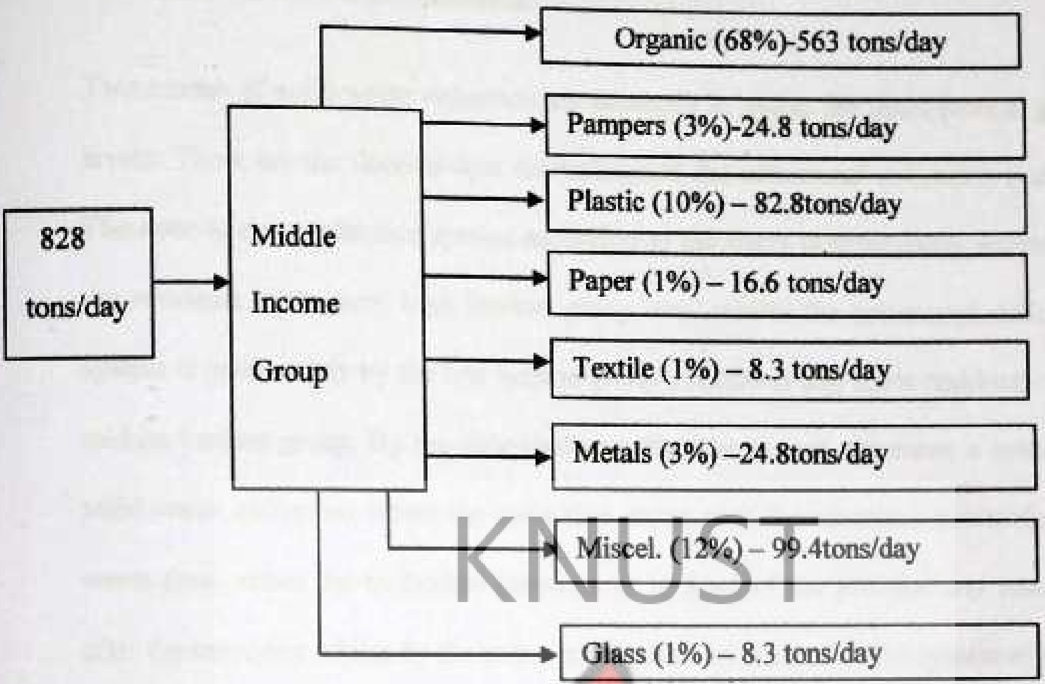

Figure 4.6: Materials flow balance in waste stream for the middle income group.

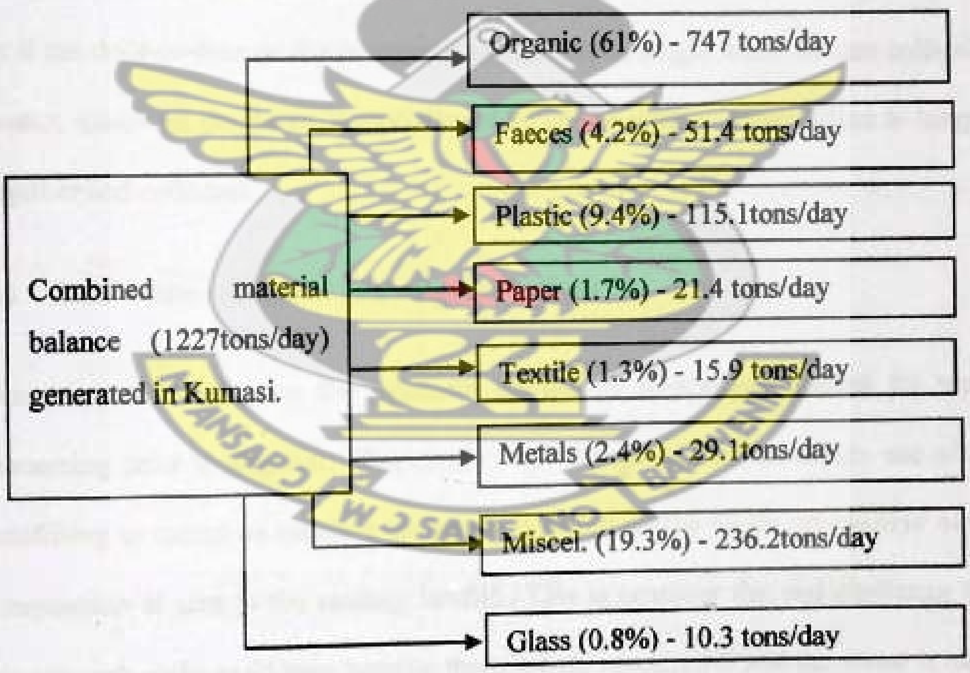

Figure 4.7: Combined material balance in waste stream for the various fractions.

4.5 Mode of solid waste collection

Two modes of solid waste collection are currently in use at the three income group levels. These are the door-to-door collection and the communal collection systems. The door-to-door collection system according to the study is extensively adopted by the residents at the very high income group level whiles the communal collection system is used mostly by the low income group's residents and some residents of the middle income group. By the door-to-door collection system, we mean a system of solid waste collection where the collection crews pick the container containing the waste from either the individual premises or in front of the premise and returns it after the emptying whiles by the communal system we mean also the system of waste collection where the households discharge their waste at a pre-fixed communal location where storage facilities are available. Currently the waste collection system, be it the door-to-door or the communal is based on a single waste stream collection system where all the waste irrespective of its heterogeneous composition is lumped together and collected.

4.6 Solid waste treatment and disposal options

The composition dictates the treatment options or technology needed for waste processing prior to disposal. The single waste stream collection makes use of the landfilling as means of handling the waste in which all the waste irrespective of the composition is sent to the sanitary landfill. This is however the real challenge that this research seeks to address because there is only one landfill and the waste is made up several different materials that do not necessarily share the same disposal characteristics.

4.6.1 Composting or anaerobic digestion option

According to the material balances for the various waste streams, the amount of organic waste generated is 747 tonnes/day (see Figure 4.7). The composting potential aside the high percentage by weight of organic waste is however supported by the favourable C/N ratios as well as the moisture contents obtained in the study (see Table 4.1). The C/N ratios for the three income groups are within the optimum range for composting which indicates that the organic waste does need C/N ratio balancing before the execution of the composting process. Similarly the C/N ratio is a determining factor for biogas production through anaerobic digestion. The C/N ratios obtained in the study were also within the optimum range for biogas production. Hence the appropriate solid waste treatment option for the handling of the organic waste is either composting or anaerobic digestion. If all the organic waste from the three income groups could be source separated, then an estimated 747 tonnes/day (see Figure 4.7) representing 61% of the waste could be diverted for either composting or anaerobic digestion hence reducing the overall amount of waste going to the landfill by that high percentage.

4.6.2 Incineration option

The calorific values obtained ranged from 12 - 41 MJ/kg which indicates possible option for incineration. Composting or anaerobic digestion of the organic waste is considered because the net calorific value after some has been used to dry the organic material is small in relation to the other combustible samples calorific values obtained. However due to the complexity of the process, MSW incineration could only be applied on a large scale and for only sorted waste. The minimum preferred capacity is at least 500 tonnes/day of waste to offset the high capital cost of incineration. The daily volume of the combustible waste readily available for incineration with the organic waste inclusive is 899.3 tonnes (representing 73.3% of the daily generated waste). This meets the least preferred capacity of 500 tonnes of daily waste to offset the high investment cost. Incineration of the organic waste would not be a suitable option due to the extreme moisture content. Hence exempting the organics from the combustible materials will leave only 152.3tonnes (12.4%), a value far less than the least preferred capacity of 500 tonnes a day. The burning of plastics is associated with air pollution due to additives such as heavy metals for colouring. Also the burning of plastic produces dioxins; unless efficient and effective mechanisms are put in place to deal with the pollution, incineration could be detrimental to human health.

4.6.3 Reuse and recycling

The option for recycling could be considered if the fraction can be sorted at source and kept clean. On the average plastics constitute about 10% by weight of household waste, its presence in household waste is significant due to its bulky volume. Taking this fraction to the landfill could shorten the lifespan of the landfill. The plastics could however be used to make sturdy products such as chairs, buckets and products which could replace hardwood products. The paper/cardboard fraction if collected dry and clean could also be used for manufacturing toilet-roll and egg crates. The plastics, paper, glass and the metals and cans are the waste fractions that can be reused or recycled. In all, a total of 15.6% of the waste generated could be reused/recycled.

4.6.4 Landfilling

The miscellaneous is the waste streams whose ultimate destination ends up at the landfill site. The volume of this fraction that resultantly ends up at the landfill is 236.2 tonnes representing 19.3% of the daily HHW.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

I. The study showed a trend that correlates higher income to higher generation rates. The largest proportion of HHW in Kumasi consists of easily degradable components termed organic waste and the materials typically found in the waste streams are the organic, paper/cardboards, plastics, glass, metals/cans, textile, miscellaneous and faeces. The solid waste in the municipality is wet.

II. The C/N ratios obtained were satisfactory in relation to what is considered the optimum for composting and anaerobic digestion of the organic waste. In comparison to the minimum amount of energy (kJ/kg) for a waste burn without auxiliary fuel, the study envisaged a rather higher energy (kJ/kg) values.

III. The physical and chemical characteristics of solid waste in the municipality by nature are heterogeneous and may not be handled easily by disposal technologies alone but also with treatment technologies.

IV. The study's identification of composting and anaerobic digestion as the appropriate treatment option for the organic waste and the potential for generating energy using the waste indicated that greater fraction of the waste could be diverted from going to the sanitary landfill site.

5.2 Recommendations

Based on the research findings and relevant conclusions the following recommendations have been made.

I. The segregation of solid waste at source is highly recommended so that clean source of raw materials could be obtained for the various waste treatment and disposal options.

II. The municipality can reduce the waste that goes to the sanitary landfill site through: composting/anaerobic digestion, reuse/recycling and incineration.

III. Further research should be conducted into other municipal solid waste streams, where the other refers to institutional, industrial etc.

IV. The law that makes provision for toilet facility in a house before issuing building permit should be enforced. This is to avert the inclusion of faeces in the waste.

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Appendices

Appendix: A

Table A. 1: Characteristics of solid waste generated from the low income group.

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	6	2.469	0.007	352.714	0.412
2	6	3.659	0.014	261.357	0.610
3	6	0.825	0.003	275.000	0.138
4	25	5.161	0.014	368.643	0.206
5	15	4.979	0.01	497.900	0.332
6	8	4.726	0.014	337.571	0.591
7	6	4.195	0.015	279.667	0.699
8	12	2.67	0.01	267.000	0.223
9	9	3.983	0.008	497.875	0.443
10	7	3.419	0.009	379.889	0.488
11	7	1.18	0.003	393.333	0.169
12	8	1.858	0.004	464.500	0.232
13	8	7.648	0.018	424.889	0.956
14	5	3.212	0.012	267.667	0.642
15	5	3.092	0.008	386.500	0.618
16	13	6.613	0.012	551.083	0.509
17	11	4.291	0.012	357.583	0.390
18	5	3.142	0.009	349.111	0.628
19	7	6.271	0.011	570.091	0.896
20	12	5.024	0.013	386.462	0.419
21	8	4.246	0.015	283.067	0.531
22	6	0	0	0.000	0.000
23	7	1.47	0.004	367.500	0.210
24	9	7.472	0.014	533.714	0.830
25	13	4.841	0.013	372.385	0.372
26	15	5.087	0.005	1017.400	0.339
27	15	4.805	0.014	343.214	0.320
28	10	7.39	0.018	410.556	0.739
29	6	3.666	0.009	407.333	0.611
30	7	1.655	0.007	236.429	0.236
		Average		**388.014**	**0.460**

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	6	1.143	0.005	228.600	0.191
2	6	6.375	0.017	375.000	1.063
3	6	2.974	0.008	371.750	0.496
4	25	3.055	0.011	277.727	0.122
5	15	9.386	0.018	521.444	0.626
6	8	5.692	0.015	379.467	0.712
7	6	8.796	0.01	879.600	1.466
8	12	2.361	0.011	214.636	0.197
9	9	5.492	0.014	392.286	0.610
10	7	6.364	0.017	374.353	0.909
11	7	4.579	0.015	305.267	0.654
12	8	7.9553	0.017	467.959	0.994
13	8	8.086	0.015	539.067	1.011
14	5	2.878	0.012	239.833	0.576
15	5	4.297	0.008	537.125	0.859
16	13	6.864	0.017	403.765	0.528
17	11	8.796	0.018	488.667	0.800
18	5	0.929	0.005	185.800	0.186
19	7	4.107	0.009	456.333	0.587
20	12	5.793	0.017	340.765	0.483
21	8	3.331	0.015	222.067	0.416
22	6	3.609	0.01	360.900	0.602
23	7	5.681	0.01	568.100	0.812
24	9	5.328	0.01	532.800	0.592
25	13	6.856	0.013	527.385	0.527
26	15	2.032	0.007	290.286	0.135
27	15	2.839	0.01	283.900	0.189
28	10	11.497	0.02	574.850	1.150
29	6	2.483	0.008	310.375	0.414
30	7	5.263	0.017	309.588	0.752
		Average		398.656	0.622

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	6	1.771	0.006	295.167	0.295
2	6	5.265	0.015	351.000	0.878
3	6	9.415	0.015	627.667	1.569
4	25	4.991	0.016	311.938	0.200
5	15	12.865	0.026	494.808	0.858
6	8	2.567	0.011	233.364	0.321
7	6	1.177	0.005	235.400	0.196
8	12	5.263	0.016	328.938	0.439
9	9	7.577	0.016	473.563	0.842
10	7	4.542	0.012	378.500	0.649
11	7	5.592	0.017	328.941	0.799
12	8	7.427	0.016	464.188	0.928
13	8	3.628	0.016	226.750	0.454
14	5	1.963	0.004	490.750	0.393
15	5	3.481	0.005	696.200	0.696
16	13	5.351	0.012	445.917	0.412
17	11	4.938	0.016	308.625	0.449
18	5	4.069	0.007	581.286	0.814
19	7	4.573	0.009	508.111	0.653
20	12	7.224	0.016	451.500	0.602
21	8	3.085	0.019	162.368	0.386
22	6	5.137	0.012	428.083	0.856
23	7	5.775	0.013	444.231	0.825
24	9	3.337	0.012	278.083	0.371
25	13	4.853	0.013	373.308	0.373
26	15	2.216	0.007	316.571	0.148
27	15	3.909	0.011	355.364	0.261
28	10	8.431	0.017	495.941	0.843
29	6	4.976	0.012	414.667	0.829
30	7	4.442	0.016	277.625	0.635
		Average		392.628	0.599

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	6	4.956	0.007	708.000	0.826
2	6	5.342	0.019	281.158	0.890
3	6	3.007	0.009	334.111	0.501
4	25	2.884	0.006	480.667	0.115
5	15	15.874	0.016	992.125	1.058
6	8	3.335	0.016	208.438	0.417
7	6	3.458	0.013	266.000	0.576
8	12	6.346	0.016	396.625	0.529
9	9	4.067	0.008	508.375	0.452
10	7	1.642	0.015	109.467	0.235
11	7	0.213	0.002	106.500	0.030
12	8	7.077	0.016	442.313	0.885
13	8	5.421	0.015	361.400	0.678
14	5	1.428	0.005	285.600	0.286
15	5	3.38	0.007	482.857	0.676
16	13	4.741	0.015	316.067	0.365
17	11	5.049	0.015	336.600	0.459
18	5	3.778	0.008	472.250	0.756
19	7	6.253	0.017	367.824	0.893
20	12	9.892	0.019	520.632	0.824
21	8	7.134	0.018	396.333	0.892
22	6	0.315	0.002	157.500	0.053
23	7	0.564	0.003	188.000	0.081
24	9	3.055	0.007	436.429	0.339
25	13	5.674	0.015	378.267	0.436
26	15	7.466	0.017	439.176	0.498
27	15	4.358	0.015	290.533	0.291
28	10	8.86	0.019	466.316	0.886
29	6	2.452	0.006	408.667	0.409
30	7	6.051	0.019	318.474	0.864
		Average		381.890	0.540

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	6	0.201	0.001	201.000	0.034
2	6	5.934	0.016	370.875	0.989
3	6	0.969	0.003	323.000	0.162
4	25	3.277	0.01	327.700	0.131
5	15	13.725	0.019	722.368	0.915
6	8	1.703	0.009	189.222	0.213
7	6	3.183	0.009	353.667	0.531
8	12	4.472	0.015	298.133	0.373
9	9	6.918	0.015	461.200	0.769
10	7	10.06	0.016	628.750	1.437
11	7	4.475	0.01	447.500	0.639
12	8	6.553	0.015	436.867	0.819
13	8	5.982	0.013	460.154	0.748
14	5	2.281	0.009	253.444	0.456
15	5	3.39	0.01	339.000	0.678
16	13	3.508	0.012	292.333	0.270
17	11	7.992	0.015	532.800	0.727
18	5	2.991	0.012	249.250	0.598
19	7	5.896	0.016	368.500	0.842
20	12	14.375	0.02	718.750	1.198
21	8	0	0	0.000	0.000
22	6	3.481	0.008	435.125	0.580
23	7	6.72	0.008	840.000	0.960
24	9	3.187	0.007	455.286	0.354
25	13	1.842	0.007	263.143	0.142
26	15	0.101	0.001	101.000	0.007
27	15	7.004	0.015	466.933	0.467
28	10	11.964	0.022	543.818	1.196
29	6	4.823	0.013	371.000	0.804
30	7	3.918	0.016	244.875	0.560
		Average		389.856	0.587

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	6	1.522	0.003	507.333	0.254
2	6	3.977	0.011	361.545	0.663
3	6	0	0	0.000	0.000
4	25	7.992	0.019	420.632	0.320
5	15	0	0	0.000	0.000
6	8	3.609	0.008	451.125	0.451
7	6	2.1531	0.013	165.623	0.359
8	12	3.492	0.011	317.455	0.291
9	9	0.283	0.017	16.647	0.031
10	7	12.716	0.02	635.800	1.817
11	7	0.65	0.002	325.000	0.093
12	8	0.205	0.001	205.000	0.026
13	8	8.336	0.017	490.353	1.042
14	5	1.43	0.003	476.667	0.286
15	5	0.953	0.003	317.667	0.191
16	13	1.879	0.004	469.750	0.145
17	11	5.792	0.015	386.133	0.527
18	5	2.657	0.005	531.400	0.531
19	7	1.015	0.013	78.077	0.145
20	12	5.216	0.02	260.800	0.435
21	8	0.487	0.016	30.438	0.061
22	6	6.229	0.013	479.154	1.038
23	7	4.845	0.013	372.692	0.692
24	9	2.381	0.007	340.143	0.265
25	13	4.867	0.012	405.583	0.374
26	15	6.936	0.017	408.000	0.462
27	15	6.983	0.013	537.154	0.466
28	10	5.567	0.016	347.938	0.557
29	6	5.229	0.014	373.500	0.872
30	7	8.365	0.018	464.722	1.195
		Average		339.211	0.453

Appendix: B

Table A. 2: Characteristics of solid waste generated from the middle income group.

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid Waste(Kg/m^3)	Generation rate(Kg/capita/day)
1	3	2.019	0.005	403.800	0.673
2	4	4.820	0.015	321.333	1.205
3	5	0.382	0.001	382.000	0.076
4	3	7.133	0.017	419.588	2.378
5	3	5.433	0.016	339.563	1.811
6	4	3.183	0.008	397.875	0.796
7	5	0.235	0.002	117.500	0.047
8	5	0.224	0.001	224.000	0.045
9	2	0.000	0.000	0.000	0.000
10	4	2.012	0.009	223.556	0.503
11	4	9.019	0.027	334.037	2.255
12	1	0.000	0.000	0.000	0.000
13	4	7.590	0.018	421.667	1.898
14	3	6.787	0.016	424.188	2.262
15	4	1.925	0.017	113.235	0.481
16	3	0.000	0.000	0.000	0.000
17	4	7.339	0.018	407.722	1.835
18	3	1.550	0.004	387.500	0.517
19	4	1.725	0.005	345.000	0.431
20	3	1.281	0.006	213.500	0.427
			Average	273.803	0.882

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	3	1.974	0.010	197.400	0.658
2	4	3.490	0.013	268.462	0.873
3	5	0.200	0.001	200.000	0.040
4	3	2.444	0.012	203.667	0.815
5	3	3.614	0.007	516.286	1.205
6	4	1.971	0.005	394.200	0.493
7	5	0.408	0.007	58.286	0.082
8	5	3.205	0.008	400.625	0.641
9	2	0.549	0.009	61.000	0.275
10	4	0.883	0.003	294.333	0.221
11	4	1.533	0.010	153.300	0.383
12	1	0.000	0.000	0.000	0.000
13	4	2.884	0.010	288.400	0.721
14	3	0.387	0.002	193.500	0.129
15	4	0.794	0.003	264.667	0.199
16	3	1.891	0.007	270.143	0.630
17	4	0.000	0.000	0.000	0.000
18	3	0.713	0.007	101.857	0.238
19	4	1.290	0.008	161.250	0.323
20	3	0.457	0.002	228.500	0.152
			Average	212.794	0.404

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	3	1.692	0.004	423.000	0.564
2	4	1.366	0.004	341.500	0.342
3	5	0.706	0.003	235.333	0.141
4	3	5.563	0.019	292.789	1.854
5	3	7.257	0.014	518.357	2.419
6	4	5.098	0.014	364.143	1.275
7	5	1.109	0.010	110.900	0.222
8	5	1.748	0.007	249.714	0.350
9	2	0.000	0.000	0.000	0.000
10	4	1.395	0.008	174.375	0.349
11	4	4.269	0.011	388.091	1.067
12	1	0.000	0.000	0.000	0.000
13	4	6.414	0.015	427.600	1.604
14	3	3.236	0.013	248.923	1.079
15	4	5.661	0.011	514.636	1.415
16	3	2.842	0.011	258.364	0.947
17	4	4.503	0.006	750.500	1.126
18	3	1.185	0.004	296.250	0.395
19	4	4.563	0.017	268.412	1.141
20	3	1.269	0.008	158.625	0.423
			Average	301.076	0.836

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	3	2.091	0.007	298.714	0.697
2	4	1.488	0.010	148.800	0.372
3	5	1.279	0.005	255.800	0.256
4	3	2.908	0.013	223.692	0.969
5	3	3.795	0.018	210.833	1.265
6	4	2.108	0.009	234.222	0.527
7	5	2.083	0.008	260.375	0.417
8	5	1.003	0.008	125.375	0.201
9	2	0.000	0.000	0.000	0.000
10	4	0.000	0.000	0.000	0.000
11	4	5.528	0.018	307.111	1.382
12	1	0.091	0.001	91.000	0.091
13	4	2.524	0.008	315.500	0.631
14	3	4.374	0.005	874.800	1.458
15	4	1.016	0.008	127.000	0.254
16	3	2.091	0.011	190.091	0.697
17	4	3.286	0.013	252.769	0.822
18	3	1.677	0.005	335.400	0.559
19	4	0.000	0.000	0.000	0.000
20	3	0.000	0.000	0.000	0.000
			Average	212.574	0.530

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	3	0.000	0.000	0.000	0.000
2	4	2.391	0.016	149.438	0.598
3	5	0.443	0.003	147.667	0.089
4	3	1.785	0.009	198.333	0.595
5	3	6.830	0.020	341.500	2.277
6	4	2.553	0.008	319.125	0.638
7	5	1.136	0.006	189.333	0.227
8	5	0.140	0.001	140.000	0.028
9	2	0.215	0.002	107.500	0.108
10	4	1.592	0.015	106.133	0.398
11	4	7.295	0.017	429.118	1.824
12	1	0.077	0.001	77.000	0.077
13	4	2.577	0.013	198.231	0.644
14	3	0.750	0.004	187.500	0.250
15	4	1.607	0.006	267.833	0.402
16	3	0.644	0.006	107.333	0.215
17	4	4.191	0.017	246.529	1.048
18	3	1.328	0.004	332.000	0.443
19	4	0.000	0.000	0.000	0.000
20	3	0.786	0.005	157.200	0.262
			Average	185.089	0.506

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	3	1.484	0.007	212.000	0.495
2	4	2.350	0.017	138.235	0.5875
3	5	2.064	0.003	688.000	0.4128
4	3	2.123	0.006	353.833	0.708
5	3	2.228	0.010	222.800	0.743
6	4	0.694	0.006	115.667	0.174
7	5	2.024	0.007	289.143	0.405
8	5	0.000	0.000	0.000	0.000
9	2	0.726	0.006	121.000	0.363
10	4	0.371	0.004	92.750	0.093
11	4	6.430	0.016	401.875	1.608
12	1	0.495	0.002	247.500	0.495
13	4	3.736	0.008	467.000	0.934
14	3	0.000	0.000	0.000	0.000
15	4	0.281	0.003	93.667	0.070
16	3	2.109	0.011	191.727	0.703
17	4	4.092	0.012	341.000	1.023
18	3	1.209	0.003	403.000	0.403
19	4	2.566	0.008	320.750	0.642
20	3	0.000	0.000	0.000	0.000
			Average	234.997	0.493

Appendix: C

Table A. 3: Characteristics of solid waste generated from the high income group.

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	1	1.529	0.004	382.250	1.529
2	4	1.439	0.004	359.750	0.360
3	3	1.733	0.013	133.308	0.578
4	4	3.135	0.006	522.500	0.784
5	4	1.491	0.004	372.750	0.373
6	1	1.424	0.007	203.429	1.424
7	2	4.437	0.009	493.000	2.219
8	4	2.618	0.005	523.600	0.655
9	5	4.496	0.013	345.846	0.899
10	3	2.872	0.01	287.200	0.957
11	5	3.344	0.016	209.000	0.669
12	5	1.521	0.008	190.125	0.304
13	5	3.516	0.012	293.000	0.703
14	3	2.847	0.002	1423.500	0.949
15	2	2.385	0.01	238.500	1.193
16	4	2.303	0.013	177.154	0.576
17	4	3.243	0.008	405.375	0.811
18	3	1.447	0.005	289.400	0.482
19	4	1.087	0.003	362.333	0.272
20	4	1.528	0.006	254.667	0.382
			Average	**373.334**	**0.806**

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	1	2.176	0.012	181.333	2.176
2	4	6.662	0.017	391.882	1.666
3	3	1.268	0.013	97.538	0.423
4	4	2.719	0.009	302.111	0.680
5	4	1.363	0.011	123.909	0.341
6	1	1.136	0.008	142.000	1.136
7	2	4.137	0.012	344.750	2.069
8	4	0.239	0.002	119.500	0.060
9	5	4.289	0.011	389.909	0.858
10	3	3.452	0.009	383.556	1.151
11	5	3.989	0.016	249.313	0.798
12	5	4.436	0.013	341.231	0.887
13	5	3.563	0.014	254.500	0.713
14	3	1.251	0.009	139.000	0.417
15	2	3.553	0.013	273.308	1.777
16	4	3.485	0.018	193.611	0.871
17	4	0.32	0.003	106.667	0.080
18	3	1.372	0.008	171.500	0.457
19	4	1.318	0.009	146.444	0.330
20	4	1.895	0.013	145.759	0.474
			Average	224.892	0.868

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	1	1.953	0.008	244.125	1.953
2	4	4.821	0.014	344.357	1.205
3	3	0.086	0.001	86.000	0.029
4	4	2.269	0.005	453.800	0.567
5	4	1.11	0.008	138.750	0.278
6	1	1.131	0.006	188.500	1.131
7	2	2.956	0.011	268.727	1.478
8	4	0.965	0.003	321.667	0.241
9	5	1.61	0.006	268.333	0.322
10	3	3.786	0.011	344.182	1.262
11	5	1.951	0.015	130.067	0.390
12	5	1.108	0.007	158.286	0.222
13	5	1.51	0.007	215.714	0.302
14	3	1.512	0.012	126.000	0.504
15	2	1.82	0.006	303.333	0.910
16	4	1.428	0.005	285.600	0.357
17	4	0.695	0.003	231.667	0.174
18	3	4.236	0.013	325.846	1.412
19	4	0.271	0.002	135.500	0.068
20	4	1.416	0.010	141.600	0.354
			Average	235.603	0.658

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	1	0.833	0.005	166.600	0.833
2	4	2.592	0.01	259.200	0.648
3	3	0.000	0.000	0.000	0.000
4	4	2.966	0.014	211.857	0.742
5	4	2.082	0.01	208.200	0.521
6	1	1.185	0.004	296.250	1.185
7	2	5.795	0.016	362.188	2.898
8	4	1.335	0.006	222.500	0.334
9	5	2.615	0.005	523.000	0.523
10	3	2.821	0.007	403.000	0.940
11	5	3.979	0.0018	2210.556	0.796
12	5	2.265	0.015	151.000	0.453
13	5	2.814	0.004	703.500	0.563
14	3	1.367	0.007	195.286	0.456
15	2	0.987	0.004	246.750	0.494
16	4	2.705	0.012	225.417	0.676
17	4	2.085	0.01	208.500	0.521
18	3	1.536	0.005	307.200	0.512
19	4	1.235	0.004	308.750	0.309
20	4	1.513	0.011	137.545	0.378
			Average	367.365	0.689

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste Kg/m^3	Generation rate(Kg/capita/day)
1	1	1.203	0.004	300.750	1.203
2	4	3.278	0.01	327.800	0.820
3	3	0.25	0.002	125.000	0.083
4	4	2.016	0.007	288.000	0.504
5	4	3.014	0.011	274.000	0.754
6	1	1.168	0.005	233.600	1.168
7	2	4.577	0.012	381.417	2.289
8	4	0.568	0.004	142.000	0.142
9	5	0.963	0.003	321.000	0.193
10	3	1.547	0.006	257.833	0.516
11	5	3.582	0.013	275.538	0.716
12	5	0.916	0.005	183.200	0.183
13	5	3.495	0.006	582.500	0.699
14	3	1.613	0.008	201.625	0.538
15	2	2.226	0.011	202.364	1.113
16	4	0.869	0.050	17.380	0.217
17	4	2.676	0.009	297.333	0.669
18	3	1.733	0.006	288.833	0.578
19	4	1.812	0.004	453.000	0.453
20	4	1.367	0.006	227.833	0.342
			Average	269.050	0.659

House No.	Family Size	Weight of Sample(Kg)	Volume(m^3)	Density of solid waste (Kg/m^3)	Generation rate(Kg/capita/day)
1	1	1.087	0.003	362.333	1.087
2	4	1.813	0.011	164.818	0.453
3	3	0.000	0.000	0.000	0.000
4	4	2.036	0.019	107.158	0.509
5	4	0.000	0.000	0.000	0.000
6	1	2.938	0.008	367.250	2.938
7	2	2.1531	0.013	165.623	1.077
8	4	2.003	0.011	182.091	0.501
9	5	0.000	0.017	0.000	0.000
10	3	3.104	0.02	155.200	1.035
11	5	0.000	0.002	0.000	0.000
12	5	0.000	0.001	0.000	0.000
13	5	5.196	0.017	305.647	1.039
14	3	1.199	0.003	399.667	0.400
15	2	0.000	0.003	0.000	0.000
16	4	1.525	0.004	381.250	0.381
17	4	2.867	0.015	191.133	0.717
18	3	2.152	0.005	430.400	0.717
19	4	0.915	0.013	70.385	0.229
20	4	4.629	0.02	231.450	1.157
			Average	367.365	0.689

Appendix: D

TableA. 4: Moisture content of waste from the three income groups.

	Wet weight(Kg)	Drying wet(Kg)	Amount of water(Kg)	Moisture content (%)
Low income	5.000	2.560	2.440	48.80
	5.000	2.770	2.230	44.60
	Average			46.70
Middle income	5.000	2.460	2.540	50.80
	5.000	1.760	3.240	64.80
	Average			57.80
High income	5.000	2.144	2.856	57.12
	5.000	1.736	3.264	65.28
	Average			61.2

Appendix: E

Table A. 5: Proximate analysis of waste for the three income groups.

Low	Sampling	Sample No.	Wet Weight	Dry Weight	Ash Weight	Amount of Water	Moisture content (%)	Total Solid	Fixed Solid	Volatile Solids
	First Sampling	1	0.632	0.316	0.145	0.316	52.800	50.000	45.886	54.430
		2	0.632	0.319	0.179	0.313	48.840	50.475	56.113	44.206
		3	0.632	0.366	0.129	0.266	46.800	57.911	35.246	65.120
	Second Sampling	1	0.632	0.335	0.156	0.297	46.990	53.006	46.567	53.768
		2	0.632	0.365	0.095	0.265	41.930	57.753	26.027	74.338
		3	0.632	0.391	0.177	0.24	37.970	61.867	45.269	55.122
	Third Sampling	1	0.632	0.307	0.121	0.325	51.500	48.576	39.414	60.893
		2	0.632	0.326	0.106	0.306	48.420	51.582	32.515	67.811
		3	0.632	0.367	0.139	0.265	41.930	58.070	37.875	62.492
	Average						46.35	54.360	40.546	59.798
	Standard deviation						4.85	4.628	8.953	8.962

Middle	Sampling	Sample No.	Wet Weight	Dry weight	Ash Weight	Amount of Water	Moisture content (%)	Total Solids	Fixed Solids	Volatile Solids
	First Sampling	1	0.632	0.23	0.086	0.402	64.530	36.392	37.391	62.839
		2	0.632	0.245	0.069	0.387	61.430	38.766	28.163	72.082
		3	0.632	0.235	0.089	0.397	60.980	37.184	37.872	62.363
	Second Sampling	1	0.632	0.234	0.057	0.398	62.970	37.025	24.359	75.875
		2	0.632	0.221	0.07	0.411	65.030	34.968	31.674	68.547
		3	0.632	0.202	0.085	0.43	68.040	31.962	42.079	58.123
	Third Sampling	1	0.632	0.327	0.097	0.305	48.250	51.741	29.664	70.663
		2	0.632	0.33	0.087	0.302	47.100	52.215	26.364	73.966
		3	0.632	0.301	0.091	0.241	38.100	47.627	30.233	70.068
	Average						57.38	40.876	31.978	68.281
	Standard deviation						10.28	7.579	5.902	5.929

High	Sampling	Sample No.	Wet Weight	Dry Weight	Ash Weight	Amount of Water	Moisture content (%)	Total Solids	Fixed Solids	Volatile Solids
	First Sampling	1	0.632	0.231	0.035	0.401	63.5	36.551	15.152	85.079
		2	0.632	0.281	0.041	0.351	55.54	44.462	14.591	85.690
		3	0.632	0.271	0.039	0.361	57.12	42.880	14.391	85.880
	Second Sampling	1	0.632	0.238	0.038	0.394	62.34	37.658	15.966	84.272
		2	0.632	0.224	0.041	0.408	64.56	35.443	18.304	81.920
		3	0.632	0.259	0.052	0.373	59.02	40.981	20.077	80.182
	Third Sampling	1	0.632	0.238	0.057	0.408	64.56	37.658	23.950	76.288
		2	0.632	0.224	0.067	0.399	63.13	35.443	29.911	70.313
		3	0.632	0.259	0.075	0.356	56.33	40.981	28.958	71.301
	Average						60.68	39.117	20.144	80.103
	Standard deviation						10.28	7.579	9.907	9.939

Appendix: F

TableA. 6: Calorific values of waste from the three income groups.

Low income group	Temperature difference(K)	Weight of sample(Kg)	Specific heat capacity of water(KJ/KgK)	Weight of water in the calorimetre+water equivalent of apparatus	Gross calorific value(KJ/Kg)
Organic sample	0.7	0.0007	4.2	2.882	12104.4
	0.8	0.0007	4.2	2.882	13833.6
	0.7	0.0007	4.2	2.882	12104.4
Average	**0.73**	**0.0007**	**4.2**	**2.882**	**12680.8**
Paper sample	0.8	0.0007	4.2	2.882	13833.6
	0.8	0.0007	4.2	2.882	13833.6
	0.9	0.0007	4.2	2.882	15562.8
Average	**0.83**	**0.0007**	**4.2**	**2.882**	**14410**
Plastic sample	2.1	0.0007	4.2	2.882	36313.2
	2.2	0.0007	4.2	2.882	38042.4
	2.2	0.0007	4.2	2.882	38042.4
Average	**2.17**	**0.0007**	**4.2**	**2.882**	**37466**
Cloth	0.8	0.0007	4.2	2.882	13833.6
	0.8	0.0007	4.2	2.882	13833.6
	0.8	0.0007	4.2	2.882	13833.6
Average	**0.8**	**0.0007**	**4.2**	**2.882**	**13833.6**
Simulate sample	0.9	0.0007	4.2	2.882	15562.8
	0.9	0.0007	4.2	2.882	15562.8
	1	0.0007	4.2	2.882	17292
Average	0.93	0.0007	**4.2**	**2.882**	**16139.2**

Middle income group					
Organic sample	0.9	0.0007	4.2	2.882	15562.8
	0.9	0.0007	4.2	2.882	15562.8
	0.8	0.0007	4.2	2.882	13833.6
Average	**0.87**	**0.0007**	**4.2**	**2.882**	**14986.4**
Paper sample	0.7	0.0007	4.2	2.882	12104.4
	1	0.0007	4.2	2.882	17292
	0.9	0.0007	4.2	2.882	15562.8
Average	**0.87**	**0.0007**	**4.2**	**2.882**	**14986.4**
Plastic sample	2.4	0.0007	4.2	2.882	41500.8
	2.3	0.0007	4.2	2.882	39771.6
	2.3	0.0007	4.2	2.882	39771.6
Average	**2.33**	**0.0007**	4.2	**2.882**	**40348**
Cloth	1	0.0007	4.2	2.882	17292
	1	0.0007	4.2	2.882	17292
	1	0.0007	4.2	2.882	17292
Average	**1**	0.0007	4.2	**2.882**	**17292**
Simulate sample	1.2	0.0007	4.2	2.882	20750.4
	1.3	0.0007	4.2	2.882	22479.6
	1.5	0.0007	4.2	2.882	25938
Average	1.33	0.0007	4.2	**2.882**	**23056**

High income group					
Organic sample	0.9	0.0007	4.2	2.882	15562.8
	1	0.0007	4.2	2.882	17292
	1	0.0007	4.2	2.882	17292
Average	**0.97**	**0.0007**	**4.2**	**2.882**	**16715.6**
Paper sample	0.8	0.0007	4.2	2.882	13833.6
	0.9	0.0007	4.2	2.882	15562.8
	0.9	0.0007	4.2	2.882	15562.8
Average	**0.87**	**0.0007**	**4.2**	**2.882**	**14986.4**
Plastic sample	2.3	0.0007	4.2	2.882	39771.6
	2.4	0.0007	4.2	2.882	41500.8
	2.3	0.0007	4.2	2.882	39771.6
Average	**2.33**	**0.0007**	**4.2**	**2.882**	**40348**
Cloth	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
Average	0	0	0	0	0
Simulate sample	1.6	0.0007	4.2	2.882	27667.2
	1.7	0.0007	4.2	2.882	29396.4
	1.5	0.0007	4.2	2.882	25938
Average	**1.60**	**0.0007**	**4.2**	**2.882**	**27667.2**