SOLID WASTE SEPARATION AT SOURCE: A CASE STUDY OF THE KUMASI METROPOLITAN AREA

BY

MIZPAH AMA DZIEDZORM ASASE

(B.Sc Chemical Engineering)

A Thesis Submitted to the Chemical Engineering Department, Kwame Nkrumah University of Science and Technology, Kumasi, in Partial Fulfilment of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Faculty of Chemical and Materials Engineering

College of Engineering

FEBRUARY, 2011

DECLARATION

I hereby declare that this submission is my own work towards my PhD degree and that, to the best of my knowledge, it contains no material published by another person or material which has been accepted in any other University for any degree except where due acknowledgement has been made in the text.

Asase, Mizpah Ama Dziedzorm .... …………......... ....……………
(Student) Signature Date
Index Number: PG7622904

Certified by:

Dr. Moses Y. Mensah …………………..…. ………………………
(Supervisor) Signature Date

Prof. Samuel K. Amponsah …………………….. ………………………
(Supervisor) Signature Date

Dr. M. Y. Woode ..………………….. ..…………………….
(Head of Department) Signature Date

ABSTRACT

Solid waste management is a very pertinent issue facing municipal and local authorities all over Ghana. Waste separation at source is often recommended for the collection of clean recyclables to support recycling as part of integrated waste management systems. Limited information exists on the quantities of various waste materials available for recycling and household's potentials for separating waste at source to aid recycling in most developing countries like Ghana. The use of system analysis tools to support waste management decision in developing countries have been found to be low. The objective of this research work is to analyze the potential of implementing source separation (SS) of household solid waste in Kumasi and to discuss the implications of SS potential on the choice of waste treatment options. The study was conducted through a pilot SS of household solid waste in households of staff of KNUST and selected households in the Asokwa Sub-Metropolitan area in Kumasi. Household were asked to separate waste into three fractions; organic, plastics and others. The SS efficiency and level of compliance were evaluated from physically analysing waste collected from each household weekly. A questionnaire survey of selected household was undertaken before and during the pilot SS study. An optimization model was also set up to integrate different waste treatment options for Kumasi. Various economic costs associated with municipal solid waste management are taken into consideration in the development of the model. In staff residencies, on the average only 1.09% of households had contaminants above 50% in the organic waste bin, whilst 29.51% and 29.55% of households had contaminants above 50% in the plastic's bag and 'others' waste bin respectively. The separation efficiency of 93.31%, 49.9% and 56.18% was achieved for organic, plastic and other wastes respectively. Waste separation efficiency and level of compliance were generally higher in the junior staff households than in the senior staff households. Organic wastes constitutes 69.2% of the total wastes analyzed with other wastes, plastics, paper, metals, textiles and glass constituting 13.4%, 7.3%, 4.4%, 2.6%, 1.8% and 1.3% respectively. In the Asokwa Sub-Metro, on the average 74.3%, 60.02% and 59.56% of organic wastes were placed in the bin designated for it from 1^{st}, 2^{nd} and 3^{rd} class areas respectively. Likewise the separation efficiency for 1^{st}, 2^{nd} and 3^{rd} class areas for plastic waste were 21.42%, 19.26% and 26.92% respectively. Furthermore, the separation efficiency for other waste for 1^{st}, 2^{nd} and 3^{rd} class areas were 51.19%, 59.57% and 62.41% respectively. Per capita waste generation rate for the 1^{st}, 2^{nd} and 3^{rd} class area was found to be 0.63, 0.52 and 0.27 (kg/person/day) respectively. The relationship between household's socio-demographic characteristics and their SS efficiency was found to be generally weak. Suggestions for the design of appropriate SS schemes in Kumasi have been enumerated. It is inferred from the results of the optimization model solution that centralized composting, community composting and plastic waste recycling if included in the waste management system in Kumasi could reduce the annual system cost substantially within the limits of assumptions made in this study. The study demonstrates the usefulness of system analysis to the understanding of system performance in supporting decisions in the selection of waste treatment options. Further research directions are suggested to support the development of sustainable integrated solid waste management in Kumasi.

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LIST OF ABRREVIATIONS, ACRONYMS AND SYMBOLS

Btu	British Thermal Unit
cap	Capita
CDM	Clean Development Mechanism
CV	Calorific Value
d	Day
EPA	Environmental Protection Agency
HDPE	High Density Polyethylene
Hh	Household(s)
HSW	Household Solid Waste
ISWM	Integrated Solid Waste Management
IWM	Integrated Waste Management
kcal	Kilocalories
kg	Kilogram
KMA	Kumasi Metropolitan Area
KNUST	Kwame Nkrumah University of Science and Technology
lb	Pound
LCA	Life Cycle Assessment
m^3	Cubic Metre
MES	Ministry of Environment and Science
MFA	Material Flow Analysis
MJ	Megajoule
MLGRD	Ministry of Local Government and Rural Development
MMDAs	Metropolitan, Municipal and District Assemblies
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MSWMS	Municipal Solid Waste Management System
MW	Municipal Waste
NIMBY	Not In My Backyard
NGO	Non-Governmental Organization
PE	Polyethylene

PET	Polyethylene-terephthalate
PP	Polypropylene
PVC	Polyvinyl Chloride
PS	Polystyrene
r	Pearson's Correlation coefficient
SWM	Solid Waste Management
SS	Source Separation
SW	Solid Waste
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WM	Waste Management
WMD	Waste Management Department

ACKNOWLEDGEMENT

When all is said and done, I cannot rest, but pause and reflect on the kindness and support extended to me by many people who made this dissertation come through and appreciate them. Above all, I wish to thank the almighty God who is the source of my life and sustenance without whom this dissertation could never have been realized. I express my sincere gratitude and respect to my supervisors Dr. Moses Mensah and Dr. Samuel Kwame Amponsah for their support, guidance and patience through the long journey of this dissertation. I am especially thankful to them for their role in securing funding from Zoomlion Ghana Limited and providing undergraduate students to help with the studies on KNUST campus and in the Asokwa Sub-metro. I am grateful to the KNUST staff development programme for the scholarship awarded me to undertake this study. My appreciation also goes to Zoomlion Ghana Limited for providing financial and logistical support for the pilot study undertaken in the Asokwa Sub-Metro. To the staff of Zoomlion at the Kumasi office, I say thank for providing me with relevant information whenever I approached them. My special thanks to the staff of the Chemical Engineering Department for their support and also to Mr. Samson Oduro-Kwarteng of the Civil Engineering Department, KNUST. To Dr. F. T. Oduro of the Mathematics Department, I say thank you for your advice and support. All undergraduate students from the Chemical Engineering Department and Mathematics Department who worked with me each year from 2005 to 2008, I thank you dearly and appreciate some of the great relationships that have been established to last a life time. I am grateful to Mr. Tony Mensah (Director - waste management department, KMA) and his staff who were apt to give me support anytime I approached them. The support of the environmental quality unit of KNUST cannot go unmentioned. Mr. Mike

Oppong-Peprah, Mr. Ampomah and your staff who worked with me I am very grateful. My appreciation also goes to the Department for Foreign Affairs and International Trade, Canada for granting me the chance to participate in a graduate student exchange program at the University of Western Ontario (UWO). I acknowledge the kind and immense assistance and advice offered me by Dr. E. Yanful who took me on as a visiting graduate student at UWO. The support and kindness extended to me by all members of the administrative staff of the Civil and Environmental Engineering Department, UWO and the Ghanaian community in London, who made my stay in London a memorable one, cannot go unrecognized. I express my profound gratitude to them. To my wonderful family, I thank you sincerely for having to put up with my years of complaining, moaning and talking about waste. I specially mention my two mothers, Kate Dzorkplenu (biological mum) and Grace Amenyogbeli (maternal aunt) who have been pillars of support and encouragement to me throughout the long tortuous journey of this work. To them I dedicate this thesis. I say thank you to Sena Anku, Aseye Loglo, Yaw Anku, Matilda Serwada, Courage Bata, David Dzorkplenu, Kofi Dzorkplenu, Enyonam Dzorkplenu and Mr Innocent Dzorkplenu. I could not have asked for a more wonderful family. To my friends and colleagues, Denis Yar, Peter Ako Larbi, Peter Osam Sanful, Caroline Thyra Kumasi, Kwame Ansah, Christopher Antwi, Racheal Awuah, Richard Kena Boadi, Marciana Kussana, Daniel Hayford, Edward Antwi, Kingsley Asante, Henrietta Addai and William Adjei, I express my appreciation for being there for me all the time. To my husband to be, George N. K. Rockson, I cannot thank you enough for your unwavering support, friendship and belief in me. To all other people on campus, everyone who discussed, advised me, provided pertinent information on my work and supported me in any way, I say may God bless you.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Municipal solid waste management (MSWM) is recognized as one of the apparent challenges encountered by both developed and developing countries. The quantity of solid waste (SW) that needs managing is continuously increasing as a result of many factors of which population growth, rapid urbanization, increasing availability of consumer products, improving living standards as a result of economic growth and poverty reduction are key. Accelerating urbanization has increased the burden on municipal governments of providing universal and efficient municipal solid waste (MSW) collection services (Beede and Bloom, 1995). MSW processing and disposal practices if not handled properly have serious adverse effects on the quality of air, water and land. Open air dumps spring up as result of the inability of ecosystems to assimilate the increasing volume of waste generated and also the deficit in the pace of instituting appropriate measure to manage the increasing volumes of waste generated (Ojeda-Benitez et al., 2002). Open air dumps poses danger to public health and the environment thereby affecting negatively quality of life (Ojeda-Benitez et al., 2002). The challenges associated with MSWM are more pronounced in urban areas of most countries. The diverse nature of materials that constitute MSW complicates the challenges associated with its management. As the amount of MSW generated increases, there is the need to put in place adequate systems for its control and management in order to prevent its negative impacts on the health, environment and resources of a community. The conditions, issues and problems of waste management (WM) in the developed and developing worlds are different. Various forms of driving forces and degree of problems have influenced the evolution and progress in solid waste management (SWM) in both developed and developing countries (Wilson, 2007; Trisyanti, 2004). Stricter regulations and further focus on sustainability for example on regional green house gases reduction programs have been cited to influence the development of SWM strategies in developed countries (Trisyanti, 2004). Environmental policies embedded in the energy and material resources utilization policies of these countries usually are shown to portray this. In developing countries however, the pressing issues identified are those that have immediate impact on human health and sanitation such as increasing collection coverage, phasing out of open dumps and local institutional capacity building (Wilson, 2007, Trisyanti, 2004).

Waste management facilities in most cities of developing countries are deemed inadequate (Schübeler et al., 1996). This was attributed to lack of access of waste collection services by a considerable number of people and partial collection of waste generated. Also in terms of environmental, economic and financial aspects, systems for transfer, recycling and/or disposal of SW are deemed to be unsatisfactory (Schübeler et al., 1996). Most local governments and urban agencies in Africa have been reported to often identify SW as a major problem that has reached proportions requiring drastic measures (Srinivas, 2004). Although most governments in developing countries in Africa for example are noted to spend about 20-50% of their budget on SWM, only 20-80% of the waste is collected (Achankeng, 2003). Solid waste management in developing countries has been reported to have received less attention from policy makers and academics than that paid to other urban environmental problems, such as air pollution and wastewater treatment (Medina, 1999). It has been noted that maximizing collection coverage and upgrading of disposal sites have been the focus of improving WM in developing countries without considering the opportunities that exist for recycling (Medina, 2000; Medina, 1999).

It has been observed that waste recycling, which can result in income generation, employment creation and reduction of the waste quantities that will finally require disposal in the existing municipal landfills or disposal sites has often been ignored (Kaseva et al., 2002) in developing countries. Source separation (SS) and effective collection systems control recycling activities. However, SS is not widely adopted in developing countries. There are few formal systems of material recovery in many developing countries especially in Africa; most of the active material recovery is carried out by scavengers. However, there is a wide reuse of plastics, bottles, paper, cardboard, cans for domestic purposes found commonly among the poor in various cities. Medina (1997) reported that social, economic and environmental benefits of the recycling activities carried out by scavengers are not fully recognized by authorities in many developing countries.

Ghana, a developing country, is experiencing rapid population growth and urbanization with associated increase in waste generation as is the case of many developing countries. It is estimated that three (3.0) million tonnes of waste is generated annually, with daily generation rate of 0.45kg per capita based on the estimated population of eighteen (18) million as of the year 2005 (Mensah and Larbi, 2005). Over three thousand (3,000) tonnes of SW is generated daily in Accra (the capital) and Kumasi (the second city) with a combined population of about Four (4) million and a floating population of about 2.5 million (Mensah and Larbi, 2005). The ever-increasing volumes of SW generated associated with rapid urbanization and lack of existing systems to adequately handle them has resulted in indiscriminate disposal of wastes in watercourses, drainage channels and on land. Huge piles of waste and overflowing waste containers are seen in many urban centres. Almost all the MSW collected are sent to landfills of different forms in the country. The landfills range from open dumps to sanitary landfills. In the rural areas and smaller towns, waste is disposed in natural depressions or sand pits, and in coastal communities, disposal of waste on the beaches is found to be the norm (Babanawo, 2006).

Disposal of waste in landfills is perceived as the most economical form of WM in the country by local authorities, though it poses several challenges to them, as issues concerning waste disposal often appear in the media. Key among these challenges is the difficulty of acquiring suitable disposal sites (the scarcity and high cost of land near urban centres and the growing public opposition) and the negative impact of worsening traffic problems (Mensah and Larbi, 2005). Since most of existing landfills are open dumps there is the possibility of the pollution of water and air (the potential for environmental damage from landfill sites), which is not being taken into account by the city authorities.

Alternative WM options need to be considered and promoted to reverse the over-reliance on landfills. These alternative WM options must be considered together in a holistic way in order to achieve a sustainable WM system. Successful MSWM increasingly is based on integrated systems. Recent developments in SWM is increasingly creating the awareness that conventional single-choice management options such as reliance on landfill sites for disposal of waste is inadequate. The current trend for disposal of SW is toward implementing waste diversion and creating integrated municipal solid waste management system (MSWMS). It is recommended that an integrated waste management (IWM) approach be taken in developing and operating SWM in the country beginning from the four largest urban areas, namely Accra, Kumasi, Takoradi and Tamale. An integrated solid waste management (ISWM) system seeks to reduce pollution, to maximize recovery of reusable and recyclable materials and protect human health and the environment (Abou and El-Fadel, 2004; EPIC and CSR, 2000; Medina, 1999; Kreith, 1994).

Resource recovery and recycling form an integral part of IWM system. The need to promote actively, to strengthen and expand waste re-use and recycling systems was recognized in Agenda 21, the agreement reached among participating nations at the United Nations conference on Environment and Development in Rio de Janeiro in 1992. As contained in the report, by the year 2000 and 2010 governments in all industrialized countries and developing countries of the UN were respectively supposed to have national programmes for WM, including, to the extent possible, targets for efficient waste reuse and recycling (UNEP, Undated). It was reaffirmed at the conference that in order to maintain the quality of the Earth's environment and to achieve sustainable development, environmentally sound practices for the management of waste is one major issue that must be addressed. Ministry of Environment & Science et al. (2002) published a manual for the preparation of district WM plans in Ghana. The main objective of this manual was to assist MMDAs to prepare their own WM plans to address their problems with SWM. According to the manual, the treatment and/or final disposal of SW has very significant financial, social and environmental cost hence waste reduction and recycling should be part of district WM plans and should not be considered as 'optional extras'. The manual also emphasizes that district WM plans should make provision for the separate collection of portions of the waste for recycling, reuse and composting. District WM plans with strategies for separate collection of waste is yet to be realized in Ghana. The revised environmental sanitation policy of Ghana recognises the need to promote alternative uses of wastes through reduction, reuse, recycling and recovery (MLGRD, 2010). Metropolitan, Municipal and District Assemblies have therefore been tasked, in conjunction with the EPA, to provide facilities and services for primary separation of SW at the household, community and public levels.

1.2 PROBLEM STATEMENT

Source separation and effective collection systems are known to control recycling activities. This practice is employed in several developed countries in an organized way to collect clean recyclables from households. However, limited information exists on the implementation of such schemes in developing countries especially in Africa.

The promotion of such schemes must be preceded with careful evaluation of potential constraints and opportunities. A good evaluation of the availability of recyclables will be a motivating factor for the private sector and local authorities to provide organized schemes for recycling of some waste fractions. Many researchers argue that SS of recyclables, whenever possible, should be preferred to the recovery of materials from mixed wastes (Medina, 1997; Nordone and Franke, 1999; Schübeler et al., 1996). According to them, SS produces cleaner, higher-quality materials, commanding higher prices. According to McDougall et al. (2001), separating materials in waste will generally increase their value if uses are available for these recovered materials. An important property of waste, as indicated by McDougall et al. (2001), is the inverse relationship between degree of mixing and value of waste materials. But SS requires active public participation. It is perceived that SS sponsored by the municipal authority in many developing countries will not necessarily significantly reduce the amounts of waste that must be disposed of by the authority (UNEP and IETC, 1996). This has been attributed to the notion that the most valuable recyclables are already diverted from the municipal waste (MW) stream by waste generators, through private and/or informal systems of waste trading and recycling in these countries. To investigate the above concerns there is a need to characterize MSW to quantify the amount of recyclables that could be recovered and diverted that may make the institution of organized municipal SS justifiable. Diversion of waste from landfills can be achieved in many ways and public understanding and participation are the most important factors in this process (Thomas, 2001). Having clear goals and objectives that satisfy the social values and aspirations of the community are said to be the first step in the development of an appropriate SWM system (Tchobanoglous and Kreith, 2002). According to Mwai et al. (2008), this demands a clear understanding of the relationship between the characteristics of the waste stream and the social economic set up of the generating community and how this relationship is likely to evolve in the future. The absence of utilizing system analysis tools to analyse and improve efficiency, effectiveness and sustainability has been identified as one of the causes of MSWM system failures in developing countries (van de Klundert and Anschütz, 2001). Mwai et al. (2008) also attribute the little progress made in alleviating the threat of SW to human health and environmental resources in developing countries to the lack of clear objectives, coupled with a lack of information and of a strong analytical base in which various policies and strategies can be formulated or aligned during the decision making processes. Waste management systems must be designed and adapted to local conditions hence there is the need to do a site specific analysis of MSWMS using appropriate tools to support decision making. This is often ignored in developing countries: hardly is the WM system assessed and analyzed before management decisions are taken.

Work done previously (Dagadu, 2005; Danso et al., 2003; Opoku, 1999) indicates the willingness of people to separate their waste at source. However, there is a knowledge gap in understanding the relationship between household characteristics and SS efficiency. Furthermore, there exist knowledge gaps in the relationship between design features of organized SS schemes in developing countries and scheme performance. It is established that SS scheme performance can be reduced by poor separation efficiency of targeted materials even though participation rates may be high. In order to incorporate waste separation at source into the existing WM system in achieving sustainability in WM, among the required data is type and composition of waste, per capita waste generation rate and ability of households to separate their wastes as required. There is also the need to investigate the economic outcomes of integrating various waste treatment options in order to aid decision making in the development of ISWM in the Ghanaian context. This study therefore seeks to provide empirical findings on the factors that could promote household SS of SW. More specifically, the study seeks to explore the effect of household characteristics in the Kumasi metropolis on the performance of household source separation of solid waste. Also, the economic outcomes of integrating various MSW treatment options in Kumasi are explored.

1.3 RESEARCH OBJECTIVES

1.3.1 General Objective

The general objective of this research work is to analyze the potential of implementing source separation of household solid waste in Kumasi and to determine the optimum cost of establishing an ISWM system in Kumasi considering various waste treatment variables and options.

1.3.2 Specific Objectives

The specific objectives of the study are as follows:

1. Quantify waste generated per capita and waste composition for households in the selected areas
2. Evaluate household's waste separation efficiency and level of compliance
3. Identify and discuss factors that will promote or limit successful implementation of source separation in households
4. Evaluate the optimal cost associated with establishing an ISWM in Kumasi considering various waste treatment variables and options

1.4 RESEARCH QUESTIONS

The main questions this research hopes to address include:

1. What is the per capita waste generation rate and composition of MSW in various income groups in Kumasi?
2. How well could households be expected to comply with an organized source separation scheme and how clean could the collected waste fractions be?
3. What is the relationship between household characteristics and their source separation performance?
4. What is the optimum cost of establishing an ISWM in Kumasi considering Landfilling, Centralized Composting, Community Composting and Plastic Waste Recycling?

No single solution has been identified that completely answers the question of what to do with solid waste; since every community is different with regards to socio-cultural, economic, physiographic and geological status. Solid waste management systems must therefore be situation and location specific for success in addressing solid waste management problems. This research contributes to the development of adequate system required to manage the increasing amounts of solid waste generated in Ghana as the country strives to reach a middle income status. This research on the potentials of implementing organized SS within the KNUST campus and the Kumasi metropolis will contribute to expanding knowledge about the issues that will help develop ISWM in Ghana. This study also presents insights and experiences concerning data collection in the area of organized SS useful for other investigators interested in further investigations in solid WM in Ghana. Some of the information needs requisite for the establishment of effective household solid waste separation system in developing countries is addressed in this study. It is expected that households that participated in the waste separation at source study will begin to appreciate the resource value of waste as well as become more aware of the environmental consequences of MSWM options. This study hopes to stimulate the interest in the use of system analysis and optimization tools to support waste management decisions among decision makers in Ghana.

1.5 SCOPE AND LIMITATIONS OF STUDY

A study of the total composition of MSW would have been interesting but due to the limitation of resources the study was conducted on household solid wastes. This study is focused on household solid wastes because it is estimated to constitute the highest proportion of total MSW in Kumasi although the exact proportion could not be given (Personal communication: Waste management director of the Kumasi Metropolitan Assembly, 2008). Household solid waste is also one of the most difficult waste categories to handle because of its heterogeneous composition which varies seasonally and geographically.

1.6 THESIS STRUCTURE

This thesis is organized into five chapters. Chapter one presents the background information, the objectives and rationale of this research work. Chapter two presents relevant literature that was reviewed to support the discussion of waste management issues and aspects related to the objectives of the study. These include the definition of waste and waste management, characteristics of municipal waste, sustainability in MSWM, differences in MSWM in developed and developing countries, resource recovery from MSWM, SS of MSW and waste management system analysis models. Chapter three describes the methods employed in data collection and analysis. Data was collected through literature reviews from published and unpublished sources, personal interviews, questionnaire survey and waste characterization. Quantitative data collected was analyzed with statistical tools in Microsoft excel and Statistical Package for Social science. The development of the optimization model is also presented in this chapter. Chapter four presents the results obtained and discusses their implications. Chapter five presents the conclusions of the study, recommendations made and some considerations for future studies. References cited in the study are then presented after chapter five. A compilation of materials that complement the understanding of the study are presented in appendices after the references.

CHAPTER 2

LITERATURE REVIEW

This chapter is divided into three parts. The first part defines MSW and discusses concepts and issues related to its management worldwide, the current situation of WM in Ghana as well as the overview of research in the area of WM in Ghana. The second part discusses SS, factors that influence the design of SS schemes, methods of measuring performance of SS schemes and some experience of SS in developing countries. The third section discusses system analysis tools applied to MSWMS.

2.1 MUNICIPAL SOLID WASTE AND ITS MANAGEMENT ISSUES

2.1.1 The Definition of Waste and Municipal Solid Wastes

Pongrácz (2002) deems the notion of waste to be relative and very dynamic. This was based on the observation that first of all an item becomes waste when it loses its primary function for the user; hence, someone's waste output is often someone else's raw material input and secondly, waste also depends on the technological state of the art and the location of its generation. The dynamic nature of the concept of waste leads to various relative definitions found in literature. Waste is defined in the Basel Convention of 1997 as "substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by provision of national law'' (Veenstra, 2000). Hoornweg and Thomas (1999) define waste as "any unwanted material intentionally thrown away for disposal". McDougall et al. (2001) refer to the Concise Oxford Dictionary to define waste as "a by-product of human activity with the attributes of lack of use or value or useless remains". McDougall et al. (2001)

argue that physically, waste contains the same materials as are found in useful products the lack of value of waste is the only difference between them. Pongrácz (2002) offered a definition of waste as a "man-made thing that has no purpose; or is not able to perform with respect to its purpose". This definition was based on the classification of waste using the "Purpose, Structure, State, and Performance" language as a tool. The four waste classes enumerated by Pongrácz (2002) are (I) Non-wanted things, created but not intended or not avoided, with no purpose, (II) things that were given a finite purpose, thus destined to become useless after fulfilling it, (III) things with a well defined purpose but their performance ceased being acceptable and (IV) things with a well-defined purpose and acceptable performance, but their users failed to use them for their intended purpose. Pongrácz (2002) proposed a second definition of waste based on the concept of ownership as "a man-made thing that is, in the given time and place, in its actual structure and state, not useful to its owner". This definition is necessary, in the view of the author, to remind people of their responsibilities over the waste they create. The lack of a clear definition of waste and its management has been cited in Tchobanoglous and Krieth (2001) as an impediment to the development of sound waste management strategies and proposed that decision makers consider public comment process to establish clear definitions early in the development of waste management strategies. It is therefore very necessary to provide a clear definition of waste in waste management strategies and documents.

Waste can be classified by a multitude of schemes: by physical state (solid, liquid, gaseous), and then within solid waste by: original use (packaging waste, food waste etc.), by material (glass, paper, etc.), physical properties (combustible, compostable, recyclable etc.), by origin (domestic, commercial, agricultural, industrial, etc.) or by safety level (hazardous, non-hazardous) (McDougall et al., 2001). Flintoff, (1984) referred to SW as the term used internationally to describe non-liquid waste arising from domestic, trade, commercial, industrial, agricultural and mining activities, and from public services. SW therefore, comprise countless different materials: dust, food wastes, packaging in the form of paper, metals, plastics or glass, discarded clothing and furnishings, garden wastes, construction wastes, factory off-cuts and process wastes, pathological wastes, and hazardous and radioactive wastes. Flintoff, (1984) noted that although human or animal excreta often end up in the SW stream, generally, the term SW does not include such materials. The nature and abundance of the SW in a region is said to be a function of the living standard and lifestyle of its inhabitants, the abundance and type of the region's resources and degree of industrialization (UNEP, 2005).

Municipal solid waste is defined as waste collected and disposed by or on behalf of a local authority (Skitt, 1992). It will generally consist of household waste, some commercial waste and taken to civic amenity (bulky) waste collection/disposal sites by the general public. It may include road and pavement sweepings, gully emptying wastes and some construction and demolition waste arising from local authority activities (Skitt, 1992). Hoornweg and Thomas (1999) define MSW to include wastes generated from residential, commercial, industrial, institutional, construction, demolition, process and municipal services. UNEP (2005) refer to MSW as the term usually applied to a heterogeneous collection of wastes produced in urban areas.

2.1.2 Properties of Municipal Solid Wastes

The main physical characteristics that describe municipal waste are the generation rate, density (specific weight), composition, moisture content and size distribution of materials. These physical properties of MSW help to determine the processing and disposal needs and costs (Beede and Bloom, 1995). In addition to the above mentioned characteristics, knowledge of several other properties of solid waste are also required for properly planning, designing, and operation of WM programmes. Among such other properties are chemical, thermal and mechanical analyses. An overview of the global characteristics of SW is presented in Table 2.1 below.

Table 2.1 Global Characteristics of Solid Waste (Cointreau, undated)

Characteristic	Low Income Country	Middle Income Country	High Income Country
Generation Rate, kg/capita/day	0.4 – 0.6	0.5 – 0.9	0.7 – 1.8
Composition, %			
Putrescibles	40 - 85	20 - 65	20 - 50
Paper	1 - 10	15 - 40	15 - 40
Plastic	1 - 5	2 - 6	2 - 10
Metal	1 - 5	1 - 5	3 - 13
Glass	1 - 10	1- 10	4 - 10
Rubber, Miscellaneous	1 - 5	1 - 5	2 - 10
Fines, %	15 - 60	15 - 50	5 - 20
Moisture Content, %	40 - 80	40 -60	20 - 30
Density kg/m^3	250 - 500	170 - 330	100 - 170
Calorific Value kcal / kg	800 - 1100	1000 - 1300	1500 - 2700

Note: Categorization by income is based on 1992 gross national product data from the 1994 World Bank Report. Waste data on a wet, “as received” condition. For self sustained incineration, a year-round minimum of 1300kcal/kg lower calorific value (as received) is needed. For waste-to-energy plants, 2200kcal/kg is the minimum calorific value desired.

The primary difference between wastes generated in developing nations and those generated in industrialised countries is the high organic content and moisture content of the former.

2.1.2.1 Waste Generation Rate

Waste generation rate is defined as "the amount of wastes originating from a defined activity or a defined number of waste producers per time unit", commonly reported in kg/capita/day, kg/household/day, kg/capita/year etc. (Skitt, 1992). It is usually said that waste generation rate increases as a country develops. However, a weak correlation was found between income and waste generation rate for middle- and upper-income countries; and waste generation is said to actually decrease in the wealthiest countries studied (Medina, 1997 as cited in Troschinetz. and Mihelcic, 2009). Bolaane and Ali (2004) also found that households with higher number of people generate less waste per capita than households with fewer people. Income and consumption patterns influenced by socio-economic development and the degree of industrialization of a region have also been reported to affect waste generation rates (World Bank, 2001). Waste generation may also vary weekly or seasonally. Weekly variations may be attributed to work pattern and leisure while seasonally variations may be due to climate, seasonal availability of certain types of food and fuel use (UNEP, 2005). The waste generation rate is useful in determining method and type of storage, type and frequency of collection, crew size, method of disposal and degree of resource recovery (UNEP, 2005).

2.1.2.2 Waste Bulk Density

The density of waste i.e. its mass per unit volume (kg/m^3) is a very important waste characteristic to determine. The bulk density is essential for the design of all elements of the SWM system from storage, transportation to disposal. As shown in Table 2.1, the bulk density of waste in low income countries is higher than those from high income countries. Hence, design and selection of waste handling equipment should consider the differences in the bulk density of the waste.

2.1.2.3 Waste Composition

Waste composition indicates the components of the waste steam given as a percentage of the total mass or volume. The component categories usually include: Organic (food & yard wastes), Plastic, Paper, Glass, Metal and Others (ceramics, textiles, leather, rubber, ashes, bulky materials and materials not included in above categories). The abundance of a particular component of the waste stream depends on the location and season within which they are generated. For example plant debris may be high in the waste stream of countries located in tropical and subtropical areas whereas ash may be abundant in areas in which coal or wood are usually used for cooking and heating (UNEP, 2005). A full knowledge of the composition of the wastes is an essential element in: 1) the selection of the type of storage and transport most appropriate to a given situation, 2) the determination of the potential for resource recovery, 3) the choice of a suitable method of disposal, and 4) the determination of the environmental impact exerted by the wastes if they are improperly managed (UNEP, 2005).

2.1.2.4 Moisture Content

Moisture content (weight of water contained in waste) is an important factor in the design and economics of various MSWM elements. The moisture content of waste is reported to be most directly related to the putrescible content (Nair, 1993), so that it is lowest in industrialised countries (20 - 30%), and highest in low income developing countries (40 - 80%; Table 2.1).

2.1.2.5 Size Distribution of Materials

The size distribution of waste constituents in the waste stream is significant in the design of waste processing equipment such as mechanical separators and shredders

(UNEP, 2005). It also affects the processing rate of biodegradable fractions. The average particle size of solid waste in developing countries is reported to be significantly smaller than in industrialised countries (Nair, 1993).

2.1.3 Municipal Solid Waste Management

Skit (1992) defines WM as "the purposeful, systematic control of the generation, storage, collection, transport, separation, processing, recycling, recovery and disposal of SW". Waste management has also been defined as "the control of waste-related activities with the aim of protecting the environment and human health, and encouraging resource conservation" (Pongrácz and Pohjola, 2004). According to Zurbrugg (2004), SWM includes all activities that seek to minimise the health, environmental and aesthetic impacts of SW. These they indicated includes all activities that control the generation, collection, processing, transportation and disposal of waste as well as the minimization of the production of waste and the conceptualization of waste as a resource.

Waste management options after generation and before final disposal comprise waste minimization, collection and sorting, re-use, recycling, composting, anaerobic digestion, energy recovery (incineration or other more advanced thermal treatment techniques) and incineration (without energy recovery). The option adopted in a particular region depends on the materials in the waste, the WM systems available locally or regionally, the available market opportunities and the established waste management policy. Strategic goals of MSW planning and management, according to Schübeler et al. (1996), are to:

- Protect health and well-being of entire urban population;
- Promote environmental quality and sustainability of the urban environment;

- Support economic efficiency and productivity of urban economy;
- Generate employment and income.

The objectives of MSWM have evolved from the primary concerns of environmental health protection to considering human safety, resource conservation and the reduction of, as much as possible, the environmental burdens of WM (energy consumption, pollution of air, land and water and loss of amenity) in recent years (McDougall and Hruska, 2000).

2.1.4 The Concepts and Drivers of Municipal Solid Waste Management Systems

In order to meet the goals of MSWM, concepts have evolved to drive the approach taken by many communities. The key concept identified worldwide currently determining the structure of waste management is the concept of sustainable waste management. Sustainable MSWM seeks to approach MSWM based on the principles of sustainable development. The major framework on which sustainable MSWM is developed is the Waste Hierarchy and Integrated Solid Waste Management (ISWA and UNEP, 2002).

The waste hierarchy presented as a stepwise approach to waste management in order of environmental priority for different waste management options (ISWA and UNEP, 2002). This was introduced in Agenda 21 (declaration on environment and development adopted by more than 178 Governments at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, 3 to 14 June 1992). The general principle of the waste management hierarchy consists of the following steps (ISWA and UNEP, 2002):

- Minimising wastes;
- Maximising environmentally sound waste reuse and recycling;

- Promoting environmentally sound waste disposal and treatment;
- Extending waste service coverage.

Most developed countries have generally accepted this hierarchy as a strategy towards an environmentally sound waste management system. This is reflected in the waste management policies of these nations.

Strange (2002) asserts that based on past experiences of unplanned and uncoordinated ways of managing waste there is the need for approaching society's use of resources and ways of managing in a sustainable way. Schertenleib and Meyer (1992b) highlighted the interrelated nature of the different components (collection, recycling and disposal) of a SWM scheme; in that changes in one of the components may often lead to or aggravate the problems of the other components. The importance of managing solid waste through an integrated approach is discussed by the UNEP International Environmental Technology Centre (2005) as follows:

1. Some problems can be solved more easily in combination with other aspects of the waste management system than individually;
2. Adjustments to one area of the waste system can disrupt existing practices in another area, unless the changes are made in a coordinated manner;
3. Integration allows for capacity or resources to be completely used; economies of scale for equipment or management infrastructure can often only be achieved when all of the waste in a region is managed as part of a single system;
4. Public, private, and informal sectors can be included in the WM plan;
5. An ISWM plan helps identify and select low cost alternatives;

6. Without an ISWM plan, some important aspects of the WM system that does not generate revenue may not given proper attention leading to negative effects of the system on public health and safety.

This line of thinking has been widely adopted in the WM study and practice culminating in the evolution of different definitions and concepts aimed at integrating WM system elements, aspects and dimensions. The term IWM is often used to describe an approach in which decisions on waste policies and practices take account of waste streams, collection treatment and disposal methods, environmental benefits, economic optimization and social acceptability (McDougall et al., 2001). The concept of IWM, according to McDougall et al. (2001), takes an overall approach and manages waste in an environmentally effective, economically affordable and socially acceptable way. It is said to involve the use of a range of different treatment options at a local level and considers the entire solid waste stream. IWM can be defined as "the selection and application of suitable techniques, technologies, and management programs to achieve specific waste management objectives and goals" (Tchobanoglous and Kreith, 2001). Two available frameworks that explain how to approach ISWM are the IWM Model (McDougall et al., 2001) and Integrated Sustainable Waste Management (van de Klundert and Anschütz, 2001).

I. Integrated Waste Management Framework

This framework is based on the concern that waste managers need to create sustainable systems that are economically affordable, socially acceptable and environmentally effective. Economic affordability, as indicated in McDougall et al. (2001), requires that the costs of waste management systems are acceptable to all stakeholders within jurisdiction of concern. Further, waste management system is said to be socially acceptable if it meets the needs of the local community, and reflects the values and priorities of that community. Also, it is indicated that environmental effectiveness requires the reduction in the overall environmental burdens of managing waste; both in terms of consumption of resources (including energy) and the production of emissions to air, water and land. Flexibility in technology application for a specific location is also an essential component of the IWM concept (McDougall et al., 2001).

II. Integrated Sustainable Waste Management Framework

Integrated sustainable waste management framework is indicated to promote the development of a waste management system that best suits the society, economy and environment in a particular location (van de Klundert and Anschütz, 2001). Integrated sustainable waste management framework, as presented by (van de Klundert and Anschütz, 2001), aims at the integration of:

- **a.** Various stakeholders; governmental or non-governmental, formal or informal, profit or non-profit oriented (Cooperation relationships)
- **b.** A variety of aspects (technical, environmental/public health, financial)
- **c.** Various collection and treatment options adapted to a specific habitat scale, i.e. household, neighbourhood and city level
- **d.** The waste management system and other urban systems (such as drainage, energy, urban agriculture)

The integrated sustainable waste management framework framework recognized that lack of money and equipment is not the cause of most solid waste management problems especially in developing countries as most municipal authorities often cite (van de Klundert and Anschütz, 2001). But rather, the attitude and behaviour various stakeholders as well as institutional and managerial incapacities are cited as some of the factors that may be the cause of most MSWM problems. Therefore it is deemed that changing social, institutional, legal or political conditions may solve some of the problems. According to van de Klundert and Anschütz (2001), integrated sustainable waste management framework seeks to avoid the tendency to use money and equipment incorrectly and at high cost in the bid to solve MSWM problems that might not be caused by lack of adequate financing or equipment in the first instance. In order to develop and implement sustainable MSWM systems based on the consideration of IWM and integrated sustainable waste management framework, a practical holistic approach will involve the consideration of specific objectives and measures in the following areas according to Schübeler et al. (1996):

1. Planning and Management
    - Strategic planning;
    - Legal and regulatory framework;
    - Public participation;
    - Financial management (cost recovery, budgeting, accounting);
    - Institutional arrangements (including private sector participation);
    - Disposal facility sitting.
2. Waste Generation
    - Waste Characterisation (source, generation rates, composition);
    - Waste minimisation and source separation.
3. Waste Handling
    - Waste collection;
    - Waste transfer, treatment and disposal;
    - Special wastes (medical, small industries).

2.1.5 Challenges of Solid Waste Management (SWM) in Developing countries

The local government is the major authority responsible for providing SWM services in many cities in developing countries (Schübeler et al., 1996; Kaseva et al., 2002). Pearce and Turner (1994) stated that the major problems solid wastes pose for the developing world are:

(a) Health hazards and environmental degradation from uncollected waste;

(b) Health hazards and environmental degradation from collected but poorly disposed of waste; and

(c) The economic burden of waste disposal on towns and cities.

Schertenleib and Meyer (1992a) and Zurbrügg and Schertenleib (1998) identified five typical problems of MSWM in developing countries as (a) inadequate service coverage; (b) operational inefficiencies of existing MSW services and management; (c) limited utilization of recycling activities; (d) inadequate final disposal of MSW; and (e) inadequate management of non-industrial hazardous waste. They related all these problems to institutional, financial and technical issues. It has been acknowledged that municipal authorities still grapple with the management of increasing amounts of waste in developing countries inspite of the efforts they had put into it (van de Klundert and Lardinois, 1995). This inability to manage urban SW according to van de Klundert and Lardinois (1995) consists of failures in the following areas:

1. Inadequate services;
2. Inadequate financing;
3. Inadequate environmental controls;
4. Poor institutional structure;
5. Inadequate understanding of complex systems;

6. Inadequate sanitation.

Onibokun (1999) argues that the inadequate capacity of governments and waste management companies to deal with increasing volumes of waste generated is the major challenge to WM in African countries. Finding appropriate staff, motivating staff through appropriate capacity building, paying of adequate salaries, incentives and difficult working conditions in the waste management sector have also been cited as obstacles to waste management (van de Klundert and Anschütz, 2001). High expenditure and low revenues coupled with inefficient treatment facilities and increasing transportation and disposal costs are also reported to be a major challenge facing municipal managers in developing countries (van de Klundert and Anschütz, 2001). Other challenges mentioned by van de Klundert and Anschütz (2001) are citizens' non compliance or cooperation through truant behaviours such as illegal dumping of wastes, littering, misuse, damage or even stealing of collection containers and resistance to payment of reasonable service fees.

2.1.6 Differences in MSWM in Developed and Developing Countries

Distinct differences have been identified in literature between MSWM in developed and developing countries. The protection of public health remains the main driver of WM in developing countries. In most developed countries, public health is no more a major driver of WM; the current focus is on optimization of WM practices with a broader goal of resource conservation and sustainability (Wilson, 2007; McDougall et al., 2001). Some of the different attributes of MSWM in developed and developing countries are summarised in Table 2.2 and Table 2.3

Table 2.2 Differences in SWM in Developed and Developing Countries

Issues in SWM	Developing Countries	Developed Countries
Environmental Laws	Maybe few, probably unenforced	Strict laws, enforced
Pollution Prevention	Minimal	Present
Recycling	Present, highly efficient	Present
Quantity of Waste	Less	More
Disposal Methods	Organized in some places	Organized everywhere
Education	None, lack of resources	Present, good resources
Waste Composition	Little industrial, mostly organic	Much industrial, less organic
Waste and Health Data	Some to none	Very good
Scavenging	Common	Against the law

Source: (Zavodska, 2000)

Schertenleib and Meyer (1992b) realised that material recovery and recycling activities are not planned and regulated in developing countries even though they are carried extensively; often inefficiently. However, they indicated that industrialized countries are yet to achieve high recycling rates although the benefits of recycling activities are generally recognized in these countries. Most industrialised countries have been motivated to focus on recycling activities due to factors such as stringent environmental regulations that translate into high tipping and transportation fess and increasing public opposition to siting of landfills (NIMBY effect) (Schertenleib and Meyer, 1992b). MSWM personnel education, waste collection and segregation, and government finances were enumerated by Troschinetz, and Mihelcic (2008) as the three biggest barriers to recycling in developing countries.

Table 2.3 Comparison of Typical SWM Practices in Countries of Different Income Levels

Activity	Low Income	Middle Income	High Income
Source Reduction	No organized programs, but reuse and low per capita waste generation rates are common.	Some discussion of source reduction, but rarely incorporated in to any organized program.	Organized education programs are beginning to emphasize source reduction and reuse of materials.
Collection	Sporadic and inefficient. Service is limited to high visibility areas, the wealthy, and businesses willing to pay.	Improved service and increased collection from residential areas. Larger vehicle fleet and more mechanization.	Collection rate greater than 90 percent. Compactor trucks and highly mechanized vehicles are common.
Recycling	Most recycling is through the informal sector and waste picking. Mainly localized markets and imports of materials for recycling.	Informal sector still involved, some high technology sorting and processing facilities. Materials often imported for recycling.	Recyclable material collection services and high technology sorting and processing facilities. Increasing attention towards long-term markets.
Composting	Rarely undertaken formally even though the waste stream has high percentage of organic material.	Large composting plants are generally unsuccessful; some small-scale composting projects are more sustainable.	Becoming more popular at both backyard and large- scale facilities. Waste stream has smaller portion of compostables than in low and middle income countries.
Incineration	Not common or successful because of high capital and operation costs, high moisture content in the waste and high percentage of inerts.	Some incinerators are used, but experiencing financial and operational difficulties; not as common as in high income countries.	Prevalent in areas with high land costs. Most incinerators have some form of environmental controls and some type of energy recovery system.
Landfilling	Low-technology sites, usually open dumping of wastes.	Some controlled and sanitary landfills with some environmental controls. Open dumping is still common.	Sanitary landfills with a combination of liners, leak detection, leachate collection, gas collection and treatment systems.
Costs	Collection costs represent 80-90 percent of the MSWM budget. Waste fees are regulated by some local governments, but the fee collection system is very inefficient.	Collection costs represent 50 to 80 percent of the MSWM budget. Waste fees are regulated by some local and national governments, more innovation in fee collection.	Collection costs can represent less than 10 percent of the budget. Large budget allocations to intermediate waste treatment facilities. Upfront community participation reduces costs and increases options available to waste planners.

Source: (Hoornweg and Thomas, 1999)

Although distinct differences exist between WM in developed and developing countries; as developing countries achieve economic growth coupled with population growth the environmental and economic burdens of solid WM will increase which will require a pragmatic approach to deal with.

2.1.7 Perspectives for Possible Approaches to Addressing the Problems of MSWM in Developing Countries.

Schertenleib and Meyer (1992a) proposed some directions that MSWM should be approached in order to address the problems of its management in developing countries. These are: (1) introduction of community-based WM schemes which involves local communities in the collection, sorting and recycling activities supported by prior research to determine how such schemes can be implemented under different conditions to increase collection coverage; (2) improving on operational efficiency by increasing private sector participation while investigating how the role and performance of the public sector can be enhanced in conjunction with the private sector; (3) official recognition of the role of the informal sector in recycling activities and studying the informal recycling system, market and price mechanisms of secondary raw materials in order to help them improve upon their activities; (4) application of institutional, financial models and guidelines for waste disposal activities as an integral part of SWM; and (5) need for appropriate guidelines for the safe handling and disposal of hazardous pathogenic waste from hospitals and clinics. Wilson et al. (2009) report that the quite high recycling rates of between 20 –50% are achieved by the informal sector in many developing countries which is deemed comparable to recycling rates achieved by modern WM systems in developed countries. This supports the argument for recognizing the role of informal sector in MSWM in developing countries leading to the building of recycling rates, addressing some of the social issues to the extent of probably reducing the overall costs of WM for the formal sector. Ojeda-Benitez et al. (2003) carried out a study in the city of Mexicali, Mexico to describe the household solid wastes generated by the community in order to identify the potential of the wastes for recycling. They found out that in the appraisal made for 41 "colonias", with socio-economic characteristics similar to the one studied, more than 64 tonnes of wastes are produced daily of which 71% are composed of recyclable and potentially recyclable wastes which were sent to landfills. This they considered translates to a waste of resources, both economic and natural, which could be utilized by being submitted to a process of recycling and or reuse. Kaseva et al. (2002) concluded that SWM in developing countries should no longer be viewed from a narrow perspective of collection and disposal, but instead SWM strategies in these countries should include separate collection and recycling which can lead to the reduction of quantities of wastes to be disposed of and generate employment and income for the urban poor. Schertenleib and Meyer (1992b) predicted that the amount of waste to be transported and disposed of in landfills will become a key issue in SWM in developing countries. They therefore proposed that more emphasis be placed on recycling of the organic putrescible fraction which accounts for the main portion of the MSW. They also foresee that composting of MSW in decentralized and small-scale communal plants will become a viable option if considerable savings in transportation costs and tipping fees (extended lifetime of landfills) can be achieved. A similar view is held by Poerbo (1991). The discussion above provides a strong basis for research on SS of MSW and recycling in developing countries in order to support programs to appropriately deal with the increasing volume of MSW with variable composition.

2.1.8 Municipal Solid Waste Management (MSWM) in Ghana

The state of MSWM in Ghana is no different from the experiences from other developing countries. Generally, waste management in Ghana is the responsibility of the Ministry of Local Government and Rural Development (MLGRD), which supervises the decentralized Metropolitan, Municipal and District Assemblies (MMDAs). However, regulatory authority is vested in the Environmental Protection Agency (EPA) under the auspices of the Ministry of Environment and Science (MES). The MMDAs are responsible for the collection and final disposal of solid waste through their Waste Management Departments (WMDs) and their Environmental Health and Sanitation Departments. The policy framework guiding the management of hazardous, solid and radioactive waste includes:

- the Local Government Act (1994), Act 462;
- the Environmental Protection Agency Act (1994), Act 490;
- the Pesticides Control and Management Act (1996), Act 528;
- the Environmental Assessment Regulations 1999, (LI 1652);
- the Environmental Sanitation Policy of Ghana (2010);
- the Guidelines for the Development and Management of Landfills in Ghana; and
- the Guidelines for Bio-medical Waste (2000).

All these Acts and Regulations emanate from the National Environmental Action Plan (UN, 2004).

MLGRD (2010) reported that about 76% of households rely on waste collection and disposal methods that are deemed inadequate in Ghana. The main methods of MSWM used in the country are collection and open dumping, controlled burning and tipping at dumpsites. In most cases municipal solid waste is disposed of without any processing and or treatment. Five major causes of MSWM problems in cities and towns as outlined in MES et al. (2002) are:

1. Poor planning for WM programmes;
2. Inadequate equipment and operational funds to support WM activities;
3. Inadequate sites and facilities for WM operations;
4. Inadequate skills and capacity of WM staff;
5. Negative habits, uncoordinated attitudes and apathy of the general public towards the environment.

Private sector participation in SWM in Ghana is observed to be limited to waste collection, transport and disposal. Waste separation and collection of recyclables are usually carried out by the informal sector through itinerant buyers and scavengers at dumpsites. The materials collected by the informal sector are those found to have a high market demand. Metals of all forms are collected and sent to both large metal industries and small scale foundries for recycling. Plastic bottles, glass jars, glass bottles and some empty metal beverage containers are commonly collected for reuse and sold at various markets. Broken rigid plastic materials and water sachets are also collected and sent to plastic recycling companies.

The Environmental sanitation policy (2010) published by the MLGRD recognises the need to promote alternative uses of wastes through reduction, reuse, recycling and recovery. In order to properly manage the increasing volumes of solid wastes generated in the country, the MMDAs in collaboration with the EPA have been tasked to make available services and facilities for primary separation of waste at the household, commercial and communal levels (MLGRD, 2010b). They are also to ensure that 20% of these services and facilities are provided by the end of 2013 (MLGRD, 2010b).

There is a need for research to support the establishment of formal waste collection systems to support recycling and recovery. A limiting factor to the establishment of formal recycling systems is the availability of suitable collection schemes to recover economically viable quantities of recyclables. This was an expressed concern of some plastic manufacturers who are considering adding recycling to their existing processes.

Several studies have been undertaken to address different concerns of WM in Ghana. Studies found to address issues of waste characteristics and elements of the MSWMS relevant to the current study are briefly discussed in this section. Gomda (2001) assessed the adequacy of the current WM in Wenchi in the light of: equipment type and adequacy, service coverage and disposal method, institutional arrangements, service cost and financing. He also investigated the SW properties by determining the generation rate, density and its characteristics. He used financial costing to prescribe an appropriate system of SWM in Wenchi based on the assessment made on the existing system. Kotoka (2001), determined generation rate, density and characteristics of solid waste from selected high-income communities in Kumasi. These he did in order to build a database for planning, selection, design and construction of SWM facilities, equipment, method and systems and to assess the various collection, storage and treatment options available. A constructive heuristic which takes into account the environmental aspect as well as the cost was designed by Amponsah and Salhi (2004) to solve the routing aspect of solid waste collection stemming from the need to address the problem of waste collection in Ghana. The composition of HSW was determined for 1st, 2nd and 3rd class area of the Bantama sub-metro area in Kumasi. The results of the study are presented in Ketibuah et al. (2004). Carboo and Fobil (2005) undertook a study to generate scientific information on both the physical and chemical composition of MSW in the Accra metropolis. Their results showed that the MSW contains moisture as high as 60% by weight of fresh wastes and calorific values ranging between 14.0-19.5 MJ/kg. Carbon to nitrogen ratios in the waste were reported to be in the range 27:1-100:1. These physical and chemical properties were found to be very variable among various waste components and also among the three zones considered in their work. They concluded by stating that the MSW in the metropolis might be a good candidate for composting programmes and that waste-to-energy conversion by incineration might not be economically viable. Mensah et al. (2003) are convinced that co-composting could be an effective component of IWM in Kumasi if a good marketing strategy is put in place to ensure the sustainability of the system. They arrived at this conviction after a study on a pilot co-composting of the organic fraction of MSW and faecal sludge in Kumasi. Dadson (2005) concluded that a sustained information, education and communication on waste reduction could influence households to practise waste separation, composting and collection of plastics for recycling after a study carried out on domestic WM in Kojo Beedu in Winneba. The study also found domestic waste composition to be 58% organic, 22% plastics and 18% miscellaneous by volume.

Opoku (1999) reports waste generation rate of 0.28 - 0.47 kg/cap/d in middle income households and 0.24 - 0.29 kg/cap/d in low income areas of Kumasi after analysing waste separation at source of 20 household for 7 weeks. Observed sorting efficiency was high in the early part (3 weeks) of the study and continued to decline even with further education of household on how to properly do the separation. Danso et al. (2003) surveyed urban household perception of SW source separation in Accra, Kumasi and Tamale and found out that 70-80% of sampled households showed no objection to separate their waste into an organic and inorganic fraction to make compost better. About 10% of households surveyed would only separate if it would be requested with extra fees for those who would not participate and only few household were not willing to participate. Danso et al. (2003) also reported findings from a pilot SS study carried out by the Institute of Mining and Mineral Engineering (2002) on 8 weeks household SS in selected suburbs of Kumasi. Sorting rate observed was relatively high between 40-50% among all households in week 2-3 and up to 5 weeks in the middle-income group. A general decline in commitment of 10-20% was recorded from week 6 on. Households' willingness to separate waste through questionnaire surveys do not readily translate into high separation efficiencies when actual separation schemes are implemented. Such was the case in a study carried out by Dagadu (2005) in selected areas of the Accra metropolitan area. The results of a study undertaken by Owusu-Ansah (2008) in Accra show that 96%, 92% and 68% of people from the "high class low density", "medium class medium density" and "low class high density" areas respectively showed their willingness to practice separation at source if the city authorities will implement such a policy. Moreover, all respondents from the three residential areas agreed that the smooth implementation will depend on other factors like incentive, government commitment, and convenience space in their homes. Asante (2008) found that the main mode for recovering items from MSW in Accra is by scavengers at dumpsites although some sorting is undertaken in households. It is further advocated that institution of incentives such as providing free waste containers for low-income households will enhance waste separation at homes.

Even though quite a number of studies have been carried out on issues bordering on WM in Ghana, there is still a dearth of information on quantification and characterisation of waste; health, social, economic and environmental impact of MSWM. Research is also lacking on the factors that will support the design of successful SS schemes as the country strives to introduce organized SS in the WM system. Continual research and implementation of research findings in supporting ISWM in various cities and towns in Ghana is very necessary as the country aspires to reach a middle income status because as the country develops economically the probability of a corresponding increase in waste quantities and variable composition is very high.

2.1.9 Perspectives for Composting of MSW in Developing Countries and Ghana

Reported experiences from previous composting projects conducted in developing countries suggest that labour-intensive composting facilities are recommended than highly automated facilities (Beede and Bloom, 1995; Hoornweg and Thomas, 1999; Etuah-Jackson et al., 2001; Drechsel et al., 2004). In spite of the recommendation of the suitability of decentralized composting for developing countries, some centralized composting systems still exist in developing countries. The issues and opportunities associated with centralized or decentralized composting in developing countries are therefore discussed.

2.1.9.1 Opportunities for Centralized Composting

Centralized schemes are large-scale, highly mechanised composting plants mostly located outside a city, often close to a dump site. The incoming waste is either market waste which has been collected separately or mixed household waste which needs a separation process prior to composting. Depending on the population size of a city, such plants are designed to process 50 to 600 tonnes of waste per day (Hoornweg et al., 1999). The handling of large amounts of waste requires mechanical equipment like conveyor belts, turning equipment and rotating drum sieves in order to avoid nuisances such as odour from anaerobically degrading organic waste. Many centralized composting plants established in developing countries failed due to various reasons. Some of which are (Hoornweg et al., 1999; Dulac, 2001; Etuah-Jackson et al., 2001; Drechsel et al., 2004):

1. inappropriate technology;
2. poor quality feed stock waste;
3. lack of operator education and training;
4. mechanical breakdown and poor maintenance;
5. high operating costs;
6. offensive odour emissions;
7. poor marketing plans for the end product;
8. insufficient focus on management; and
9. lack of cooperation from the public and municipal governments.

Despite the failures of past large scale centralized composting plants opportunities for its relevance in achieving sustainable waste management in developing countries could be explored following considerations in these areas:

1. **Clean Development Mechanism (CDM):** Composting falls under the category of greenhouse gas avoiding measures. Organic waste, which is composted under aerobic conditions, produces less greenhouse effect (in terms of carbon dioxide equivalents) than organic waste incorporated in landfills. In October 2005, the Dutch company "World Wide Recycling" together with the NGO "Waste Concern" succeeded in registering composting as greenhouse gas abating measure under the United Nations Framework Convention on Climate Change (UNFCCC) (Boone, 2009). According to Drescher and Zurbrügg, (2006),

revenues from compost sales in addition to selling carbon dioxide certificates could make composting more attractive though from the financial point of view especially in developing countries which have ratified the Kyoto Protocol. They further reckon that the increased revenues could support the development of markets and distribution networks for compost products in countries in which prevalent institutional challenges in relation to SWM have been resolved.

2. **Strategy for Compost Marketing:** Proper strategies instituted for the marketing of compost could ensure that enough revenues are generated to support its production. Some lessons can be learnt from the experience of "Waste Concern" where compost is enriched with mineral fertilizer, the involvement of known agro-fertilizers sellers to market compost and the use of demonstration farms (Zurbrügg et al., 2002)

2.1.9.2 Opportunities for Decentralized Composting

Decentralized composting systems usually located close to the waste generation source. Backyard composting, in which only a household's waste is composted, is noted as the smallest unit of a decentralized composting system (Drescher and Zurbrügg, 2006). Community-based decentralized systems compost waste of one neighbourhood with plant capacities not exceeding 10 tons of waste per day (Drescher and Zurbrügg, 2006). These low amounts of waste is said to keep investment costs low since little mechanical equipment may be required. Also, odour from the plant is minimized as waste is delivered daily to the site preventing the anaerobic degradation of the waste. Drescher and Zurbrügg (2006) enumerated several advantages of decentralized composting over centralized composting as:

1. Reduction in transportation costs through the diversion of the major faction of municipal waste stream close to the generation source;

2. The life span of landfills are prolonged;
3. Decentralized composting can easily be initiated without the need for large investments;
4. They are more flexible in management and operation can better adapt to changes in communities;
5. Provides employment in the community as labour-intensive technology is applied ;
6. It may offer safer income opportunities the informal sector;
7. Decentralized composting could significantly enhance environmental awareness in a community.

Despite the afore-mentioned advantages decentralized composting encounters similar problems as centralized composting plants in many urban areas. Etuah-Jackson et al., (2001) reported that the failure of a community based composting project in the Ashiedu-Keteke sub-metro established in 1998 could be attributed to difficulty in the marketing of the compost produced, conflicting collection service with a local service provider and difficult accessibility to community compost site.

The potentials of decentralized composting as CDM projects exist. It is recommended that several decentralized schemes could be bundled into one project to secure approval under the CDM since it might be impossible to register a single small-scale composting plant (Descher and Zurbrügg 2006). Also, the marketing schemes could also be improved as perceived for centralized composting.

In view of the experiences with both centralized and decentralized composting schemes, Hoornweg et al. (1999) propose that composting should be considered as part of an ISWM strategy with appropriate processing technologies selected based on market opportunities, economic feasibility, and social acceptance. Cost effective and sustainable composting is deemed possible within the context of an ISWM strategy.

2.1.10 Perspectives for Plastic Waste Recycling in Developing Countries and Ghana

Increasing waste volumes and environmental concerns necessitated plastic recycling in developed countries whereas in developing countries plastic waste recycling is carried out mainly for income generation from its use as a valuable raw material for small scale production (Vest, 2000). Historically, the composition of plastic waste in the waste stream in Ghana increased from 1.4% to 4% from 1979 to 1993 by 1999/2000 its proportion increased to 8% (Fobil and Hogarh, 2006). The number of plastic manufacturing and recycling companies has increased over the years in Ghana. It was reported that in 1996, there were about 20 plastic producing establishments in Ghana by the year 2000, there were about 40 plastic manufacturing companies producing about 26,000 metric tonnes of assorted plastic products annually in Ghana, with 90% of the companies in the Accra-Tema Metropolitan Area (Fobil and Hogarh, 2006). Current discussions with the chairman (personal communication; Mr. Ken Kuranhyie) of the Ghana Plastic Manufacturers Association suggest that over 50 registered plastic manufacturing companies exist in Accra with a number of small scale plastic recycling companies springing all over the city of Accra. The major challenge to recycling of plastic waste in Ghana, as enumerated by some recyclers, is the inability to collect enough quantities of plastics due the lack of adequate logistics and low storage capacity. Although some kind of plastic waste collection is taking place, much of the plastic waste still remains unrecovered mainly attributed to the insufficient number of companies available to recycle the different types of the plastic waste and the difficulty of retrieving and recycling plastics from the mixed waste stream. For instance, the total collection of plastic waste by Plastic Waste Collectors Association of Ghana in Accra amounts to 30% of plastic wastes in the waste stream (personal communication: Mr. Emmanuel Kojo Woassey). The separation at source of the plastic waste is also advocated by the plastic waste collectors to enhance their recovery. Hence, any strategy to increase the recycling of plastic waste must target how to retrieve substantial amounts from the waste stream through source separation and development of the capacity of the collection sector.

2.2 SOURCE SEPARATION AND FACTORS THAT INFLUENCE DESIGN OF SOURCE SEPARATION SCHEMES

This section looks at the definition of SS, the type of existing SS systems, the need for SS in the SWM system and also the issues and dilemmas that arise in implementing SS schemes.

2.2.1 Source Separation

Source separation or separation at source refers to "the practice of setting aside post-consumer materials and household goods so that they do not enter the mixed waste stream for the purposes of recycling, reuse or improved WM" (Lardinois and Furedy, 1999). According to Lardinois and Furedy (1999) the items that are commonly separated from the household waste streams include:

1. Reusable items (such as clothes and accessories, utensils and appliances, containers, books and magazines);
2. Materials which are usually regarded by the primary consumer as 'wastes' (such as newspapers, scrap paper, cardboard, broken or irreparable plastic items such as buckets and basins, food and drink cans and containers);
3. Organic matter (such as food wastes, organic residues and garden wastes);
4. Toxic and hazardous wastes that are dangerous in landfills (such as biomedical items, used oils and pressurized cans).

Lardinois and Furedy (1999) categorized the modes of SS as customary practices and collectively organized interventions. The customary practices they as they stated are made up of gift, barter and sale of post-consumer materials related to charity, trading and recycling. The type of materials separated in the customary system is said to be determined by the requirements or specification of end users and at times even by religious observances. Government or non-governmental organizations promoting or requiring the separation by waste generators usually implement collectively organized interventions (Lardinois and Furedy, 1999). Collection of materials for recycling and composting usually drives organized systems in the developed countries which may be financed by local authorities and may sometimes be mandated by the state (Lardinois and Furedy, 1999). In collectively organized systems separated materials may be collected either using drop-off or kerbside collection methods. Improving the status and conditions of waste workers and encouraging resource recovery from waste by various stakeholders have often introduced organized SS in developing countries, usually on voluntary basis (Lardinois and Furedy, 1999). Most description of SS and collection of recyclables in literature are termed as municipal/household/ residential recycling programmes.

2.2.2 The Need for Source Separation (SS) of Municipal Solid Wastes

The main methods that can be used to recover recyclable materials from MSW are to collect source-separated recyclable materials by either the generator or collector (with and without subsequent processing), or to collect mixed waste with processing for recovery of the recyclables materials. Source separation in its various forms has been found to have several advantages over recovery of materials from non-separated waste. The difference between SS and centralized separation of recyclables as reported by Veeken et al. (2005) is presented in the Table 2.4 below.

Table 2.4 Main Differences between SS and Centralized Separation of MSW Components

Source separation	Centralized separation
Better product quality	More polluted products
Increased waste awareness	Shielding waste awareness
Complex logistics	Easier logistics
Public involvement needed	Less involvement needed

Source: Veeken et al. (2005)

The benefits of separation at source of organic and inorganic wastes according to Lardinois and van de Klundert (1994) are: a reduction in injuries and better health status of waste workers (scavengers, collection crew etc.), increase in value of recyclables and in quality of compost produced from separated organic waste, reduction in the amount of waste collected and subsequently disposed, and increased treatment options. IETC (1996) report indicates that the cost of waste disposal in any region could be reduced through a SS program if an economically viable market exists for the separated materials. According to Murray (1999), optimal SS will "minimize energy and labour inputs to any downstream sorting process, reduce health hazard associated with sorting of mixed refuse, lower recycling costs and provide opportunities for innovation". Raheem et al. (1999) suggested that SS should be introduced with adequate citizen's education to ensure high participation and level of separation in order to increase the lifespan of landfills in West African Cities. Santos et al. (2005) investigated the environmental pollution caused by cleaning of plastics during the recycling process of polyolefins (HDPE and PP) and polyethylene terephtha-late (PET). They found that, the source of plastics strongly influenced the level of environmental pollution generated during their cleaning, therefore the use of wastes from a kerbside SS program could reduce the emission of some pollutants overall costs of recycling of those plastics. Schertenleib and Meyer (1992b) argue that SS of recyclables could increase the price and markets for recyclable since cleaner or purer materials attracted higher prices. Many researchers support the argument that SS of recyclables, whenever possible, should be preferred to the recovery of materials from mixed wastes (Medina, 1997; Nordone and Franke, 1999; Schübeler et al., 1996). Paolo S. Calabrò (2009) believe that, separate collection of waste does not only maximize the quantity and the quality of recyclable materials but also reduces the impact of MSW by removing from waste streams items containing dangerous substances, such as batteries, wastes from electric and electronic appliances and drugs. They therefore saw SS as a real pre-treatment of waste before subsequent treatment. Ferh et al. (2000) advance the argument that SS will naturally attract the informal sector and will facilitate their incorporation into the formal waste management system. Some general advantages and disadvantages of organized SS are summarized in Table 2.5. Gould et al. (1992) discuss the possible drawbacks of SS of organic wastes. The drawbacks enumerated are: additional demand on waste generators, potential odours and additional storage space requirements, potentially lower capture rates leading to higher disposal costs, greater uncertainty and technological risk because quantity and quality of the material collected depends on the behaviour of participants, and separate collection may induce additional costs.

The method employed to collect source-separated wastes determines how costly the system will be. Avoided costs associated with the reduced need for landfilling should be included in the computation of SS program costs since total waste management costs may increase with the introduction of such a program and revenue from the sale of recovered materials may not be adequate to offset added expenses (Lardinois and Furedy, 1999).

Table 2.5 Advantages and Disadvantages of Organized Source Separation

Advantages	Disadvantages
Cleaner post-consumer materials that may fetch higher prices[1]	Logistical and technical adaptations for the existing system necessary
End products (such as compost) of better quality	High unit costs (although total costs seem acceptable in the quality cases studied)
Increased environmental awareness	Implementation is time-consuming and rather complex
More efficient and effective recovery	Risk for creation of conflicts among main stakeholders
Creation of new jobs	Professional and dedicated personnel necessary
Relatively clean working conditions when sorting source separated mixed recyclables	
Possibilities for (former) waste pickers to work in cleaner circumstances	

Source: (Lardinois and Furedy, 1999) [1] Prices are influenced by a number of factors, among them availability of (competing) materials, quantity to be sold, relation with buyers, etc

2.2.3 Design of Source Separation Schemes

According to Noehammer and Byer (1997) and Woodard et al. (2006), there are many variables (with different options) and issues that define the design and performance of a residential SS programme. These include whether participation in the program by residents is mandatory or voluntary; the types of materials to be recycled; whether the recyclables are segregated or commingled for collection; whether a collection container is provided and its type; and collection frequency and day of collection. The design of education programs, demographics of the target population and types of incentives are also important issues considered in the design of a SS scheme. In order for any designed SS scheme to meet the goals or targets for which they are implemented, the various design variables and options available must be understood and carefully selected since they impact the success of the scheme. The prerequisites for the successful implementation of a SS programme as stated in the IETC (1996) report are that the scheme should be easily seen in the region of implementation, economically sustainable and means of transport and market of targeted materials to be separated should be available. The report of Lardinois and van de Klundert (1994) on expert opinions suggest that the following factors influence the propensity to separate at source: " habit, frugality or thrift, religio-cultural factors, charitable motives, socio-economic status, status and wages of household servants, space in the household, convenience of disposing of separated materials, environmental education and gender". The level of inconvenience posed to a waste generator through the type and design of collection scheme may influence participation rates in SS programmes (Perrin and Barton, 2001). Lardinois and Furedy (1999) concluded that SS may not be recommended under all circumstances and in all situations therefore SS should be considered from a local perspective integrating environmental, financial, economic, social, institutional and educational aspects.

2.2.3.1 Mandatory versus Voluntary SS Programmes

Participation in a SS programme by households may be mandatory or voluntary. In a mandatory programme all residents in the programme area are required by law to participate in the SS programme hence the type of enforcement mechanism employed influences participation and recovery rates (Noehammer and Byer, 1997).

In contrast, voluntary SS programmes give residents the choice whether to participate or not. As a result, it is crucial for features of voluntary programmes to include the provision of some incentives for residents to participate. In the United States it was found that more recyclable materials are collected through mandatory SS as compared to voluntary SS (Everett and Pierce, 1993). However, Tchobanoglous and Kreith (2001) and Noehammer and Byer (1997) argue that there is no indication that well-communicated and implemented voluntary SS scheme cannot achieve the same levels of success as a mandatory programme.

2.2.3.2 Types of Material to be Recycled and Separation Methods

The SS programme cost and the quality of recovered materials is significantly influenced by how the recyclable materials are collected. It is important that sufficient quantities and markets for materials that are targeted for separate collection exist (Lund, 1993). Bolaane (2006) found out that materials separated for recycling that have known markets and are of significant financial value are more likely to be source separated by individuals. The recyclable materials may be collected from the individual waste generator (kerbside or door-to-door collection) or the waste generator may the required to send the recyclables to a drop-off or buy-back location. Kerbside collections are found to generally yield much more material per capita but are also much more expensive than drop-off or buy-back collection (Craighill and Powell, 1995; Tchobanoglous and Kreith, 2001)**.**

Two collection methods also exist depending on the number materials collected in a bin; single material collection or commingled collection (Noehammer and Byer, 1997; Lund, 1993; Tchobanoglous and Kreith, 2001). In the single material collection system, waste generators are required to place one type of material in a bin for example it was indicated that residents in some German cities had up to seven different bins in which to place different materials (Woodard et al, 2001). Woodard et al. (2006) found that the participation rate is higher in schemes that collect more types of materials and reported participation rates of 38%, 49% and 65% schemes that collected 1, 2 and 3 material types, respectively in England.

In the commingled collection system waste generators are required to place all targeted recyclable materials in one bin for collection i.e. to separate recyclable from non-recyclable materials. In this case recyclable materials once collected are transported to a central place or material recovery facility (MRF), where they are sorted into separate recyclable components to meet end user requirements (Tchobanoglous and Kreith, 2001; Noehammer and Byer, 1997). Lyas et al. (2005) suggested that to improve commingled system of collection of recyclables resources should be directed towards reducing contamination, promoting a wider waste minimisation message and targeted promotion.

2.2.3.3 Provision and Type of Container

In a SS scheme containers may be provided to waste generators free of charge or at a fee or no container may be provided by the local authorities (Noehammer and Byer, 1997). The provision of free container in SS programmes significantly influences higher participation rates (Folz, 1991; Crichton et al., 2003; Lyas et al., 2005). The high participation rates and recovery levels associated with the provision of a free container are owing to increased convenience, a visual reminder to recycle and peer pressure, since the absence of a container clearly identified non-recyclers (Everett and Pierce, 1993). Crichton et al. (2003) also assert that the provision of free containers in a SS scheme indicates the commitment of the local authority to the program and reminds the waste generators of the service that is being provided. Noehammer and Byer (1997) concluded that provision of a container impacts to a higher degree the participation rates in voluntary SS programmes as provision of a container didn't seem to have the same impact in mandatory SS programmes.

Everett and Pierce (1993) indicated from their literature review that participation and recovery rates are higher with the provision of rigid containers although initial cost of such programmes may be high. Findings by Wang et al. (1997) suggest that the most dominant factor that facilitates participation in SS schemes is the provision of durable containers. Crichton et al. (2003) found that out of the three types of containers (sacks/bags, wheelie bins, boxes) provided for SS schemes bins or boxes are usually preferred to bags. This they attributed to the assumption that scheme users often see the bins or boxers as been more tidy, can be stored outside their facilities, re-usable and cannot be easily blown away. It was further indicated that the scheme users assume ownership of the bins/boxes and this serves as a reminder for them to separate their waste.

2.2.3.4 Collection Frequency and Collection Day

Everett and Pierce (1993) argue that it is more convenient to scheme users when materials are collected frequently. This is because there may be less build up of recyclables that may inconvenience the scheme participants especially should one pick-up day be missed (Everett and Pierce, 1993). Crichton et al. (2003) indicated that collection frequency is dependent on other factors such as the existing waste collection schedule and type of container used. They found that higher material recovery rates are more likely achieved with more frequent collections. Noehammer and Byer (1997) identified five common collection frequencies among SS programmes as weekly, biweekly, once every three weeks, monthly and bimonthly. The cost of collection may influence the decision of selecting which collection frequency is most appropriate for any region (Everett and Pierce, 1993; Noehammer and Byer, 1997) as well as the type of container provided (Crichton et al., 2003). Although research carried out on the impact of collection frequency and day has shown conflicting results, collection of recyclables on the same days as residual waste may be more convenient (Everett and Pierce 1993) and this may lead to higher participation and recovery rates (Everett and Pierce, 1993; Crichton et al., 2003). It is also suggested that collection containers be of uniform recognizable colour within the region where SS scheme is implemented to improve participation (Crichton et al., 2003). Some recognizable collection container colours cited by Crichton et al. (2003) are: red or blue containers for dry recyclables; green or brown for biodegradables; white for paper/card; grey bins for residual wastes and yellow containers for healthcare and clinical wastes.

2.2.3.5 Source Separation Scheme Promotion and Education

Adequate communication and information in SS programme design are important because they can influence the habits and traditions as well as attitudes and motivations of the waste generators ensuring that the goals and targets of SS schemes are met (Evison and Read, 2001). Barr et al., 2001 found knowledge on eligible materials to be collected and how these materials can be recycled in a community to be a significant issue that needs to be addressed in implementing any SS programme. This was confirmed by Budak and Oguz (2008) who found the most statistically significant factor in assessing households' participation in recycling programmes as knowledge of the benefits of recycling and understanding how to participate in a designed scheme. Read (1999) suggested that SS scheme promotional materials be simple and easy to understand since it can lead to higher participation and recovery rates.

Adverts, newsletters and special events are some techniques mentioned to have been used to stimulate individuals to participate in SS programmes as noted in Table 2.6 (Read, 1999).

Table 2.6 Common Methods used by Local Government to Promote Waste Management Programmes

Passive approach	Active approach	Interactive approach
Advertising on collection vehicles	Cards delivered door-to-door to explain the system	Door-to-door surveys and education
Displays for use at fairs and public events	Collection receptacles provided free to residents	Presentations in schools, to groups or at conferences
Household leaflets	Promotional videos	Public meetings
Newspaper articles each month covering waste	Seasonal promotions to encourage participation	Radio spots, adverts or phone-ins
Reminder cards, answering questions	Community newsletter	Telephone hotline
Stickers to designate recycling bins	Display boards	Visits to the recycling centre/education facility

Source: Read (1999)

Evison and Read (2001) also reported that SS scheme promotion through the mass-media positively impacted the recovery of all materials whether the promotion targeted single or multiple materials. Findings of Reams and Ray (1993) as reported by Evison and Read (2001) however show, with statistical evidence, that household SS schemes promoted through direct and personal contact are more effective in stimulating participation than providing general information through the media. This was attributed to increased awareness and peer pressure effects. Folz (1991) and Folz and Hazlett (1991) found that most successful recycling programmes surveyed in the United States of America were observed in cities where publicity and educational campaigns were prepared by local authorities with the help of local education personnel, environmental organizations or other citizen groups. This is linked to the assertion that the emphasis on citizen involvement in programme design may deepen the sense of personal responsibility and commitment to the success of the programme. Perrin and Barton (2001) identified that recoveries of all materials increased when SS scheme participants were provided with feedback on their performance through a leaflet. The feedback leaflet was thought to have reminded households of the scheme requirements and given them an idea of their performance. Mee and Clewes (2004) found 75% of respondents indicating that communications, done mainly through a newsletter and personalized letters, had influenced their participation in a recycling scheme instituted in a pilot area of Rushcliffe Borough Council in Nottinghamshire in the United Kingdom.

2.2.4 Measuring the Performance of Source Separation Systems

Thomas (2001) points out that the meeting the goals of a SS programme does not only depend on the number of participants but also on how well participants conform to the scheme design. Tchobanoglous and Kreith (2001) and Thomas (2001) agree that it is difficult to measure quantitatively the performance of SS programmes on a consistent and standardized basis. However, it is necessary to measure SS scheme performance regularly to find out areas where interventions could be made to improve the scheme in order to meet recycling targets or scheme objectives. Tchobanoglous and Kreith (2001) and Thomas (2001) identified four performance measures that are generally reported: capture rate, participation rate, recycling rate and diversion rate.

2.2.4.1 Capture Rate

Capture rate (also referred to as the source recovery factor) is defined as "the weight percent of an eligible material in the total SW stream actually separated out for recycling" (Tchobanoglous and Kreith, 2001). Capture rate applies to individual material, not recyclables in general. For example Friends of the Earth (2008) reported the following capture rates for various materials collected through recyclable collection trials in 4500 households in Mersea-Essex:

- Green waste – 358kg collected out of 360kg available per household per year
- Glass and cans- 78kg collected out of 201kg per household per year
- Paper and card- 176kg collected out of 319kg available per household per year
- Plastic bottles – 11kg collected out of 15kg available per household per year
- Textiles – 3kg collected out of 17kg available per household per year

The capture rate measures how well householders are separating available recyclable materials for collection as this indicates whether a SS programme is meeting its targets. Knowledge of the quantities of various materials in the waste stream is necessary in computing the capture rate therefore warrants some form of household characterizations studies before a SS programme set up (Crichton et al., 2003).

2.2.4.2 Participation Rate

Participation rate is defined as "the percent of households (or businesses) that regularly set out recyclables" (Tchobanoglous and Kreith, 2001). It is also defined as "as the ratio of the number of generators participating at least once in a four week period to the total number of generators served by the programme in the same four week period x 100" by the European Recovery and Recycling Association (Thomas, 2001). Participation rate is computed on a monthly basis since it assumed that households actively participating in a scheme will put out materials for collection at least once in a month even if collection is provided weekly of fortnightly (Woodard et al., 2006). The type of materials or quantities of materials collected in a SS scheme is not indicated through the participation rate but the participation rate shows the extent to which waste generators are involved in the scheme (Wang et al., 1997; Tchobanoglous and Kreith, 2001).

2.2.4.3 Recycling Rate

Recycling rate is defined as "the quantity of material from households sent for recycling (materials recycling and centralized composting)/total quantity of household waste available ×100" by United Kingdom Department of the Environment, Transport and the Regions (Thomas, 2001). It may also be used to represent the quantity of recyclables collected per household per unit of time (e.g., 35 kg/residence/month) (Tchobanoglous and Kreith, 2001). The recycling rate normally addresses what was collected without regard to whether the material was actually sold or what amount of contamination was present in the recyclables.

2.2.4.4 Diversion Rate

The diversion rate is a measure of the total quantity of waste that is 'diverted' from landfill as a fraction of the total waste generated each year, often expressed as a percentage (Tchobanoglous and Kreith, 2001). For example, a 40% diversion rate was achieved in the city of London, Ontario – Canada through various recycling programmes like the blue box collection of recyclables, kerbside depots and self management of yard wastes, garbage container limits, household special waste depots, electronics recycling depots and the banning of appliances from garbage collection (City of London, 2007). The diversion rate gives an indication of how well waste reduction, reuse, recycling and composting strategies decrease the volume of waste that end up at landfills.

2.2.4.5 Overall Recovery Rate

Overall recovery rates for waste materials is said not to be dependent on the number of households participating only but also the householder's sorting efficiency (McDougall et al., 2001). The percentage of targeted material correctly sorted and separated by participants in a SS scheme relates to the amount of material recovered in the equation (McDougall et al., 2001):

Amount of material recovered = Amount of targeted material in waste stream x the percentage of households participating x separation efficiency 2-1

Where, the separation efficiency is defined as the percentage of material correctly sorted and separated. Perrin and Barton (2001) emphasized that the how efficient each targeted material is recovered depends on: (1) When and where the waste material is generated; (2) if it requires immediate storage; and (3) households recognition of its recyclability.

2.2.5 Some Studies on Source Separation in Developing Countries

There are various socio-economic and socio-demographic factors that influence SS of solid waste at the household level. These factors include income, gender, age, education level, space in the household, distance from home to community dumping site, religion, and so on (Furedy and Lardinios, 2000). Bennagen et al. (2002) indicate that the probability of household to participating in SS of solid waste is a function of three sets of variables, i.e., socio-economic household characteristics; household waste management-related attributes, and a community waste management-related feature.

Few studies have been reported in literature on the evaluation of organized SS at the household level in developing countries. Some identified studies are reported as follows. To facilitate sorting of the waste at the source, three plastic bags were distributed to 80 households in a middle income community in Dar es Salaam Tanzania for storage of compostable, recyclables and other wastes. The waste generation rate and composition were reported from the study. However, there was no mention of how well households adhered to the waste separation at source (Kaseva et al., 2002). Ranninger et al. (2006) reported an average wrongly sorted materials in the organic MSW of 4% wet matter after evaluating an annual collection of two stream of waste (bioorganic MW and Residual MW) from proposed 244 households during a pilot study in China. They reported that out of 95% of households in selected areas that agreed to participate in the study 85% delivered the requested two streams of waste during the first months with the average participation rate stabilizing at about 70% during the course of 12 months of the study. It was also reported that willingness of households to participate in SS was increased from 86% at the onset of study to 97% at the end of 12 months of the study. 100% of the project participants also thought that the government should be encouraged to introduce obligatory SS. Further it was indicated that 77.8% of project participants may continue the SS even if no waste bins would be available in the courtyard and only 2.3% may stop SS without waste bins. Nguyen (2005) undertook a one week pilot project of SS of compostable conducted in 67 residences in Danang, Vietnam. Results from the project show the high purity of the separated compostable waste as reported separation efficiency of compostable waste was 97.8%. It was further indicated that the high number of participants (44 out of 67) separating waste correctly indicates their willingness to participate in a waste separation programme.

The results from the studies enumerated above, although limited, indicates that the willingness of households in developing countries to separate their waste at source is high and with incentives and careful scheme design, taking into consideration local conditions, source separation of household wastes in developing countries could be achieved successfully.

2.3 ANALYSIS OF MODELS FOR MUNICIPAL SOLID WASTE MANAGEMENT (MSWM)

Developing sustainable WM programmes requires decisions to be made considering the key technical, legal, economic, environmental, political, and social issues related to MSWM (Abou Najm et al., 2002a). The complex interactions and interdependencies within elements of the MSWM system make it quite challenging to make decisions explicitly. For example, complex interactions exist among collection and transportation systems, land use patterns, public health considerations, and treatment options (Gerlagh et al., 1999). Also, disposal methods for instance can influence collection and vice versa. Systems analysis and mathematical modelling techniques are being used to assess MSWMS due to the interactions and interdependencies in the system. According to Gerlagh et al. (1999) modelling ensures an orderly interpretation of data and a consistent representation of a system, provides a quantitative indicator of the efficiency of resource use and can be used to anticipate the response of a system when the context changes. Therefore they asserted that models may be used to assess alternative policies, optimize total system costs and assess impacts on the system through different operations. Many sophisticated quantitative models have been developed to address different important aspects of SWM such as allocation of waste over disposal sites, routing of collection vehicles, waste estimation and prediction, rankings of disposal alternatives and location of SWM facilities such as transfer stations, processing plants and disposal sites, and predicting environmental burdens of SWM processes. Also a large number of modelling tools and approaches that can be used for supporting waste management decisions at different levels in society have been developed. Examples include Life Cycle Assessment (LCA) and different types of Material Flow Analysis, Cost-Benefit Analysis, Life Cycle Costing, different types of optimizing models, etc. (Finnveden et al., 2006). Social, environmental and economic compatibilities are observed to be the dimensions of sustainable waste management models or strategies (Morrissey and Browne, 2004). Some of these models found in literature are briefly discussed below.

2.3.1 Waste Estimation and Prediction Models

Successful SWM frequently depends on accurate predictions of waste generation. Conventional prediction models frequently use socio-economic and demographic factors on a per-capita basis which may be fixed over time or projected to change with time. Based on the estimation of generation rates and the composition of urban solid waste and socioeconomic variables in Morelia, Mexico, Buenrostro et al. (2001) used multiple linear regression analysis to forecast the generation of residential and non-residential solid waste. The independent variables analyzed were monthly wages, persons per dwelling, age and educational level of the heads of the household for residential sources and number of employees, area of facilities, number of working days, and number of working hours per day for non-residential sources. They observed that the variables useful for forecasting residential waste generation were monetary income and density of dwellers per household. The number of working hours was found to be useful for forecasting non-residential waste generation.

Chang and Lin (1997) opine that by analyzing time series data, forecasters can identify trends embedded in solid waste generation over time and can develop hypotheses regarding the policy change or the continuation of these trends into the future. They applied time series intervention modelling to evaluate recycling impacts on solid waste generation. A demonstration of how this forecasting information can be used for the capacity evaluation of incinerators in Taipei City of Taiwan was also demonstrated. Navarro-Esbrı´ et al. (2002) proposed a prediction technique for MSW generation based on non-linear dynamics; its performance was compared with a seasonal auto regressive and moving average methodology, dealing with short and medium term forecasting. A practical implementation consisting of the study of MSW time series of three cities in Spain and Greece was presented. The non-linear forecasting technique gave results that were comparable to the ones obtained by the seasonal auto regressive and moving average methodology.

2.3.2 Material Flow Analysis and Input-Output Models

Material flow analysis (MFA) such as Life Cycle Analysis or Substance Flow Analysis, and Input-Output Modelling, has been used to generate consistent relations between consumption, production, and flows of various materials in the economy. Most of the models developed based on life cycle analysis are used to evaluate the environmental burdens associated with various waste management strategies from a systems perspective.

An input-output methodology was used by Pimenteira et al. (2005) to examine the potential of energy conservation related to the recycling of domestic waste in the state of Rio de Janeiro. They represented the interdependency among various sectors of the economy with a static input-output model where waste is considered as a generated and processed commodity. A comparative profile was developed from the state of recycling and the various aspects of SWM, both from the perspective of its economic feasibility and the social aspects involved. This model is limited to energy savings and the impact on green house gas emissions of recycling and disposal of waste and does not consider the other waste management alternatives. Drescher et al. (2006) combined the methods of MFA and cost accounting in order to visualize and estimate cost implications of existing SWM system and proposed composting units from the municipality's viewpoint in Asmara, Eritrea. The MFA tool Umberto was used to facilitate the modelling and data calculation. Their results show that decentralized composting strategy significantly reduces transportation costs which partly compensate the investments and operation costs of the decentralized composting systems.

One approach being used to compare the environmental performance of alternative systems is Life Cycle Assessment (LCA). LCA considers and quantifies all relevant environmental consequences of a product system over its entire life. Solano et al. (2002) developed an integrated solid waste management decision support tool using the LCA technique. The model is to assist in identifying alternative SWM strategies that meet cost, energy, and environmental emissions objectives. The mass flow of each item through all possible combinations of unit processes is represented in a linear programming model using a unique modelling approach. A life-cycle approach is used to compute energy consumption and emissions of carbon monoxide, fossil- and biomass-derived carbon dioxide, nitrogen oxides, sulphur oxides, particulate matter and greenhouse gases. Other ISWM models developed using LCA include: EASWASTE developed by Kirkeby (2004), WASTED developed by Diaz and Warith (2006) and Integrated Solid Waste Management (IWM-2) developed by McDougall et al. (2001).

2.3.3 Optimality Analysis Models

Cost minimization has been the objective of many municipal waste managers hence there has been the focus of using optimization tools to select least cost alternatives for MSWMS. Gerlagh et al. (1999) reiterated that a model of a waste sector in a developing country should be different from a comparable model of a developed country, for various reasons. They gave reasons as first; the two regions have different forms of waste generation, collection and processing and secondly the major differences in waste management priorities. These differences should be reflected in the model, either in its structure or in the scenarios which are run. They developed a linear programming model with the prime objective of minimizing the overall systems cost and identifying the low cost alternatives for managing waste effectively. The model described the activities of the waste management sector resulting from the demands in other parts of the economy for the processing of waste and for secondary output. The costs related to these activities were determined by a combination of demand and supply of production factors such as labour and capital. Although the model was developed as a single objective model, it integrated other important social and environmental objectives associated with solid waste management. Without this characteristic the model would have been deemed considerably less valuable for policy makers. The possibility to fine-tune the model to a local situation is a strength, but also a weakness as noted by the developers. They indicated that extensive set of data is required to run the model, which is difficult to come by in especially developing countries, were the quality of data may vary significantly. It was also noted that generating data on the environment and on the informal sector could be daunting and a basic level of understanding on linear programming and economic principles is required to use the model. Therefore, policy makers may require the support of economic researchers or a user support system to operate this model.

Jain et al. (2005) proposed a model whose prime objective was to minimize overall system cost and to identify the low cost alternatives to manage generated waste effectively taking clues from the model of Gerlagh et al. (1999) discussed above. The model was applied to calculate the cost incurred and the amount of energy recovered from MSW for the various disposal options such as biomethanation digester process, composting, incineration, and landfilling to suggest the most economically viable option. On the basis of preliminary calculations of the economical viability of various technological options, it appeared that landfill gas technology, composting, or biomethanation digester plant technology can give profit for MSW treatment, whereas, incineration always incurs a loss. Other system cost optimization models have been developed by Abou Najm et al. (2002a, 2002b) and Nle et al. (2004); based on a linear programming formulation, Costi et al. (2004); by the formalization of a constrained non-linear optimization problem and Chang and Wang (1996); employing the technique of multi-objective mixed integer Programming. Rathi (2007) developed and applied a linear programming model to optimize the integration of various economic and environmental costs and stakeholders involved in the MSWM in Mumbai. The optimal solution of the model indicated that community compost plants were the best option whereas sanitary landfills were indispensable for waste management in Mumbai.

With the introduction of recycling into the MSWM system, some models have also been developed to evaluate the costs and environmental impacts associated with various schemes for resource recovery or the optimal design of recycling systems. Diamadopoulos et al. (1995) suggested an integer linear programming methodology for the optimal design of MSW recycling systems. An integer linear programming approach was followed in order to specify the optimal recycling scheme, as well as the optimal life of the disposal site. The model considered all costs, in present values, concerning recycling of products, disposal of solid wastes, closure of the old landfill and opening of a new one. Economic benefits included revenues coming from the selling of the recycled goods, and those originating from extending the life of the landfill. Application of the model to the city of Chania, Greece, for the recycling of paper, glass, aluminium and organic residues (putrescible matter) showed that recycling brought about a significant reduction in the mean annual cost of SWM by 35%, as well as an increase in the life of the landfill by six years.

A computer model was developed and applied for studying integrated MSWM in the Helsinki Metropolitan Area by Tanskanen (2000). This model was based on a method developed for analyzing on-site collection systems of waste materials separated at the source for recovery. The aim of the Helsinki study was to find and analyze separation strategies fulfilling the recovery rate targets adopted for MSW in Finland, i.e. 50wt. % by the end of 2000 and 70wt. % by 2005. The model developed proved to be a suitable tool for strategic planning of MSWM. It was indicated that the analysis of collection systems helped to identify potential separation strategies and to calculate the amounts of materials collected for recovery. Modelling of MSWM systems also made it possible for the determination of the effects of separation strategies on costs and emissions caused by the whole MSWM.

It is often considered a main weakness of cost-benefit studies that they only account for those factors which are measured in monetary terms, neglecting the socio-environmental costs which are not expressed in monetary units, such as health impacts due to pollution. It is noted that both qualitative and quantitative variables should be analysed together in order to achieve sustainability in MSWMS (Gerlagh et al., 1999). If an emphasis is put on the incorporation of many criteria, a technique like Multi-Criteria Analysis is used to select the preferred waste disposal options.

Sudhir et al. (1996) developed a nonlinear goal programming model within the critical operational research framework to facilitate consensus/conflict resolution among the many actors involved in MSWM. To choose the best SWM system out of existing alternatives for the Oulu region in Finland, Hokkanen and Salminen (1997) applied the ELECTRE III decision aid. They opted for ELECTRE III, since it can easily consider imprecise data and indicated that Multi-Criteria Analysis may serve as an important tool for environmental decision making by accommodating both technical information in its original form as well as evaluative criteria. However, it is reported that biased results may be obtained if suitable selection criteria and assignment of appropriate weights are not properly considered (Gerlagh et al., 1999).

2.3.4 Summary

It may be inferred, from the review of application of system analysis tools in waste management that the choice of modelling approach utilized depends on the type of WM decisions that confronts decision makers. These modelling approaches are tailored to suit the specific needs of the regions that they were designed for. Hence, a tool developed for one region cannot be applied directly in another without modification.

CHAPTER 3

METHODOLOGY

This chapter provides information on the two areas studied as well as the methods employed to collect and analyze necessary data. The first section presents the profile of the two study areas and the description of the current SWM system in these areas. The second section presents an overview of methods utilized for waste characterization studies and the specific method employed to undertake waste characterization and pilot source separation in the study area. A description of the waste treatment options considered for establishing an ISWM system in Kumasi and the formulation of linear programming model for optimization of the waste treatment options is presented in the third section.

3.1 STUDY AREAS: KUMASI METROPOLITAN AREA (KMA) AND KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY (KNUST)

3.1.1 The KMA an Overview

3.1.1.1 General Description of KMA and Asokwa Sub-metropolitan Area

A brief description of Kumasi by the Kumasi Metropolitan Assembly (Ghanadistricts, 2008) is presented as follows: Kumasi is located in the transitional forest zone and is about 270 km north of Ghana's capital, Accra. It lies in latitude 6.35^o – 6.40^o and longitude 1.30^o – 1.35^o, an elevation of 250 – 300 m above sea level with an area of about 254 km^2. The average minimum temperature is about 21.5^{o}C and a maximum average temperature of 30.7^{o}C. The average humidity is about 84.16% at 0900 GMT and 60% at 1500 GMT. The city has a double maxima rainfall of 214.3 mm in June and 165.2 mm in September. The Kumasi Metropolitan Area has been estimated to have a daytime population of about 2 million. The population has grown rapidly over the inter-censal periods from 346,336 in 1970, 487,504 in 1984 to 1,170,270 in 2000. It has been projected to have a population of 1,610,867 in 2006 and 1,889,934 by 2009 based on a growth rate of 5.47% per annum. The growth of industries and the large volume of commercial activity in and around Kumasi as well as the high migrant number may account partly for the relatively high urban population. The Metropolis falls within the wet sub-equatorial type (Ghanadistricts, 2008).

Kumasi has been divided into ten Sub-metropolitan areas namely: Asawase, Asokwa, Bantama, Kwadaso, Manhyia, Nhyiaeso, Oforikrom, Suame, Subin and Tafo. The research was carried out in Asokwa Sub-metropolitan area. The Asokwa Sub-Metro is the area under the jurisdiction of the Asokwa Sub-Metro council. This sub-metro area is located at the south eastern part of the Kumasi metropolis. It shares boundaries with the Oforikrom Sub-Metro on the east, Subin Sub-Metro on the north and Nhyiaeso Sub-Metro on the west. It comprises ten (10) communities namely: Old Asokwa, New Asokwa, Ahinsan, Ahinsan Estates, Kaase, Atonsu-Agogo, Gyenyase, Dompoasi, Kuwait and Chirapatre. The sub-metro area has a population of over 200,000. The characteristics of the population are urban and peri-urban in nature. Solid waste collection in the sub-metro area has been contracted to a company called SAK-M. Two waste collection methods are present in the sub-metro area; door-to-door collection and communal collection. The Kumasi Metropolitan Assembly has stratified the areas in the city into three classes based on the characteristics of housing and infrastructure as; 1st, 2nd and 3rd class areas.

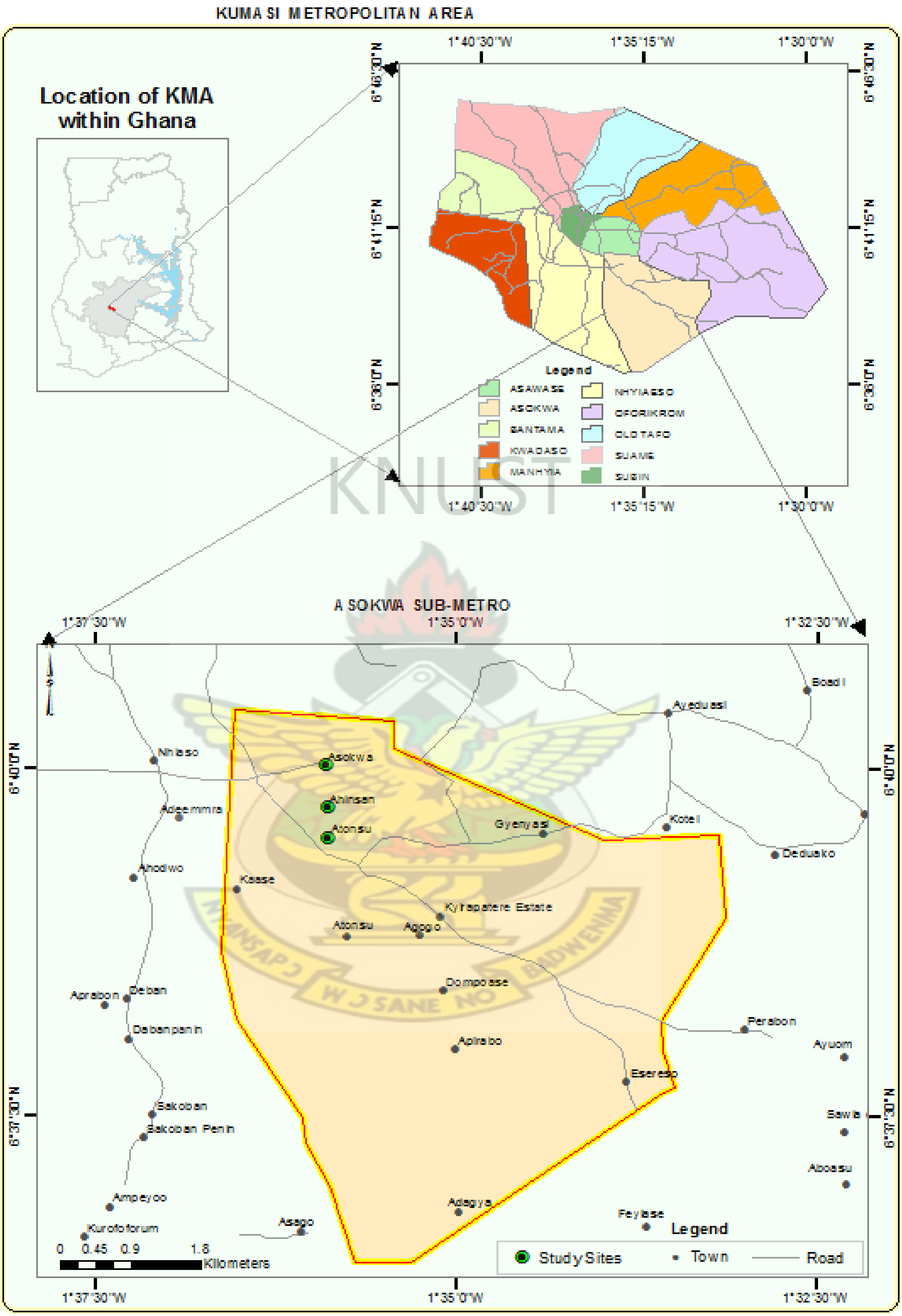

Figure 3.1 Map of KMA Showing Sub-Metropolitan Areas and Selected Areas of Study in the Asokwa Sub-Metropolitan Area

High income, low population areas with access to good infrastructural facilities are designated as 1st class areas, low income, densely populated areas with poor infrastructural facilities are designated as 3rd class areas and the 2nd class areas are middle income areas with population density and level of infrastructural facilities found in between the 1st and 3rd class areas. Three communities, Asokwa, Atonsu and Ahinsan, representing the classification of households into first, second and third class areas respectively were selected in the Asokwa Sub-Metro for the study. Thirty-five houses from each residential class were to be included in the study.

3.1.1.2 Waste Management System in Kumasi

a. Waste Generation

The municipal waste generation in Kumasi based on the projected population of 1,610,867 (2006) is 1000 tonnes per day. It is estimated that households generate the highest amount of waste in the municipality, followed by Markets then industries with the least from institutions. The waste generation rate in the municipality is expected to go up by 15% by the year 2010 (personal conversation with Director of the waste management department (WMD- KMA, 2008).

b. Waste Composition

The composition of waste in Kumasi is predominantly made of biodegradable materials with a high percentage of inert materials as well. The inert material is mostly made of wood ash, sand and charcoal. The percentage of various streams in the waste in Kumasi is shown in table 3.1

Table 3.1 Waste Composition Data, Kumasi in 1998

Waste component	Kumasi,%
Biodegradable/ Organic	64
Paper	3
Plastic	4
Metals	1
Inert	22
Wood	3
Textiles	3

(Source: WMD-KMA, 2008)

c. Collection Methods, Service Coverage and Transportation

Two types of methods are employed for the collection of MW in Kumasi. These are the house-to-house (kerbside) solid waste collection utilizing compactor trucks and communal solid waste collection. The Communal Collection System entails the location of metal containers (skips) at designated sites known as transfer stations, which are shared by a number of houses within that community. When the skips are full, they are transported and emptied at a final disposal site by skip loading trucks. Collection of waste from institutional and industrial premises also relies on container services including limited sections of the Kwame Nkrumah University of Science and Technology campus. The average waste collection cost US$ 350,000/month with waste generators bearing 15% and the municipal authority 85% (WMD-KMA, 2008). Approximately 85% of the waste generated is collected in the municipality. The waste collection service in the city is carried out by the private sector under various agreements with the municipal assembly.

d. Waste Treatment and Disposal

The waste collected from the city is disposed of at two sites with a total capacity of 4,587,456 m^3; a sanitary landfill site and an open dump. The sanitary landfill is constructed on a 100 acre land and treats both solid waste and sewage. The estimated cost of operating the landfill is US$ 250,000/month excluding the cost of land use and facility closure (personal conversation with director of the WMD- KMA, 2008). The government bears 95% of the landfill management cost. The sanitary landfill is managed by a private contractor on behalf of the city authority. Waste diversion through recycling and reuse is carried out on an informal basis which is not widely recognized as contributing to WM in the city. Solid waste disposal practices of households in the Kumasi metropolis (GSS, 2000) is presented in table 3.2 below. The information presented in table 3.2 suggests that waste generated from about 16.7% of households in the city is not collected for proper disposal. High percentage of households dispose their waste in public dumps, these dumps could be communal collection sites or sites within communities where waste is dumped without any evacuation to designated landfill sites.

Table 3.2 Means of solid waste disposal of households in the Kumasi Metropolis (GSS, 2000)

Disposal Method	Percentage of Households
Collected	2.2
Burned by household	3.6
Public dump	81.2
Dumped elsewhere	10.1
Buried by household	2.4
Other	0.6

e. Municipal Solid Waste Management (MSWM) Strategic Plan

The Kumasi Metropolitan Assembly produced a strategic sanitation plan for Kumasi for the period 1990-2000 which was later reviewed and extended for the period 1996-2005. The component of SWM within the plan seeks to develop a landfill for the city and to engage the private sector in waste management services. This has, so far, been achieved in the city. The KMA is in the process of developing an integrated SWM plan for the city.

f. Government Laws and Regulations

The Kumasi Metropolitan Assembly has byelaws related to handling of wastes which are deemed to be outdated, particularly, in terms of penalties. The enforcement of these byelaws has also been weak. Current WM challenges that city authorities enumerate are;

1. Inadequate funding for capital investment for effective delivery of waste management services;
2. Inadequate equipment holding culminating in limited coverage of service delivery;
3. Inadequate byelaws and lack of enforcement of available ones;
4. Inadequate revenue mobilization to finance WM Service costs;
5. Bad attitude of residents such as indiscriminate disposal of household waste and littering due to lack of effective environmental health education and service promotion strategy;
6. Poor infrastructural condition particularly road networks and waste collection points, mostly in new settlements, which impacts negatively on service delivery.

3.1.2 KNUST Overview

3.1.2.1 General Description of KNUST campus

The Kwame Nkrumah University of Science and Technology (KNUST) is situated in Kumasi, the second largest city of Ghana. It covers a total land area of about 16 square kilometres. The KNUST campus is a medium to high class community with a yearly increase in population especially in terms of students. The inhabitants of the university are mainly students, academic staff and the non- teaching staff. The student population as of 2006/2007 academic year was 22,121 and about 3,307 academic and non-academic staff (KNUST, 2007).

The university has a good layout of roads most of which are tarred and they make most areas of the university accessible. KNUST can be categorized into four main zones; the halls of residence for students (which are often densely populated), the residential staff bungalows, the faculties and offices, and the commercial area. The areas from which staff bungalows were selected for this study are shown in figure 3.2 below.

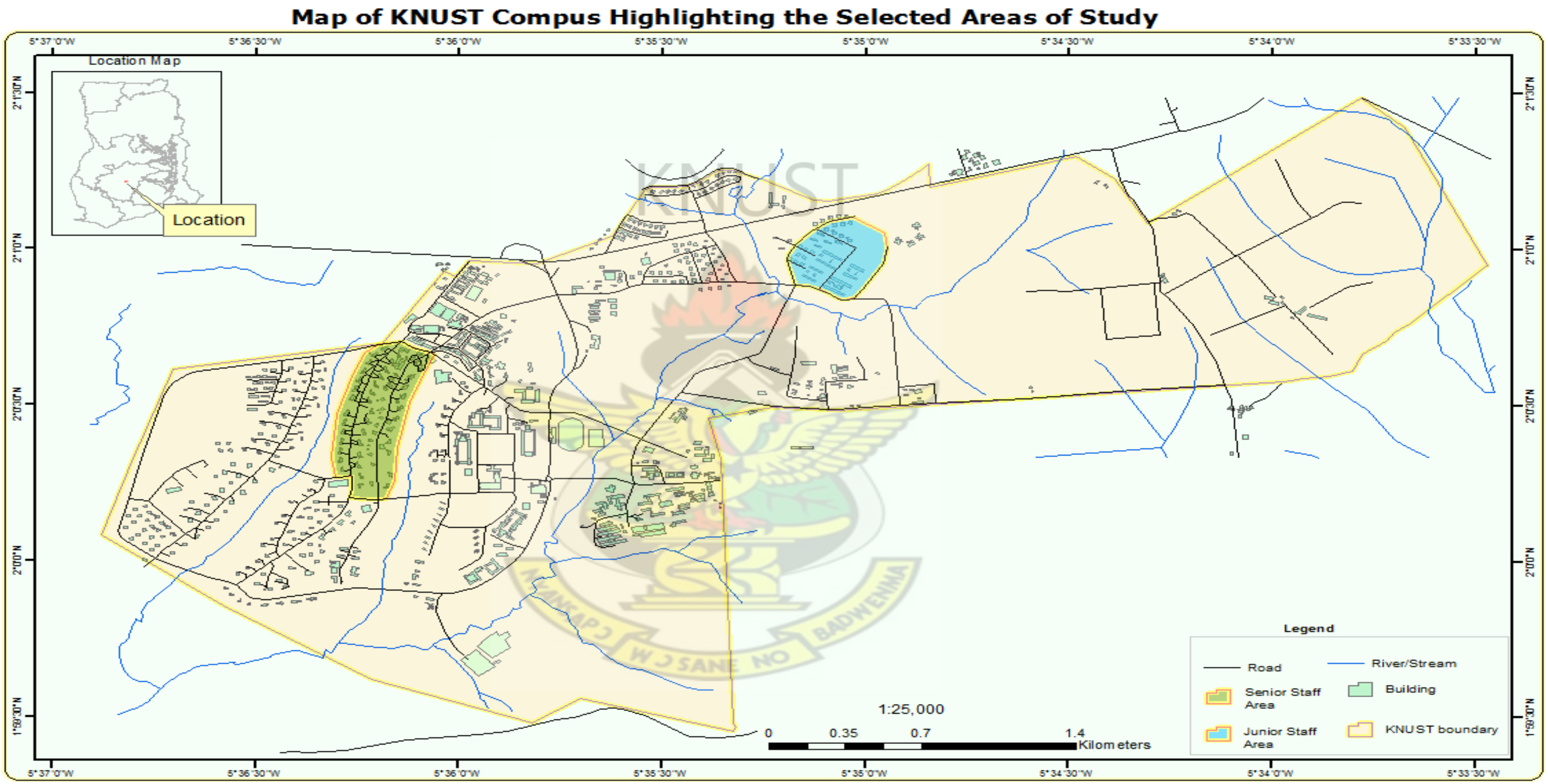

Figure 3.2 Map of KNUST Campus Highlighting the Selected Areas of Study

3.1.2.2 Solid Waste Management on KNUST Campus

Primarily, inhabitants of KNUST store their SW in bins at their various homes, halls and other production areas. These dustbins are emptied every morning by labourers who transfer the waste to concrete containers (skips) with wheelbarrows for secondary storage. From the concrete containers, the wastes are later taken to the final waste disposal site by either a side-loader or a compacter truck provided by the University. The transportation of waste from the various sites to final disposal site is done on a fairly regular basis. The collected waste is dumped on a piece of land belonging to the university. The university as of the time of this study had no strategic plan for SWM and estimates for the quantities of waste handled were also non-existent.

3.2 WASTE CHARACTERIZATION AND SOURCE SEPARATION STUDY

It has been indicated in literature that because of the heterogeneous nature of MSW, determination of composition is not an easy task. Strict statistical procedures are difficult, if not impossible, to implement. An overview of methods used in waste characterization studies is presented in this section followed by the particular methodology adopted for this study.

3.2.1 Overview of Waste Quantification and Characterization Studies

Waste characterization refers to the quantification of various waste components. The output is the weight and the composition of the various waste fractions (Dahlén, 2005). There are two basic methods for characterizing MSW— the material flow and direct sampling method (Tchobanoglous and Kreith, 2001).

3.2.1.1 Material Flow Method

This method applies the concept of conservation of mass to track quantities of materials as they move through a defined system or region in order to estimate the composition of the SW stream. In this approach, a material balance is undertaken for a material in a region to derive the quantity of that material that would be expected to report to the waste stream. The material flow methodology is based on the production data by weight for materials and products. Waste generation in this case is computed by making specific adjustments to production data for imports, recycling and materials that are deemed not to end up in the MSW stream as well as the estimated life span of a material (Tchobanoglous and Kreith, 2001). Difficulty in quantifying product residues, such as food left in the container and detergent remaining in the package and the inability to address variations in local waste generation conditions are cited as the main drawbacks of this method (Chung and Poon, 2001). Reinhart and McCauley-Bell (1996) criticises this method for focusing on product categories instead of waste stream categories and the possibility of excluding some significant waste components that do not originate in the product sector, such as yard waste. However, they acknowledge that this method may be more suitable to large geographical areas, i.e. the entire country, rather than local studies.

3.2.1.2 Direct Waste Sampling Method (Output Method)

Direct sampling involves sampling, manually sorting the waste into several categories or components, and weighing each component from the waste stream of a specific generator (households, commercial entity, institution etc.) (Bernache-Pérez, 2001). Direct waste sampling has been carried out in different ways depending on the sampling unit such as from households are at final disposal site (Parfitt and Flowerdew, 1997). Physical and chemical analysis such as moisture content, specific density, specific energy (calorific value) and elemental analysis are usually undertaken after waste composition has been determined through the direct sampling method.

The direct sampling method is reported to have the advantage of providing critical information that is relevant for planning waste collection, recycling, treatment, and disposal methods on a local level (Reinhart and McCauley-Bell, 1996). However, the number of samples analysed through this method is often limited due to the high cost associated with it, which might affect the accuracy of the data, and it is often deemed an unpleasant task to physically hand-sort waste into different categories (Parfitt and Flowerdew, 1997). Also, it is shown that poor planning with regard to demographic issues, seasonality, irregular events, etc. may lead to bias in the results obtained through the direct sampling method (Reinhart and McCauley-Bell, 1996). No consensus has emerged in the international research literature as to the most appropriate methodology for conducting compositional analysis of household wastes as is evident in reviews carried out by Parfitt and Flowerdew (1997) and Dahlén (2005). A discussion on how to address the question posed above in conducting direct sampling analysis is discussed below.

3.2.1.3 How to Obtain Representative Samples

Dahlén (2005) recommended sampling at household level and analyzing the content of each waste bin separately, when differences in the behaviour of householders are considered important for undertaking a waste characterization study and sampling from the loads of waste collection vehicles when individual household's characteristics are not important. Usually the entire quantity of solid waste being generated cannot be economically or practically sorted. Therefore a representative sampling method must be used to obtain study samples and these samples must be analyzed to estimate the composition of the entire waste stream. To address the issue of collecting representative samples for analysis, the number and types of strata required must be based on the objects of the analysis. WHO (1996) defines that the residential areas involved in the study must represent different socio-economic population groups (e.g. according to ethnic groups and/or income levels: low, middle and high income groups, family size). It is also suggested, that to allow variation in waste generation over a week to be accounted for, each sample should cover at least one full week of household activities and samples should be collected in different seasons of the year to account for local seasonal variations in waste generation (Dahlén, 2005).

3.2.1.4 Determining Sample Size

In the determination of sample size a lot of approaches are employed. Some of these include: census (for small populations), using published tables, using samples sizes of similar studies and the use of formulas to calculate a sample size (Israel, 1992). Determining the size of samples is dependent on the purpose of the study, population size, confidence level and the allowable sampling error (Israel, 1992). Aside knowing the purpose of the study and the population size, the level of precision, the level of confidence or risk, and the degree of variability in the attributes being measured must be known in order to determine the appropriate sample size (DEFRA, 2004; Israel, 1992). Although it has been argued that following strict statistical procedures for waste stream analysis is difficult to implement, two formulas have been identified based on the central limit theory that have been used in estimating required sample sizes for household based waste sampling. They are both based on calculating using the mean and standard deviation of a previous comparable study.

The 1st formula (Israel, 1992; DEFRA, 2004) is as follows:

$$n = \left[\frac{z_{\alpha/2}\sigma}{E}\right]^2 \qquad 3\text{-}1$$

Where

n - the sample size

$z_{\alpha/2}$ - the standard Normal deviate corresponding to the desired two-sided confidence level (e.g. $z_{\alpha/2}$ = 1.96 for 95% confidence level)

σ - an estimate of the population standard deviation

E - the desired precision or 'margin of error'

.
The 2nd formula (Dahlén, 2005) is as follows:

$$n = \left[\frac{s.t}{e.x} \right]^2 \qquad 3\text{-}2$$

where

n – desired number of samples

s - the relative standard deviation (*i.e.* coefficient of variation) for the proportion of the waste component in question, in a number of samples from an earlier study or a pre-investigation

t - a t-test table value for a chosen confidence level and the degree of freedom (*i.e.* number of samples in the pre-investigation – 1)

e - the desired relative confidence interval, for example 0,1 if the confidence interval is ± 5% of the mean

x - the mean value of the proportion of the component in question, known from an earlier study or a pre-investigation

3.2.1.5 Waste Categories

The categories into which the waste stream is sorted during a waste characterization study depends on the purpose of the study. The waste stream is usually sorted into major categories such as food waste (organic waste), plastics, paper, glass, and metal. It is reported that a limited number of primary categories (also called main components), and a large number of secondary, tertiary, *etc*. categories (sub-components), are applied depending on the aim of a particular study (Dahlén, 2005). In order to reduce the risk of misunderstanding and to enable useful comparisons to be made among waste composition data, it is suggested that a limited number of primary categories (not more than 10), based on physical material and stringently defined, should be used (Dahlén, 2005).

3.2.2 Materials and Equipment for Waste Characterization and Source Separation Study

Direct sampling method is deemed most appropriate for this study because waste production data are readily unavailable in Ghana, which leaves the material flow method with gross limitations. In direct sampling waste characterization studies, the equipment and materials used depends on the availability of infrastructure and study design. The materials and equipments listed in this section cover both waste characterization on KNUST as well as the pilot source separation studies undertaken on KNUST campus and Asokwa Sub-Metro. The equipments and materials used are:

1. Scale (Maximum weight: 20kg and 50kg Minimum weight: 0.05kg and 0.2kg respectively) - to weigh the waste
2. Work table
3. Plastic buckets for containing sorted fractions for weighing
4. Detergent to wash equipments and hands after waste analysis
5. Disinfectant to disinfect equipments after washing
6. Trash polythene bags for collecting samples from households
7. A shed to provide shade at analysis site
8. Protective clothing: hand gloves, nose mask, Overalls, Wellington Boots
9. Waste bins
10. Masking tape and markers for labelling samples
11. Benches
12. Plastic sheet for covering work table
13. Brooms for cleaning the analysis site

14. Printed data sheets

3.2.3 Waste Characterization Study: KNUST Campus

A waste characterization study was undertaken in staff residencies to obtain data to estimate the sample size for the pilot source separation study. Sampling of waste generator, which includes the direct sampling of solid waste from specific sources, was employed. Sampling and manual sorting, a labour intensive manual process of sorting, classifying and weighing all items in each sampling unit, and a detailed recording of the data was employed. A whole week's waste generated was analyzed from each selected household.

3.2.3.1 Selection of Household

The streets or blocks of staff residencies were written on paper and folded. A block for each staff area was selected randomly. Buroburo Road which extended to the Four Stars Estate was selected for the senior staff area and F-Line was selected for the junior staff area. The households on these streets to be surveyed were also selected randomly.

3.2.3.2 Sample Size

Thirty households were selected for the study. The thirty households were selected based on previous work by Kotoka (2001). Seventeen household were selected from Buroburo Road and thirteen from F-Line according to the proportion of number of households from senior and junior staff residencies on KNUST campus.

3.2.3.3 Sample Collection and Analysis

Samples were collected twice a week to obtain a full week's waste. The study was carried out in two weeks for each area in from second week in March to the second week in April, 2006 to capture where there is transition from the dry to the wet season. The waste collected from each household was deposited in a black polyethylene bag which was the unit of analysis for the study. The content of each bag was emptied into an 80 litre plastic container and its weight and volume taken, after which the contents were sorted and weighed according to the categories presented in Appendix D. The waste generated per household per week was computed, the average composition was determined as well as the density and moisture content.

3.2.4 Pilot Source Separation Study: KNUST Campus

3.2.4.1 Selection of Areas

On KNUST campus, two areas were selected from both senior staff and junior staff residential areas. Buroburo road and four stars estate were the areas selected for senior staff residences and F-line was selected for junior staff residences. These areas were selected randomly. Senior staff and junior staff areas were selected to reflect broadly two different income groups of staff resident on KNUST campus.

3.2.4.2 Selection of Households

The houses were selected according to clusters based on blocks on a street. Cluster sampling was employed to reduce logistical problems if participating households are scattered across the study area. Scattering participating households across the study area could limit the visibility of the scheme that could have developed a wider community interest. All households on Buroburo Road were to be included in the study. F-Line has several blocks; hence each block was written on a sheet of paper and folded. Three blocks were selected randomly, to obtain the required number of households.

3.2.4.3 Sample Size

Based on the preliminary waste characterization study 59 samples were required for the study based on a 15% error and 90% probability (Appendix F1). Seventy (70) households were then targeted for the project. Forty (40) households from the senior staff areas and thirty (30) from junior staff areas reflecting the distribution of houses for staff residencies computed with data obtained from the University's estate organization.

3.2.4.4 Sample Collection and Analysis

The study was conducted from the last week of February 2007 to the last week of July 2007. A questionnaire was distributed to households and collected over 2 weeks which was followed by the distribution of a brochure (Appendix B1) to explain the process of waste separation and what the households were required to do. Plastic dustbins (30L) were then distributed with stickers pasted (Appendix B2) on them to denote what to put in each bin. Households were required to separate solid wastes into three fractions: organic, plastics and others (any waste material that was not organic or plastic). Most of the households already had one metal dustbin which was designated for other wastes while a plastic dustbin was provided for organic waste and a weekly supply of plastic bag for plastic waste. Households that did not have any dustbin were provided with two dustbins. Wastes were collected from households twice a week for analysis, on Wednesdays and Saturdays. The wastes were accumulated till the collection days to ensure that the whole week's waste from each household was analyzed. Labelled plastic bags were used to collect waste samples from each household. The contents of each labelled bag was weighed and emptied unto a table for sorting. The waste was sorted and weighed in to eleven categories namely: Organic (food and yard waste), plastic film, PVC (polyvinyl chloride) & PET (polyethylene terephthalate) rigid plastic, PP (polypropylene) & PE (polyethylene) rigid plastics, other plastics, other packaging materials (other pack. mat.), metals, glass, paper, textiles and others (materials not belonging to any of the above listed categories).

3.2.4.5 Data Analysis

The per capita waste generation rate was calculated for each of the study areas using the total amount of waste collected from each household and the number of persons in the households. The number of persons in each household was calculated from the answers provided in a questionnaire survey conducted prior to the start of the project. The share of material which is correctly separated by households who participated in the source separation of their solid waste was calculated based on the weight of material in each bin as the separation efficiency. The level of compliance was evaluated by finding the percentage of households that were properly sorting out their wastes. This was graded according to the following definitions:

Excellent - percentage of households that placed only the designated material in a particular bin e.g. percentage of households who placed only organic waste in the bin designated for organic wastes

Good - percentage of households that placed a majority of designated waste in a bin with the percentage of contaminants between 0.1 - 10%

Fair - percentage of households that placed a majority of designated waste in a bin with the percentage of contaminants between 10.1 - 50%

Poor - percentage of households that placed materials in a designated bin with contaminants above 50%

3.2.5 Pilot Source Separation Study: Asokwa Sub-Metropolitan Area

3.2.5.1 Selection of Areas

The Asokwa Sub-Metro was selected due to its proximity to KNUST Campus which will reduce the cost of the study. Asokwa is the only area designated as first class in the Sub-Metro hence it was automatically included in the study. Atonsu and Ahinsan were selected to represent second and third class areas respectively because they were close to Asokwa. A suitable site where the analysis was carried out was also located at a community dump at Ahinsan which made the collection of samples easier.

3.2.5.2 Selection of Households

Prior to the start of the study, the selected areas were explored in order to select streets with households that represent the class of interest. The number of selected households from each class was not proportional to the actual percentages of households in each class due to the difficulty in assessing reliable data. During the preliminary tour of the sub-metro areas it was realised that the boundaries between classes of areas within a community were difficult to define, for example Atonsu is designated as a second class area but has sub communities which are basically first class or third class areas. Due to the mixture of classes within the area, which is reflected even in the waste collection methods in the area, it is difficult to actually find data on population and number of houses/households that fall within a particular class to facilitate the utilization of a strict stratified random sampling procedure. Hence, it was decided to target equal number of households in area selected with care taken to select households that depict the classes of areas they represent.

3.2.5.3 Sample Size

Due to limitation of resources historical data from waste characterization studies in other sub-metro was utilized to estimate the sample size required. The number of samples (thirty) selected in studies carried out by Kotoka (2001) and Gomda (2001) plus additional five households from each selected area were deemed sufficient for the study. Therefore, thirty-five houses each from Asokwa, Atonsu and Ahinsan were to be included in the study.

3.2.5.4 Sample Collection and Analysis

A leaflet informing households on the proposed source separation project in their households were distributed initially (Appendix B3). Two enumerators visited each house and key persons met in the houses were allowed to ask questions to make sure they understood what was about to take place as far as the handling, storage and disposal of their SW was concerned. A brochure was also distributed to households along with the distribution of bins (Appendix B4). Three bins were distributed to each household. A green bin was provided for organic wastes, a yellow bin for all plastic wastes and a red bin for any other type of waste. The household numbers as well as what was to be put in each bin was inscribed on the lid of the bins. A labelled plastic bag was placed in each bin. This was replaced at each collection. Two tricycles were used to cart waste from households to the analysis site. Wastes were collected from Asokwa on Mondays and Thursday, whilst collection of waste was done on Tuesdays and Fridays from Atonsu and Ahinsan. This ensured the collection of a whole week's waste from each participating household. Samples were collected over twelve weeks, from the 14th of February to 8th of May 2008 to ensure that both the dry and wet seasons is accounted for. The collection of separated wastes was done for thirteen weeks. The collected separated wastes were brought to the point of analysis near the main area dumpsite at Ahinsan. The composition of each bin was determined by emptying the content of each labelled bag unto a table, sorting and weighing the various components in small plastic buckets. The data was recorded on to a prepared data sheet (Appendix D2).

3.2.5.5 Data Analysis

The waste generation rate and composition as well as the level compliance and separation efficiency of households were determined using the same methods and definitions employed for the study on KNUST campus.

3.2.6 Questionnaire Survey: Asokwa Sub-Metropolitan Area and KNUST Campus

Two questionnaire surveys were undertaken within the study areas. The first one was administered before the onset of the SS study to household that were willing to participate in the study. The number of questionnaires administered corresponds to the number of participating households. The questionnaire was accompanied by a covering letter explaining the aim of the survey and providing assurances about confidentiality. This was done to collect information on household waste disposal practices, respondent's attitude and opinions about WM recycling and SS, demographic information of the respondents and household members. The second questionnaire was administered to follow up on households concerns and comments after the introduction of the pilot source separation study. Demographic information, information on household's participation in the waste collection scheme and suggestions for improving the collection schemes was solicited from respondents through the follow up questionnaire. Samples of the two questionnaires are presented in Appendix C.

The data was prepared on Microsoft excel and then analyzed using Microsoft excel and SPSS software for data analysis. Both descriptive statistics, paired t-test of means and regression analysis tools were used to pursue the stated objectives of the study.

3.3 OPTIMIZATION OF INTEGRATED SOLID WASTE MANAGEMENT SYSTEM FOR KUMASI

The optimization of municipal solid waste management system requires the knowledge of available management alternatives and technologies, economic and environmental costs associated with these alternatives, and their applicability to the specific area. In this study only economic cost are considered since the current environmental sanitation policy support waste treatment options that are economically sustainable.

3.3.1 System Optimization Model

This section describes the mathematical formulation of the linear programming model for the proposed integrated waste management system for Kumasi. The objective function and model constraints are derived taking into consideration economic costs. The model formulation follows the approach used by Rathi (2007), however environmental costs are not considered here. On the other hand, capital costs of each treatment option is considered which was not considered by Rathi (2007) because the latter assumed treatment options considered to be already in existence; but in this case the treatment options are not yet in existence therefore will need capital investments to set them up. The analysis effectively reduces variable costs and performance characteristics to a common basis, measured in terms of cost per tonne as employed by Yedla and Kansal (2003) and Rathi (2005). Annualized capital cost uses the normal financial calculation of an annuity payment. Calculation of capital costs per tonne of waste handled follows procedure employed by Renkow and Rubin (1996) as debt service charges.

3.3.1.1 Definition of Variables and Objective Function

Let's assume

Generation area - *i*

Centralized composting plant – *j*

Community composting plant – *k*

Landfill – *m*

Plastic recycling plant – *n*

Decision variables (measured in tonnes):

W_{ij} – Denotes waste transported from generation area '*i*' to centralized composting plant '*j*'

W_{ik} - Denotes waste transported from generation area '*i*' to community composting plant '*k*'

W_{in} - Denotes waste transported from generation area '*i*' to plastic recycling plant '*n*'

W_{im}- Denotes waste transported from generation area '*i*' to landfill '*m*'

W_{jm}- Denotes waste transported from centralized composting plant '*j*' to landfill '*m*'

W_{km}- Denotes waste transported from community composting plant '*k*' to landfill '*m*'

W_{nm}- Denotes waste transported from plastic recycling plant '*n*' to landfill '*m*'

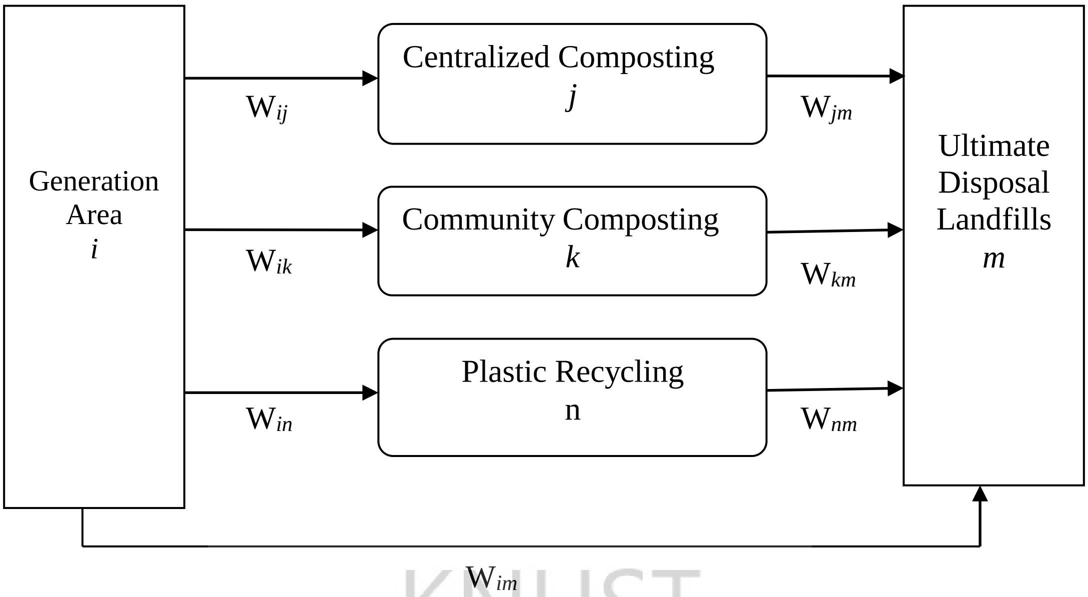

Figure 3.3 Waste Flow Network Showing Decision Variables

The objective function is to minimize the net cost of a chosen waste management system

Minimize (CT –BT)

Where

CT – total cost associated with the waste management system

BT – is the total benefit associated with the waste management system subject to certain constraints.

3.3.1.2 Definition of System Costs

1. Total Cost of handling waste at the Landfill (CL)

CL = $C_{Coll} + C_{Trl} + C_{Cal} + C_{Ll} + C_{O\&Ml}$ 3-3

$$\sum_m CL_m = \sum_m \sum_i Coll \times W_{im} + \sum_m \sum_i Trl \times W_{im} + \sum_m \sum_i Cal \times W_{im} + \sum_m \sum_i Ll \times W_{im} + \sum_m \sum_i O\&Ml \times W_{im}$$

Where:

C_{Coll} → total collection cost associated with landfilling

Coll - Collection cost per tonne of waste destined for the landfill

$$C_{Coll} = \sum_{m}\sum_{i} Coll \times W_{im} \qquad 3-3a$$

C_{Trl} → total transportation cost associated with landfilling

Trl – transportation cost per tonne of waste associated with landfilling

$$C_{Trl} = \sum_{m}\sum_{i} Trl \times W_{im} \qquad 3-3b$$

C_{Cal} → total capital costs associated with landfilling

Cal – capital cost per tonne of waste handled at the landfill

$$C_{Cal} = \sum_{m}\sum_{i} Cal \times W_{im} \qquad 3-3c$$

C_{Ll} → total cost of land associated with landfilling

Ll – land costs per tonne of waste handled at the landfill

$$C_{Ll} = \sum_{m}\sum_{i} Ll \times W_{im} \qquad 3-3d$$

$C_{O\&Ml}$ → operation and maintenance cost associated with landfilling

O&Ml – operation and maintenance cost per tonne of waste handled at the landfill

$$C_{O\&Ml} = \sum_{m}\sum_{i} O\&Ml \times W_{im} \qquad 3-3e$$

2. Total cost of processing waste at a centralized compost plant (CC)

$$CC = C_{Colc} + C_{Trc} + C_{Cac} + C_{Lc} + C_{O\&Mc} + C_{DRc} \qquad 3\text{-}4$$

$$\sum_j CC_j = \sum_j \sum_i Colc \times W_{ij} + \sum_j \sum_i Trc \times W_{ij} + \sum_j \sum_i Cac \times W_{ij} + \sum_j \sum_i Lc \times W_{ij} + \sum_j \sum_i O\&Mc \times W_{ij} + \sum_j \sum_m Cal \times W_{jm} + \sum_j \sum_m Ll \times W_{jm} + \sum_j \sum_m O\&Ml \times W_{jm}$$

Where:

C_{Colc} → total collection costs associated with centralized composting

Colc – Collection cost per tonne of waste destined for centralized composting

$$C_{Colc} = \sum_j \sum_i Colc \times W_{ij} \qquad 3-4a$$

C_{Trc} → total transportation cost associated with centralized composting

Trc – transportation cost per tonne of waste associated with centralized composting

$$C_{Trc} = \sum_j \sum_i Trc \times W_{ij} \qquad 3-4b$$

C_{Cac} → total capital costs associated with centralized composting

Cac – capital cost per tonne of waste treated at the composting facility

$$C_{Cac} = \sum_j \sum_i Cac \times W_{ij} \qquad 3-4c$$

C_{Lc} → Total Cost of land associated with centralized composting

Lc – land costs per tonne of waste processed at composting facility

$$C_{Lc} = \sum_j \sum_i Lc \times W_{ij} \qquad 3-4d$$

$C_{O\&Mc}$ → operation and maintenance cost associated with centralized composting

O&Mc – Operation and maintenance cost per tonne of waste processed at centralized composting facility

$$C_{O\&Mc} = \sum_j \sum_i O\&Mc \times W_{ij} \qquad 3-4e$$

C_{DRc} → residue disposal cost associated with waste sent from centralized composting plant to the landfill

$$C_{DRc} = \sum_j \sum_m Cal \times W_{jm} + \sum_j \sum_m Ll \times W_{jm} + \sum_j \sum_m O\&Ml \times W_{jm} \qquad 3-4f$$

3. Total cost of processing waste at a community compost plant (CCC)

$$CCC = C_{Cacc} + C_{Lcc} + C_{O\&Mcc} + C_{Colcc} + C_{Trcc} + C_{DRcc} \qquad 3\text{-}5$$

$$\sum_k CCC_k = \sum_k \sum_i Cacc \times W_{ik} + \sum_k \sum_i Lcc \times W_{ik} + \sum_k \sum_i O\&Mcc \times W_{ik} + \sum_k \sum_m Colcc \times W_{km} + \sum_k \sum_m Trcc \times W_{km} + \sum_k \sum_m Cal \times W_{km} + \sum_k \sum_m Ll \times W_{km} + \sum_k \sum_m O\&Ml \times W_{km}$$

Where:

C_{Cacc} → total capital costs associated with community composting

Cacc –capital cost per tonne of waste treated at the community composting facility

$$C_{Cacc} = \sum_k \sum_i Cacc \times W_{ik} \qquad 3-5a$$

C_{Lcc} → Total Cost of land associated with community composting

Lcc – land costs per tonne of waste processed at community composting facility

$$C_{Lcc} = \sum_k \sum_i Lcc \times W_{ik} \qquad 3-5b$$

$C_{O\&Mcc}$ → Operation and Maintenance Cost associated with community composting

O&Mcc – Operation and maintenance cost per tonne of waste processed at community composting facility

$$C_{O\&Mcc} = \sum_k \sum_i O\&Mcc \times W_{ik} \qquad 3-5c$$

C_{Colcc} → total collection costs associated with community composting

Colcc – Collection cost per tonne of waste transported from community compost plant to landfill

$$C_{Colcc} = \sum_k \sum_m Colcc \times W_{km} \qquad 3-5d$$

C_{Trcc} → total transportation cost associated with community composting

Trcc – transportation cost per tonne of waste associated with community composting (transporting residues from community composting plants to landfill)

$$C_{Trcc} = \sum_k \sum_m Trcc \times W_{km} \qquad 3-5e$$

C_{DRcc} – residue disposal cost associated with waste sent from community composting plant to the landfill

$$C_{DRcc} = \sum_k \sum_m Cal \times W_{km} + \sum_k \sum_m Ll \times W_{km} + \sum_k \sum_m O\&Ml \times W_{km} \qquad 3-5f$$

4. Total cost of processing waste at a Plastic Recycling Plant (CPR)

CPR = C_{Colpr}+ C_{Trpr} + C_{Capr} + $C_{O\&Mpr}$ + C_{DRpr} 3-6

$$\sum_n CPR_n = \sum_n \sum_i Colpr \times W_{in} + \sum_n \sum_i Capr \times W_{in} + \sum_n \sum_i Lpr \times W_{in} + \sum_n \sum_i O\&Mpr \times W_{in} + \sum_n \sum_m Trpr \times D_{nm} \times W_{nm} + \sum_n \sum_m Cal \times W_{nm} + \sum_n \sum_m Ll \times W_{nm} + \sum_n \sum_m O\&Ml \times W_{nm}$$

Where:

C_{Colpr} → total collection costs associated with community plastic recycling

Colpr – collection cost per tonne of waste destined for community plastic recycling

$$C_{Colpr} = \sum_n \sum_i Colpr \times W_{in} \quad 3-6a$$

C_{Capr} → total capital costs associated with community plastic recycling plant

Capr –capital cost per tonne of waste treated at the plastic recycling

$$C_{Capr} = \sum_n \sum_i Capr \times W_{in} \quad 3-6b$$

C_{Lpr} → total cost of land associated with community plastic recycling plant

Lpr – land costs per tonne of waste processed at community plastic recycling plant

$$C_{Lpr} = \sum_n \sum_i Lpr \times W_{in} \quad 3-6c$$

$C_{O\&Mpr}$ → operation and maintenance cost associated with community plastic recycling plant

O&Mpr – Operation and maintenance cost per tonne of waste processed at community plastic recycling plant

$$C_{O\&Mpr} = \sum_n \sum_i O\&Mpr \times W_{in} \quad 3-6d$$

C_{Trpr} → total collection and transportation cost associated with community plastic recycling plant residue disposal

Trpr – transportation cost per tonne of waste associated with disposal of residue at the community plastic recycling plant

Colprr – collection cost per tonne of waste associated with disposal of residue at the community plastic recycling plant

$$C_{Trpr} = \sum_{n}\sum_{m}(Trpr + Colprr) \times W_{nm} \qquad 3-6e$$

C_{DRpr} → residue disposal cost associated with waste sent from plastic recycling plant to the landfill

$$C_{DRpr} = \sum_{n}\sum_{m} Cal \times W_{nm} + \sum_{n}\sum_{m} Ll \times W_{nm} + \sum_{n}\sum_{m} O\&Ml \times W_{nm} \qquad 3-6f$$

5. Overall system Cost (CT)

$$CT = \sum_{m} CL_m + \sum_{j} CC_j + \sum_{k} CCC_k + \sum_{n} CPR_n \qquad 3-7$$

3.3.1.3 Definition of System Benefits

Benefits are derived from compost produced from centralized composting plants and community compost plants and recycled plastic pellets produced from community plastic recycling plants. Benefits are also derived from sale of recovered plastics and metals.

i. Benefits from Centralized composting plant (BC)

$$\sum_{j} BC_j = \sum_{j}\sum_{i} \eta \times bio_c \times W_{ij} \times pCc + \sum_{j}\sum_{i} Pr_c \times W_{ij} \times pPrc + \sum_{j}\sum_{i} M_c \times W_{ij} \times pMc \qquad 3-8$$

Where:

η - is factor of waste reduction for the composting process

bio_c – biodegradable fraction of waste delivered to centralized composting plant

Pr_c – Recyclable plastic fraction of waste delivered to centralized composting plant

M_c – Metal fraction of waste delivered to centralized composting plant

pCc – price per tonne of compost produced at the centralized composting plant

pPrc – price per tonne of recyclable plastic recovered at the centralized composting plant

pMc – price per tonne of metals recovered at the centralized composting plant

ii. Benefits from Community composting plant (BCC)

$$\sum_k BCC_k = \sum_k \sum_i \eta \times bio_{cc} \times W_{ik} \times pCcc + \sum_j \sum_i Pr_{cc} \times W_{ij} \times pPrcc + \sum_j \sum_i M_{cc} \times W_{ij} \times pMcc \qquad 3-9$$

Where:

bio_{cc} – biodegradable fraction of waste delivered to community composting plant

pCcc – price per tonne of compost produced at the community composting plant

Pr_{cc} – Recyclable plastic fraction of waste delivered to community composting plant

M_{cc} – Metal fraction of waste delivered to community composting plant

pPrcc – price per tonne of recyclable plastic recovered at the community composting plant

pMcc – price per tonne of metals recovered at the community composting plant

iii. Benefits from Community plastic recycling plant (BPR)

$$\sum_n BPR_n = \sum_n \sum_i \gamma \times pPl \times P_{pr} \times W_{in} \qquad 3-10$$

Where:

γ – waste reduction factor during processing of plastics due to production losses

P_{pr} – recyclable plastic fraction in waste delivered to plastic recycling plant

pPl – price per tonne of plastic pellets

iv. Overall system benefits (BT)

$$BT = \sum_j BC_j + \sum_k BCC_k + \sum_n BPR_n \quad 3-11$$

3.3.1.4 Constraints

Mass Balance Constraints

All solid waste generated at source 'i', should be transported either to a centralized composting plant 'j', community compost plant 'k', a plastic recycling plant 'n', or a sanitary landfill 'm'.

$$G_i = \sum_j W_{ij} + \sum_k W_{ik} + \sum_n W_{in} + \sum_m W_{im} \quad 3-12$$

Where:

G_i = amount of waste generated at generation area 'i'

Capacity Limitation Constraints

Planned capacity at each facility should be less than or equal to the maximum allowable capacity of the facility.

$$\sum_i W_{ij} \leq Cap_{max,j} \quad 3-13$$

$$\sum_i W_{ik} \leq Cap_{max,k} \quad 3-14$$

$$\sum_i W_{in} \leq Cap_{max,n} \quad 3-15$$

Where:

$Cap_{max,j}$ – maximum capacity of centralized composting plant 'j'

$Cap_{max,k}$ – maximum capacity of community compost plant 'k'

$Cap_{max,n}$ – maximum capacity of plastic recycling plant 'n'

Material Requirement Constraints

All non-biodegradable and miscellaneous materials (residual waste) reaching centralized composting plant or community composting plant has to be transported to the landfill

$$\sum_{j}\sum_{m} W_{jm} \geq \sum_{i}\sum_{j} fnb_c \times W_{ij} \qquad 3-16$$

$$\sum_{k}\sum_{m} W_{km} \geq \sum_{i}\sum_{k} fnb_{cc} \times W_{ik} \qquad 3-17$$

Where:

fnb_c – fraction of non-biodegradable material in the total waste stream sent from generation area to the centralized composting plant excluding recyclable plastic and metals

fnb_{cc} - fraction of non-biodegradable material in the total waste stream sent from generation area to the community composting plant excluding recyclable plastic and metals

W_{jm} – amount of waste transported from centralized composting plant to the landfill

W_{km} – amount of waste transported from community composting plant to the landfill

All non-plastic materials and all plastics either than PP, HDPE and LDPE reaching plastic recycling plant have to be transported to the landfill.

$$\sum_{n}\sum_{m} W_{nm} \geq \sum_{i}\sum_{n} fnp \times W_{in} + \sum_{i}\sum_{n} fop \times W_{in} \qquad 3-18$$

Where:

fnp – fraction of non-plastic material in the total waste stream sent from generation area to the plastic recycling plant

fop – fraction of other plastic apart from PP, HDPE and LDPE plastics in the total waste stream sent from generation area to the plastic recycling plant

W_{nm} – amount of waste transported from plastic recycling plant to the landfill

3.3.2 Waste Treatment Options

The waste treatment options considered for ISWM for Kumasi are centralized composting, community composting, plastic waste recycling and landfilling. The process description and cost estimation for these waste treatment options are presented in this section.

3.3.2.1 Centralized Composting

The cost of composting varies as a function of the scale of operation, type of feedstock and type of technology used. Because of the wide range of conditions that impact cost, feasibility studies require information involving specific conditions to calculate the cost of composting. The cost of composting is a function of number of unit operations, type of equipment, number of employees and throughput of the operation (Governo et al., 2001). The choice of capacity and technology for centralized composting is based on the work done by Müller (2006) since it provides details of system cost in relation to the capacity and process description.

The chosen process is described in Figure 3.4, where the collection vehicles are weighed on the weighing bridge. After that, they discharge the waste in the reception area (A, in Figure 3.4). From there the waste is transferred by a front loader into the feed hopper with an incorporated steel slat conveyor. In the pre-sorting station, cardboard and office waste paper, glass, plastic, textiles and bones are separated by hand and thrown into the respective boxes where recovered materials are kept (B). The ferrous metals are removed to a large extent by an overhand magnetic separator.

The selected sub-products are likewise baled by the presses. The materials free from ferrous metals drop into the mixing and screening drum where its moisture content is optimised by adding water. At the same time a general homogenization of all products is then separated into two fractions namely fresh compost to the fermentation park and unsuitable material for composting as rejects (C). The screen product is then automatically delivered via an inclined belt conveyor to the fermentation park where the product stacks up to a primary windrow. Here a windrow turning machine takes over, moving the windrows periodically and gradually away from the centre of the building towards its periphery. The coarse compost (D) from the outermost windrow can be either sold directly for land reclamation projects and general agriculture or it can be refined by the fine treatment line (E)

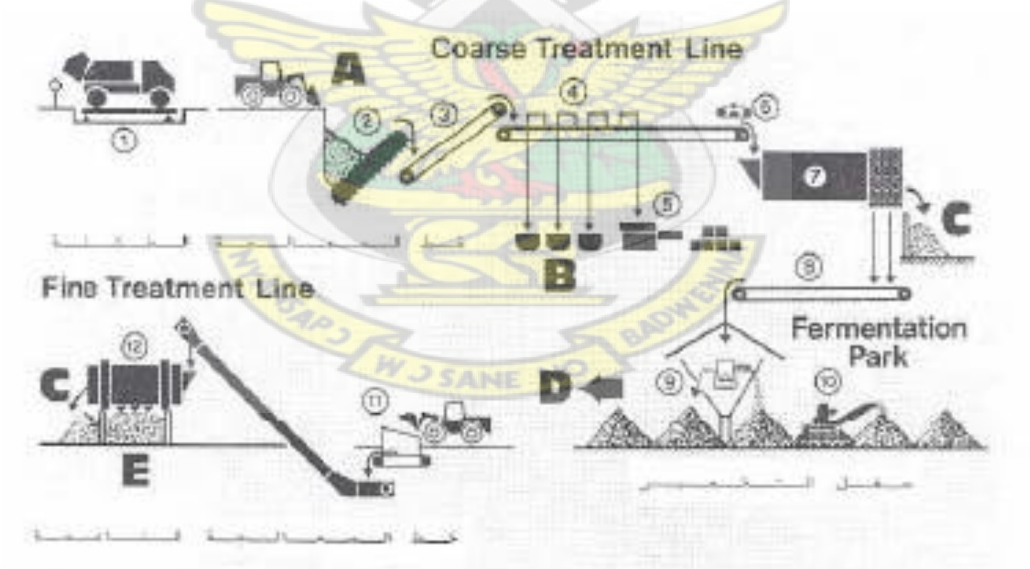

Figure 3.4 Schematic Description of Processing Solid Waste at a Centralized Composting Plant (Bühler, 1986, in Müller, 2006)

Legend for Figure 3.4:

1) Weighing bridge 2) Steel slat conveyor 3) Belt conveyor 4) Hand picking station 5) Presses 6) Magnetic separator 7) Mixing drum 8) Belt conveyor
9) Hangar belt conveyor with tripper 10) Windrow turning machine
10) 11) Box feeder with chain conveyor 12) Sieving drum

It is assumed that the centralized composting plant will be located at the current landfill site in Kumasi. Being located at the landfill site induces a few logistical advantages resulting in cost savings. The rejected waste coming out of the separation process can be disposed of close by. Hence, costs for transport can be saved. Furthermore, existing front loader from Kumasi's landfill can be used thus; an additional loader is not required. The landfill site has provision for a recycling facility hence the land cost is also nil. Due to landfilling operations, the area is already levelled; with access roads and a weigh-bridge in place therefore site preparation costs are expected to be comparatively low. Based on data from existing centralized composting plants in developing countries and work done by Müller, 2006, characteristics of the plant are summarised in Table 3.3. Additional information on the cost is provided in Appendix G1.

3.3.2.2 Decentralized Composting

The capacity of decentralized schemes broadly varies depending on the number of households served, the land available and the skills of the operators. The proposed community composting process follows the process described by Müller (2006) and Rytz (2001). Processing of waste at the community composting plant begins with the manual sorting of incoming waste into easily degradable materials, other recyclable materials and rejects. The recyclables will be sold and the rejects disposed off into skip containers at the communal collection points for onward disposal at the landfill. After the separation the organic waste will be piled around an aerator. The piles are to be covered by a shed, which protects the organic matter as well as the workers from rain and direct sunlight. Furthermore, the piles will be turned and watered periodically in order to optimize degradation of organic matter. Temperature and moisture content of piles are to be monitored systematically.

Table 3.3 Cost Assumptions for a Centralized Composting Plant having a capacity of 180t/d of Incoming Mixed Waste

Investment costs	Unit	Quantity	GH¢
Land acquisition	GH¢6.2/m^2	20000m^2	Available/124000
Site development	\$5.6/m^2	20000m^2	112000
Machinery	Truck (compost sales)	1	56000
	Front loader	0	Available at landfill
	Weigh bridge	0	Available at landfill
	Steel slat conveyor	1	14000
	Belt conveyor	2	5600
	Handpicking station	2	28000
	presses	1	14000
	Magnetic separator	2	112000
	Mixing/screening	1	252000
	Hangar belt conveyor with tripper	1	42000
	Windrow turning machine	2	560000
	Box feeder with chain conveyor	1	14000
	Rotating sieve drum	1	32200
Sub-Total			**1241800**
Operational Costs			
Labour salaries	manager	2(GH¢10080/year)	20160
	Technical officer	4(GH¢7200/year)	28800
	Technician	8 (GH¢4752/year)	38016
	Electrician	2(GH¢4752/year)	9504
	Unskilled worker	75 (GH¢1584/year/worker)	118800
	Vehicle driver	1	2880
Supplies and tools			8000
Fuel and Lubricants			71327.57
Power supply		264000kWh/year	117886.8
water		5000m^3/year	9108
Maintenance and repairs	10% of equipment cost		112980
Marketing			514800
Training of labour			5000
Sub-Total			**1057262.37**
Others	10% of operational costs		10572.6237
Total			**1162988.607**

Adapted from Müller, 2006

The decomposition process requires 40 days depending on climatic conditions Rytz (2001). The maturation period of two weeks is proposed before final screening of the compost is done. The compost is assumed to be sold to local users in the community without bagging.

Due to the much lower capacity of decentralized plants a lot of small plants are required in order to process the generated waste in Kumasi. In this scenario the existing communal collection points are considered as appropriate locations for decentralized plants. Furthermore, space for decentralized plants is expected to be available at these communal sites which were verified by staff of KMA-WMD. At the communal site households are expected to deliver separated organic waste which will be processed into compost and all other waste are placed in the skip containers and transported to the landfill. To provide an incentive for household's that separate their waste it is proposed that they are paid GH¢0.05 for every 10kg of organic waste disposed at the site. It is assumed that this will reduce the amount paid by households for disposing a head load of waste at the communal site. The assumed costs for community composting are presented in Table 3.4. Additional information concerning the costs is presented in Appendix G2. According to KMA-WMD there are currently 140 communal collection sites in Kumasi out of which 80% is expected to have enough space around them to accommodate a composting plant. Therefore, it is assumed that 112 community composting plants will be established in the city each processing 858 tonnes of incoming waste annually.

Table 3.4 Cost assumptions for a Community Composting Plant having a Capacity of 3t/d of Incoming Mixed Waste

Investment costs	Unit	Quantity	GH¢
Land acquisition	GH¢6.2/m^2	450m^2	2790
Construction of:			
Roofed sorting platform	GH¢36/m^2	35m2	1260
Roofed composting shed	GH¢36/m^2	113.7m2	4093.2
Maturing shed	GH¢36/m^2	32.4	1166.4
Roofed screening area and bagging	GH¢36/m^2	21.2	763.2
Storing shed	GH¢36/m^2	42.0m2	1512
Water and electricity connection			1000
Construction of office and fence			2000
Sub-Total investment			**14584.8**
Sub-total without land cost			11794.8
Operational Costs			
Unskilled worker	GH¢1584/year	6	19008
Site supervisor	GH¢3168/year	1	3168
Supplies and tools			1200
Power supply		600kWh/year	186.72
water		100m^3/year	187.2
Maintenance and repairs			300
Incentive	GH¢5/t	858t/year	4290
Marketing			772.2
Sub-Total			**19608.12**
Others	10% of operational		1960.812
Total operational cost			**21568.932**

Adapted from Müller (2006) and Rytz (2001)

3.3.2.3 Plastic Recycling

In this case, it is expected that households deliver separated plastic waste to communal sites and are paid GH¢0.2/kg for it. Tricycles are then used to send separated plastics to community plastic recycling plants.

The plastic recycling process follows the steps described by Lardinois and van de Klundert (1995). These steps typically involve inspection for removal of contaminants or further sorting, washing and drying, grinding or shredding, agglomeration (conversion into crumbs) and conversion into pellets (extrusion and pelletization). Plastic film waste delivered to the recycling plant is to be first inspected and contaminants removed from them. They are then processed in the agglomerator to cut, pre-heat (or pre-plasticize) and dry these plastics. The agglomerated material is then processed in an extruder and then finally pelletized. Rigid plastic waste is to be first washed with labels removed then shreddered before agglomerated and pelletized. It is assumed that the capacity of a plastic recycling plant is 1.3 tonne/day of incoming plastic waste. The cost estimations for the plastic recycling plant are presented in Table 3.5. Additional information on the cost estimates can be found in Appendix G3. A survey of some plastic recycling companies in Accra revealed that agglomerated plastic crumbs and pelletized plastics are bought by end users at the same price. Therefore, these companies usually sell agglomerated plastic without further processing in to pellets. Currently, the major plastic polymers recycled in Ghana are polyethylene (both Low density and High density) and polypropylene. Based on the availability of these polymers in the waste stream it is assumed that 20 community plastic recycling plants will be required.

3.3.2.4 Landfilling

A sanitary landfill is currently operated in Kumasi for waste disposal. The landfill was constructed in 2003-2004 and was designed to handle waste for 15 years. The landfill is managed by a private company on behalf of KMA. Cost information on the landfill was obtained from the WMD of KMA. Details of these costs are found in Appendix G4.

Table 3.5 Costs Assumptions for Plastic Recycling Plant

	Cost type	Unit Cost, GH¢/t
A.	**Capital Cost**	
	Equipment Cost	13.72
	Cost of structure	13.8
	Sub total A	**27.52**
B.	**Collection cost**	
	Cost of tricycle	1.02
	Cost of bins	5.03
	Fuel cost	1.11
	Maintenance	0.61
	Labour	35.79
	Supplies	9.94
	Incentive	200
	Contingencies	24.74
	Subtotal B	**278.24**
C.	**Operational and maintenance**	
	Labour	115.4
	Sale of recycled plastic	16
	Equipment maintenance	24
	Electrical Power costs	120
	Water	6.7
	Detergents	40
	Subtotal B	**322.1**
	Contingencies @ 10% of O&M cost	32.21
	Total C	**354.31**
D.	**Land rental cost**	**1.75**

3.3.2.5 Summary of Model Input Parameters

The input parameters into the developed linear programming model are presented in Table 3.6 and Table 3.7. The details of waste composition and other model input parameters are found in Appendix G5. The optimization model is solved using Solver feature in Microsoft Excel.

Table 3.6 Cost Input Parameters

Parameters (Costs)	Cost, GH¢/t
Coll	1.1 – communal
Trl	10 –communal collection
	33.6 –house to house collection
Cal	7.49
Ll	0.02
O&Ml	7.2
Colc	1.1
Trc	10 –communal collection
	33.6–house to house collection
Cac	4.95
Lc	0, (scenario I:0.5)
O&Mc	22.6
Cacc	2.82
Lcc	0 (Scenario I: 0.7)
O&Mcc	25.14
Colcc	1.1
Trcc	10
Colpr	278.24
Capr	27.52
Lpr	1.75
O&Mpr	354.31
Trpr	10
Colprr	1.1

Table 3.7 Benefit and Constraints Input Parameters

Parameter (Benefits and Constraints)	Value
η	0.5
bio_c	0.57
Pr_c	0.06
M_c	0.02
pCc	GH¢40/t (Scenario II: 0)
pPrc	GH¢200/t
pMc	GH¢250/t
bio_{cc}	0.66
pCcc	GH¢30/t (Scenario II: 0)
Pr_{cc}	0.032
M_{cc}	0.005
pPrcc	GH¢200/t
pMcc	GH¢250/t
γ	0.93
P_{pr}	0.75
pPl	1100
fnb_c	0.35
fnb_{cc}	0.3
fnp	0.2
fop	0.05

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the results obtained for both waste characterization and pilot SS studies undertaken on KNUST campus and Asokwa Sub-metropolitan area. Also, the results of optimization model are presented in this chapter. The first section puts across the results from the questionnaire survey undertaken prior to the implementation of the pilot SS study and the follow up questionnaire. The second section presents and discusses results on waste composition and generation rates obtained in the study areas. Results on SS efficiency and level of compliance from the pilot SS study are then presented and discussed in the third section. The fourth section integrates results from the pilot SS study and questionnaire survey. This is undertaken to identify relationships between respondents/household characteristics and the potentials for SS as well as pertinent issues that could influence the success of organized SS in the study area. The results of optimization of the options for waste treatment in supporting the development of ISWM system in Kumasi are then discussed in the final section.

4.1 QUESTIONNAIRE RESULTS

Questionnaires successfully received and analyzed from senior and junior staff areas was 16 out of 25 participating households and 22 out of 28 participating households respectively during the preliminary survey. During the follow up 25 and 27 questionnaires were collected and analyzed from senior and junior staff areas respectively. In Asokwa Sub-Metro during the Preliminary survey, 34 questionnaires were completed and received from households that participated in the project of which 30 were analyzed from Asokwa, 34 questionnaires were received and analyzed from households that participated in the project in Atonsu and in Ahinsan 8 questionnaires were received and analyzed from households that participated in the project. Follow up questionnaires collected and analyzed from Asokwa, Ahinsan and Atonsu were 30, 33 and 6 respectively. The questionnaire results are presented in four sections namely: socio-demographic characteristics of respondents and households, household waste disposal practices, respondents' knowledge and opinions about WM and recycling.

4.1.1 Socio-Demographic Characteristics of Respondents and Households

The socio-demographic characteristics of respondents in the project areas was sought in order to establish the differences in the areas selected for the project. Information was collected on the age of the respondents, gender, highest level of education, occupation, marital status, position in the household and average household size. The results of the socio-demographic characteristics of respondents are presented for both the preliminary and follow up questionnaires.

4.1.1.1 Socio-Demographic Characteristics: KNUST

The largest numbers of respondents from both areas as shown in Figure 4.1 were male: 68.8% and 54.5% from senior staff and junior staff areas respectively. Females constitute 31.3% and 45.5% of respondents from senior and junior staff areas respectively. In the senior staff area, 18.3% of respondents have had education up to the secondary level whilst 81.3% have up to the tertiary level. In the junior staff area, 13.6% of respondents have had no formal education, 4.5% basic education, 36.4% secondary education and 36.4% tertiary education. 25% of respondents were single and 75% married in the senior staff area. 22.7% of respondents were single and 77.3% married in the junior staff area.

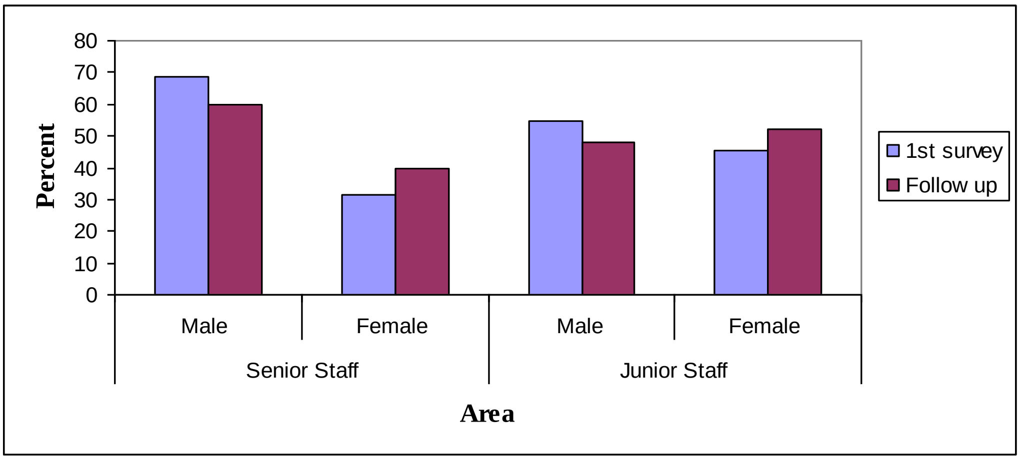

Figure 4.1 Gender of Respondents: KNUST

Most of the respondents from the two areas are between the ages of 35 to 59. The age group of respondents are presented in Table 4.1.

Table 4.1 Age of Respondent: KNUST

	1st Survey		Follow Up	
Age Group	Senior Staff, %	Junior Staff, %	Senior Staff, %	Junior Staff, %
Below 26 years	12.5	13.6	8	15
26-34	12.5	0	12	0
35-44	25	27.3	20	18.5
45-54	31.25	45.5	32	55.5
55-59	12.5	13.6	16	11
60 years an above	6.25	0	12	0

The status of respondents in their household is presented in Table 4.2. It can be observed that majority of respondents were parents in their respective households.

Table 4.2 Status of Respondent in Household: KNUST

	1st Survey		Follow Up	
Status in Hh	Senior Staff, %	Junior Staff, %	Senior Staff, %	Junior Staff, %
Father	56.25	50	48	48.1
Mother	18.75	36.4	28	37
Child	18.75	9.1	20	14.8
Other	6.25	4.5	4	0

The range of monthly incomes of households is shown in Table 4.3. It is observed that most households in the junior staff area recorded monthly incomes between GH¢100 and GH¢500. However, most households in the senior staff area recorded monthly incomes between GH¢200 and GH¢1000.

Table 4.3 Household Monthly Income: KNUST

	Area	
Household Income	**Senior Staff, %**	**Junior Staff, %**
less than Gh¢100	0	22.7
Gh¢100-200	12.5	27.3
Gh¢200-500	25	31.8
Gh¢500-1000	43.75	
above Gh¢ 1000	6.25	
Not provided	12.5	18.2

The average household size recorded in the senior and junior staff areas was 4.9 and 6.1 respectively.

4.1.1.2 Socio-Demographic Characteristics: Asokwa Sub-Metro

The percentage of male to female respondents for both questionnaires in the three areas is indicated in Figure 4.2. It is observed that female respondents were higher in all the areas for both questionnaire surveys.

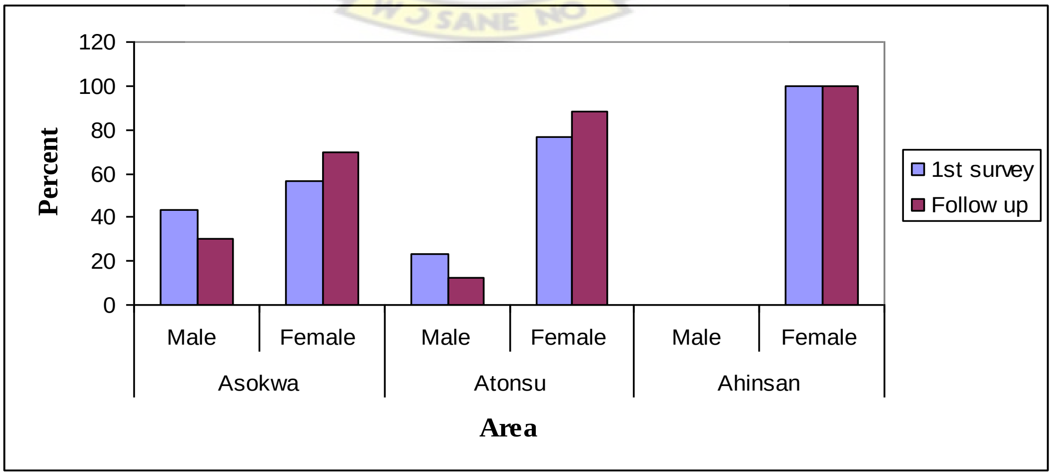

Figure 4.2 Gender of Respondents: Asokwa Sub-Metro

The age group of respondents are presented in Table 4.4. Majority of respondents (over 50%) fall between the ages 26 to 54 in all the areas for the two surveys.

Table 4.4 Age of Respondent: Asokwa Sub-Metro

	1st Survey			Follow up		
Age of Respondents	**Asokwa**	**Atonsu**	**Ahinsan**	**Asokwa**	**Atonsu**	**Ahinsan**
Under 26 yrs, %	30	23.5	25	33.3	24.2	0
26-34 yrs, %	20	17.6	12.5	36.7	30.3	33.3
35-44 yrs, %	20	14.7	37.5	20	6.1	33.3
45-54 yrs, %	20	20.6	0	6.7	21.2	16.7
55-59 yrs, %	0	2.9	12.5	0	6.1	16.7
60 yrs and above, %	10	20.6	12.5	3.3	12.1	0

In Asokwa, 23.3% of respondents have had education up to the junior secondary level, 30% up to senior secondary, 26.7% up to the tertiary level whilst 20% did not respond. The highest level of education of respondents in Atonsu were: 41.2% up to junior secondary, 8.8% senior secondary, 23.5% Tertiary, 5.9% vocational training and 20.6% had no formal education. In Ahinsan, the highest level of education of respondents were 50% basic education, 37.5% secondary and 12.5% had no formal education. In Asokwa, 53.3% of respondents were single, 43.3% married, and 3.3% did not respond to the question. In Atonsu, 29.4% of respondents were single whilst 70.6% were married. In Ahinsan, 25% of respondents were single, 62.5% were married and 12.5% did not give any response to the question. The status of respondents in their household is presented in Table 4.5. It can be observed that majority of respondents were mothers in their households. The average household size was calculated to be 6, 8 and 19 for Asokwa, Atonsu and Ahinsan respectively.

Table 4.5 Status of Respondent in Household: Asokwa Sub-Metro

		1st Survey			Follow up	
Status in Hh	**Asokwa**	**Atonsu**	**Ahinsan**	**Asokwa**	**Atonsu**	**Ahinsan**
Father	16.7	11.8	0	6.7	6.1	0
Mother	36.7	58.8	62.5	30	66.7	100
Child	30	26.5	25	30	15.1	0
Other	13.3	2.9	12.5	26.7	3	0
No response	3.3	0	0	6.7	9.1	0

4.1.3 Household Waste Disposal Practices

Household SW disposal practices are surveyed by establishing the means of HSW disposal, frequency of disposal, number of bins available in a household, alternative disposal methods employed by household and the common items that are disposed of through the alternative means.

4.1.3.1 Household Waste Disposal Practices: KNUST

About 87% of households surveyed on KNUST campus have single bins which are emptied daily into concrete skips for temporal storage. The remaining households who live close to the concrete skips, used for temporal storage, dispose of their waste directly into the skips. It was investigated further to establish alternative waste disposal methods employed by households. 56.3% and 45.5 % of household from the senior staff and junior staff areas respectively do not put all wastes generated in their household bin. The reasons for alternative waste disposal methods as well as the common waste items diverted are given in Table 4.6 and Table 4.7.

Table 4.6 Alternative HSW Disposal Methods: KNUST

Waste Disposal Method	Senior Staff, %	Junior Staff, %
Burnt	37.5	13.64
Reused at home	6.25	
Sold to itinerant buyers		
Burnt and buried	6.25	
Reused and sold to itinerant buyers		4.55
Burnt, reused	6.25	
Other		13.64
Not applicable	43.75	68.18

Table 4.7 HSW Diverted from Conventional Collection and Alternative Disposal Methods: KNUST

Common waste items not put in bin	Common disposal methods
Carcasses	Buried
Dried leaves	Burnt
Cans	Sold to itinerant buyers
Plastic bottles	Reused at home, sold to itinerant buyers
Plastic bags	Reused at home, sold to itinerant buyers
Bottles	Reused at home, sold to itinerant buyers
Diapers & sanitary towels	Burnt
Organic & food waste	Used to feed animal, land application as manure
Old gadgets	Burnt
Paper	Burnt

It can be admitted from the results presented above that there is a considerable level of customary separation at source of HSW in staff residencies on KNUST campus.

4.1.3.2 Household Waste Disposal Practices: Asokwa Sub-Metro

In Asokwa, 66.7% of respondents are served with door to door collection services whilst 33.3% disposed of their waste in a nearby communal container. 80% of households had single bins and 20% had two bins in their households with 20% disposing of their waste daily, 73.3% weekly 3.3% were not sure of the consistency of their waste disposal and 3.3% did not give any answer. The high weekly disposal indicated is because of the weekly collection made by the waste collection company serving that area. None of the households buried any item they considered as waste. This may be due to the fact that the compounds in most houses in this area are paved and walled; hence there may not be any land available to bury waste. 33.3% of household burned some waste materials whilst 66.7% did not. 33.3% of households claimed to give away post-consumer items (which will otherwise be waste), 66.7% did not. 60% of household reused some items like empty bottles that would otherwise be waste, 33.3% did not and 6.7% did not give any response. 46.7% of households sold items to itinerant buyers, 50% did not and 3.3% did not give any response.

In Atonsu, all households surveyed in this area send their SW almost daily to a nearby communal collection point. This is because that is the arranged waste collection method by the local authorities. 82% of households had single bins, 6% had two, 9% had three bins and 3% did not give any answer. None of the household buried any item they considered as waste. 62% of household burned some waste materials whilst 35 did not, 3% did not answer this question. Most of the wastes burnt were papers and dried leaves. 21% of households claimed to give away post-consumer items (which will otherwise be waste), 79% did not. 65% of household reused some items especially empty bottles that would otherwise be waste whilst 35% did not. 50% of households sold items to itinerant buyers, 50% did not.

In Ahinsan, all households in this area send their solid wastes daily to a nearby communal dump site as arranged by the local authority. 62.5% of households had single bins, 12.5% had two bins and 25% had three bins in their houses. None of the household buried any item they considered as waste. 12.5% of household burned some waste materials whilst 87.5% did not. 87.5% of households claimed to give away post-consumer items (which will otherwise be waste), 12.5% did not. 75% of household reused some items like empty bottles that would otherwise be waste, 25% did not. 37.5% of households sold items to itinerant buyers, 62.5% did not.

It can be seen from the results from the survey that the three areas vary in their waste disposal methods. Households served with door to door collection, dispose their waste weekly. However, households that dispose their waste in communal containers or dump do so daily. Burying of waste is not common in these areas; this may be attributed to lack of unpaved soil in the compounds of household to serve this purpose. Burning of waste is common in all the areas to various degrees. Reuse of waste is high in all the areas especially empty plastic bottles. Selling of post-consumer materials to itinerant buyers is also common to a great extent in all the three areas.

4.1.4. Respondents' Knowledge and Opinions about Waste Management and Recycling

The importance of the knowledge, attitudes and opinions of people to the success of establishing waste separation schemes cannot be overemphasized, since the behaviour of individuals directly results in the success or failure of such schemes. In order to explore the attitudes of respondents to SWM, their knowledge of the company responsible for collecting their waste as well as the final disposal site of collected waste was sought. The concern for safe disposal of collected waste was also explored as well as opinions on the waste management situation in the neighbourhood. Knowledge of recycling and SS was also investigated as well as the source of the knowledge. To provide information to support the design of appropriate SS, respondents were asked whether SS should be mandatory or voluntary during the first survey and follow up. Respondents' willingness to provide their own bins for SS, patronize central collection point for separated waste and to receive cash for waste sent to central collection point was also explored.

4.1.4.1 Respondents' Knowledge and Opinions about Waste Management and Recycling: KNUST

Only 37.5% and 45.5 % of respondents from senior staff and junior staff areas respectively claimed they know the ultimate disposal site of the waste collected from their households. The proportion of respondents who are concerned, unconcerned or uncertain about the safe and acceptable disposal of waste from their households is given in Table 4.8

Table 4.8 Concern for Safe and Acceptable Disposal of Waste: KNUST

Response	Senior Staff, %	Junior Staff, %
yes	62.5	54.55
no	6.25	13.64
don't know	12.5	18.18
not provided	18.75	13.64

Less than 50% of respondents knew the final disposal site of waste collected from their households from both areas out of which more than 50% of them are concerned about the safe and acceptable disposal of waste collected from their households as can be deduced from Table 4.8. 75% and 50% of respondents from senior staff and junior staff areas were satisfied with waste disposal in their neighbourhood respectively. The perceived most urgent problem related to the disposal of solid waste in the neighbourhood by respondents is presented in Table 4.9. Only a small percentage of households in both areas perceive personal health, littering of neighbourhood and pollution of living area as the most urgent problems related to waste disposal in their neighbourhood. However, to varying degrees, each of the enumerated problems was perceived as most urgent in relation to waste disposal in the neighbourhood.

In the senior staff area, 62% of respondents sell items to itinerant buyers, 18.8% do not but are willing to sell to itinerant buyers if asked to do so. However, 12.5% do not sell to itinerant buyers and are unwilling to do so and 6.2% did not provide any answer. In the junior staff area, 50% of respondents sell items to itinerant buyers, 9.1% do not but are willing to do so if asked to, 27.3% do not sell to itinerant and unwilling to do so is asked to and 13.6% did not provide any answer.

Table 4.9 Perceived Most Urgent Problem Related to Waste Disposal in Neighbourhood: KNUST

Problem	Senior Staff, %	Junior Staff, %
Personal health	12.5	27.27
Littering of neighbourhood	12.5	18.18
Pollution of living area	18.75	18.18
Other	25	
Personal health and pollution	6.25	4.55
Littering and pollution of living area	6.25	4.55
Personal health, littering and pollution of living area	6.25	
Not provided	12.5	27.27

Different reasons were cited as motivation to sell to itinerant buyers. Households who sold items to itinerant buyers did so because they thought the buyers have use for the materials or that they could make some money from it. Some saw it as a means of getting rid of unwanted materials in their homes. One respondent in the senior staff area sold to itinerant buyers in order to reduce the size of disposal materials. A high percentage of respondents have knowledge of recycling; 100% and 95.5% from senior and junior staff areas respectively. The sources of respondent's knowledge of recycling are indicated in Table 4.10. Most respondents perceive recycling as a good option for managing their waste.

Table 4.10 Sources of Knowledge on Recycling: KNUST

Source	Senior Staff, %	Junior Staff, %
Literature	6.25	13.64
Media	50	72.73
Other	12.5	4.55
Not provided	0	4.55
Literature and Media	25	4.55
Literature and Other	6.25	0

In reference to Table 4.10 the media can be said to be a major source of information to respondents. Most respondents from the senior staff area have participated in recycling programmes overseas. Consequently, 93.8% of respondents in the senior staff area have also heard of or participated in SS. Only 22.7% of respondents in the junior staff area have heard of SS. The major sources of knowledge of SS in the senior staff areas was overseas and from the electronic media in the junior staff areas.

In the senior staff area, 87.5% of respondents think SS should be made mandatory whilst in the junior staff area, 72.7% think so. 50% and 59.1 of respondents are willing to provide their own bins to store separated waste from the senior and junior staff areas respectively. Table 4.11 presents the willingness to participate in central collection of separated waste by respondents with and without cash incentive.

Table 4.11 Willingness to Patronize Central Collection of Separated Waste: KNUST

	No cash incentive		With cash incentive	
Response	**Senior Staff, %**	**Junior Staff, %**	**Senior Staff, %**	**Junior Staff, %**
yes	68.75	63.64	75	59.09
no	25	27.27	12.5	31.82
no answer provided	6.25	9.09	12.5	9.09

4.1.4.2 Respondents' Knowledge and Opinions about Waste Management and Recycling: Asokwa Sub-Metro

In Asokwa, 36.7% of respondents had knowledge of the company responsible for collecting their solid waste and only 10% of respondents claimed they knew where their waste was finally dumped. In Atonsu, 29.4% of respondents had knowledge of the company responsible for collecting their solid waste and only 5.9% of respondents claimed they knew where their waste was finally dumped. The Ahinsan township has a crude dumpsite which is managed by one labourer. The results from

Asokwa and Atonsu suggest that many of the respondents do have knowledge of the company collecting their waste and where the waste is finally disposed. Table 4.12 indicate the concern of the respondents for the safe and acceptable disposal of collected waste.

Table 4.12 Concern for Safe and Acceptable Disposal of Waste: Asokwa Sub-Metro

Response	Asokwa, %	Atonsu, %	Ahinsan, %
yes	76.9	73.5	50
no	3.3	14.7	37.5
don't know	13.3	2.9	13.8
not provided	6.7	8.8	12.5

Although very few respondents from Asokwa and Atonsu knew the final disposal site of the waste collected from their households, more than 70%, as indicated in Table 4.12, of them claim they are concerned about the safe and acceptable disposal of their collected HSW. Further, 23.3%, 5.9% and 62.5% of respondents think waste management in their area was satisfactory from Asokwa, Atonsu and Ahinsan respectively. The perceived most urgent problem related to the disposal of solid waste in the neighbourhood by respondents is presented in Table 4.13. It can be observed from Table 4.13 that most households from the three areas did not respond to the question of the most urgent problem of waste disposal in the neighbourhood, perhaps they could not understand the implications of improper disposal of waste.

Table 4.13 Perceived Most Urgent Problem Related to Waste Disposal in Neighbourhood: Asokwa Sub-Metro

Problem	Asokwa, %	Atonsu, %	Ahinsan, %
Personal health	6.7	23.5	0
Littering of neighbourhood	26.7	17.6	0
Pollution of living area	13.3%	26.5	0
Other	0		0
Not provided	53.3	23.5	75
Personal health and pollution	0		0
Littering and pollution of living area	0		25
Personal health, littering and pollution of living area	0	8.8	0

In Asokwa, Atonsu and Ahinsan respectively, 26.7%, 32.35% and 12.5 of households do not sell to itinerant buyers but are willing to do so if asked to. 23.35%, 20.59% and 25% do not sell to itinerant buyers and are unwilling to do so if asked, however. Households that sold items to itinerant buyers did so because some thought there was use for those materials elsewhere, to avoid accumulation of items in their homes and mostly to earn some cash. More than 70% of respondents have knowledge of recycling; 73.3%, 73.5% and 87.5% from Asokwa, Atonsu and Ahinsan respectively. The sources of respondent's knowledge of recycling are indicated in Table 4.14. Most respondents perceive recycling as a good option for managing their waste. It can be observed from Table 4.14 that majority of households in the three areas had their knowledge of recycling from the electronic media; hence future education programmes might be effectively disseminated through the electronic media.

In Asokwa, 33.3% of respondents have had knowledge of waste separation at source mostly from their experiences abroad, through the media and friends, 43.3% had no knowledge of waste separation at source and 23.3% did not respond. In Atonsu, 6.5% of respondents have had knowledge of waste separation at source mostly from their experiences abroad, school, through the media and friends, 58.8% had no knowledge of waste separation at source and 14.7% did not respond. None of the respondents have had knowledge of waste separation at source in Ahinsan.

Table 4.14 Sources of Knowledge of Recycling: Asokwa Sub-Metro

Source	Asokwa, %	Atonsu, %	Ahinsan, %
Literature	6.7	5.9	25
Media	43.3	29.4	37.5
Literature and media		8.8	
Abroad	26.7	26.5	
Individuals			37.5
No answer	23.3	29.42	

In Asokwa 63.3% of respondents think waste separation should be made mandatory, whilst 30% think otherwise, 6.7% gave no response. In Atonsu, 94.1% of respondents think waste separation should be made mandatory, whilst 2.9% think otherwise, 2.9% gave no response. In Ahinsan, 62.5% of respondents think waste separation should be made mandatory, whilst 37.5% think otherwise.

In Asokwa, Atonsu and Ahinsan respectively, 23.3%, 38.2% and 12.5% of respondents were willing to buy their own bins for waste separation. Table 4.15 presents the willingness to patronize collection of separated waste by respondents with or without cash incentive.

Table 4.15 Willingness to Patronize Central Collection of Separated Waste: Asokwa Sub-Metro

	No cash incentive			With cash incentive		
Response	Asokwa, %	Atonsu, %	Ahinsan, %	Asokwa, %	Atonsu, %	Ahinsan, %
yes	86.7	88.2	75	83.3	85.3	62.5
no	10	8.8	25	13.3	14.7	37.5
no answer provided	3.3	2.9	0	3.3	0	0

4.1.5 Feedback on the Performance of Pilot Source Separation Scheme

During the follow up survey, it was sought to establish if households were actively participating, if they had difficulties identifying which bin to place some particular materials in and if some HSW were diverted from the proposed collection scheme. Households' satisfaction with the SS scheme and perception on adopting SS after participating in the project was also investigated.

4.1.5.1 Household's Participation in SS Program on KNUST Campus

Most respondents had no difficulty in identifying what to place in a particular bin; however 24% and 25.9% of respondents could not identify which bin in which to place certain materials in the senior and junior staff areas respectively. Some of the materials mentioned were glass, metals, parts of electronic gadgets, sanitary towels and paper, plastic boxes and foil. Some households also said they had difficulty in separating organic from inorganic waste and also plastics from other wastes. The difficulty in identifying where certain materials should be placed could be a result of lack of understanding of the scheme instructions or perhaps not all household members were educated on the separation procedure by the key person who received the education materials. Some households emptied their bins in between the collection days; 36% and 25.9% in senior and junior staff areas respectively. This could undermine the quantity of waste collected from each household. In addition, 76% and 44.4% of households respectively do not place all their waste in the bins provided. The types of materials not placed in the bins and what is done with those materials are similar to those reported during the first survey (Table 4.7). Majority of respondents were satisfied with the project; 80% and 92.59% in senior staff and junior staff areas respectively. Further, 92% and 85.18% of respondents in senior staff and junior staff areas think SS should be adapted into the waste management system on KNUST campus. Respondents who do not support the adoption of SS on KNUST campus cited lack of interest and understanding of the project, inadequate number of bins and twice a week collection as reasons for their stance.

4.1.5.2 Household's Participation in SS Program in the Asokwa Sub-Metro

Most respondents had no difficulty in identifying what to place in a particular bin; however 33.33%, 24.24% and 66.67% of respondents could not identify which bin in which to place certain materials in Asokwa, Atonsu and Ahinsan respectively. Some households emptied their bins in between the collection days; 3.33% and 6.06% in Asokwa and Atonsu respectively. No household in Ahinsan emptied their bins in between the collection days. In addition, 36.67%, 66.67% and 50% of households do not place all their waste in the bins provided in Asokwa, Atonsu and Ahinsan respectively. The types of materials not placed in the bins include diapers and sanitary towels; fish waste, toilet paper, leaves and ashes. Common disposal methods indicated by households include: direct disposal at local dump site, burning and other means which were not specified. Majority of respondents were satisfied with the project; 73.33%, 90.9% and 100% in Asokwa, Atonsu and Ahinsan respectively. Further, 93.3%, 93.9% and 100% of respondents in Asokwa, Atonsu and Ahinsan respectively think SS should be adapted into the waste management system in the Asokwa Sub-Metro.

4.1.6 Comments and Observations from the Study

The comments and concerns of respondents from both questionnaires surveys are enumerated in this section. Observations made during the study are also listed.

1. Summary of concerns from the senior staff area on KNUST campus indicate the preference for daily collection of waste especially for organic waste,

more education and elaborate education materials, provision of bins for plastic wastes instead of bags, provision of an additional bin for bottles and cans.

2. Daily collection was also advocated in the junior staff area. Other concerns were provision of bigger bins, communal collection of separated waste instead of household collection, provision of rewards for separation and increased education.
3. Some households agreed to participate only with the consent of their landlords in the third class Area (Ahinsan). This brings to the fore an important issue of including landlords in stakeholders that are important to consult in the design of SS schemes.
4. There is also lack of space in third class area to accommodate bins for waste separation. This implies SS schemes targeting recyclables in this area should consider alternative approaches such as decentralized collection points or collection of recyclables daily at the community waste dumps or communal collection sites.
5. Lack of toilets in households is a major threat to placement of bins in the third class area, since people were afraid faeces will be wrapped in black polythene bags and placed in the bin. For this reason most households opted out of the project although they originally agreed to participate when bins were being distributed. Which was actually the case during the project: some households in the third class area always had wrapped faeces in their bin.
6. Another observation from some households in compound houses in the second class area was that, they were not comfortable with a collection service that might require several families using one bin especially if they

have to pay for the service, since from their experiences they feel exploited by their landlords when fees have to be shared.

Provision of free bins and a reliable and consistent collection scheme are the major concerns expressed by household for the adoption of SS in the Asokwa Sub-Metro area. While on KNUST, where waste collection from the household is consistent, a scheme that matched their daily collections was advocated.

4.2 WASTE COMPOSITION AND GENERATION RATE

The total quantity of waste collected and analysed during the project period of 18 weeks from staff residencies on KNUST campus was 11448.75kg. From senior staff area 6098.95kg of waste was collected and 5349.8kg from the junior staff area. The total amount of waste collected from Asokwa, Atonsu and Ahinsan was 10095.5kg, 11372.55kg and 3104.4kg respectively over the project period of 12 weeks.

4.2.1 Waste Composition

4.2.1.1 Waste Composition KNUST Campus

The waste composition is a basic data required for planning of waste management strategies in any given locality. The average composition of household wastes for staff residencies on KNUST campus is presented in Figure 4.3. The figures for each waste component can be found in Appendix F2.A. The components of household solid waste for the different staff areas are given in Table 4.16.

Table 4.16 Waste Composition from Senior and Junior Staff Areas

Material	Senior Staff % of Total Waste	Junior Staff % of Total Waste
Organic	73.43	64.36
Plastics	6.97	7.69
Metals	2.96	2.27
Glass	1.79	0.81
Paper	4.97	3.79
Textiles	1.94	1.56
Others	7.93	19.53

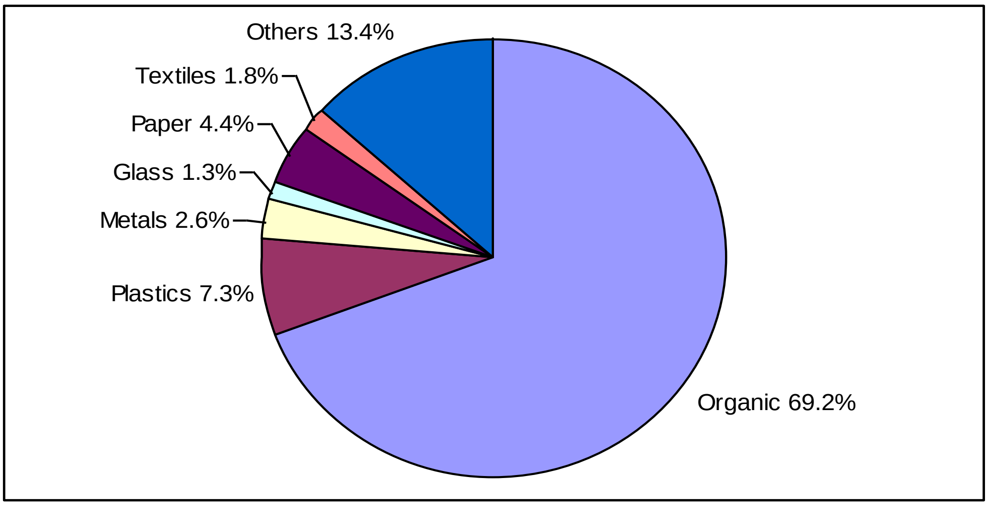

Figure 4.3 Average Waste Composition - KNUST Staff Residencies

The weekly variations in waste composition over the study period are presented in figures 4.4 and 4.5 for senior staff and junior staff areas respectively. The actual weekly weights of each component can be found in Appendix F2.C and F2.D.

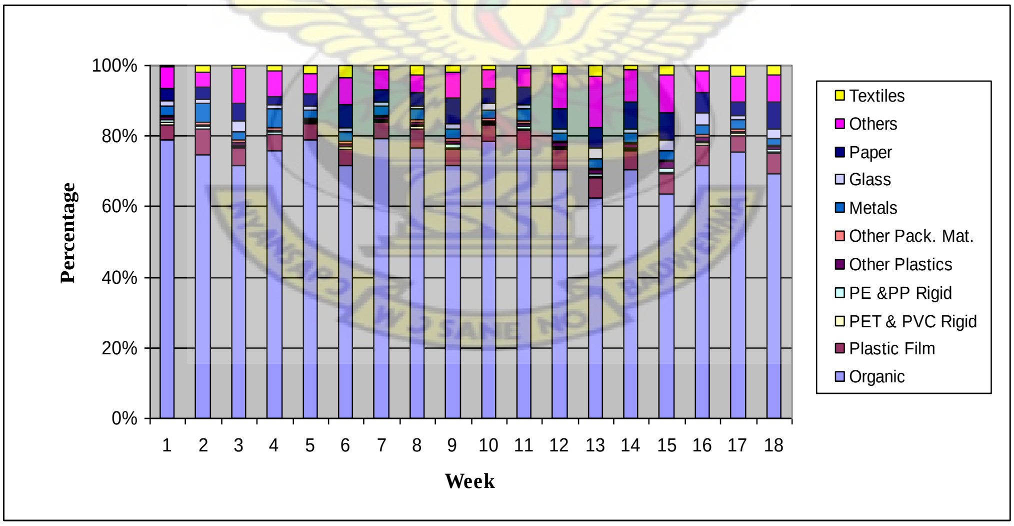

Figure 4.4 Weekly Waste Composition: Senior Staff Area

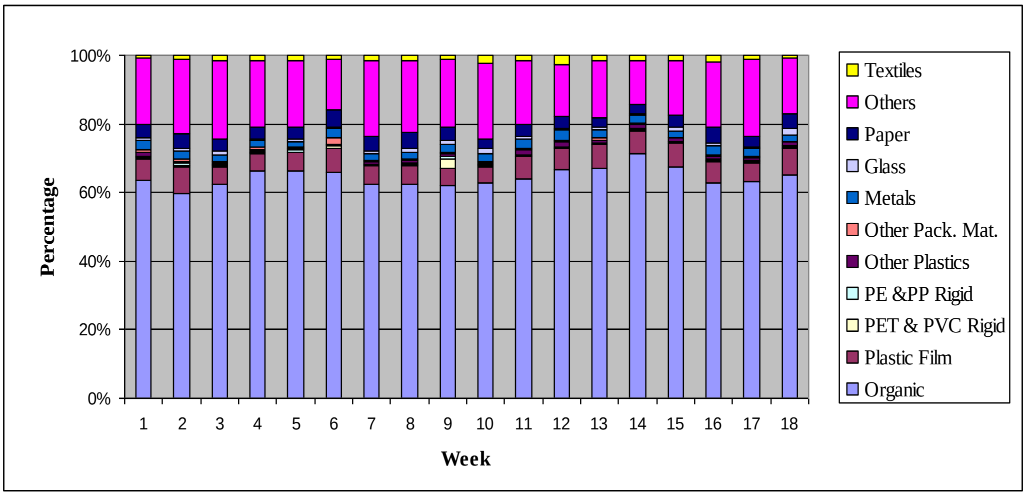

Figure 4.5 Weekly Waste Composition: Junior Staff Area

4.2.1.2 Waste Composition: Asokwa Sub-Metro

The average waste composition obtained for Asokwa sub-metro is given in Figure 4.6. The figures for each waste component can be found in Appendix F2.B. The components of household solid waste for the different classes of areas are given in Table 4.17.

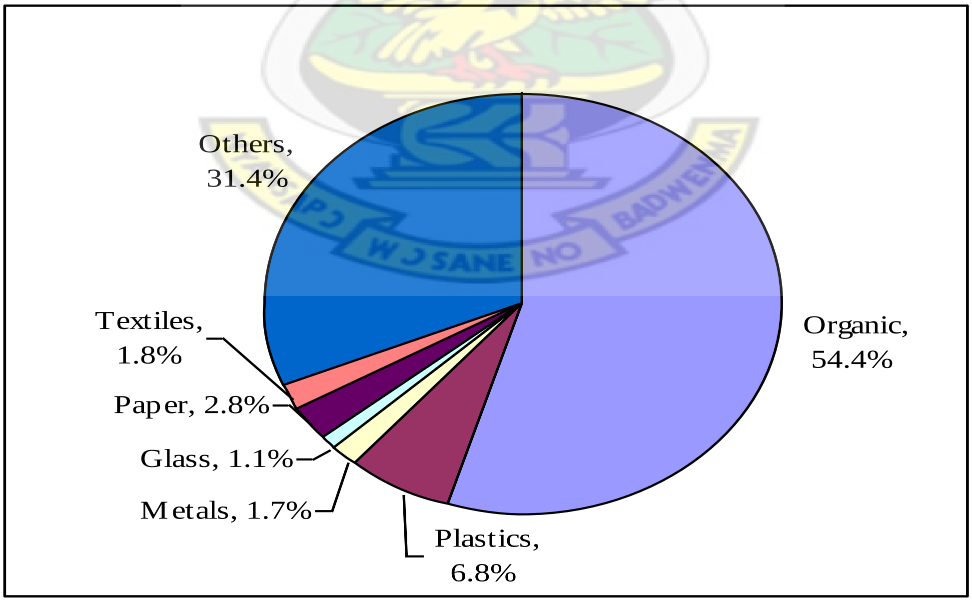

Figure 4.6 Average Waste Composition – Asokwa Sub-Metro

Table 4.17 Waste Composition from the Three Areas in Asokwa Sub-Metro

	Asokwa	Atonsu	Ahinsan
Material	**% of Total waste**	**% of Total Waste**	**% of Total Waste**
Organic	61.83	50	46.24
Plastics	7.1	5.95	8.6
Metals	2.21	1.45	1.01
Glass	1.39	0.96	0.66
Paper	3.38	2.37	2.33
Textiles	1.4	1.7	3.81
Others	22.69	37.56	37.34

The weekly variations in waste composition over the study period in the Askowa Sub-Metro are presented in figures 4.7 - 4.9. The actual weekly weights of each component can be found in Appendix F2.E – F2.G.

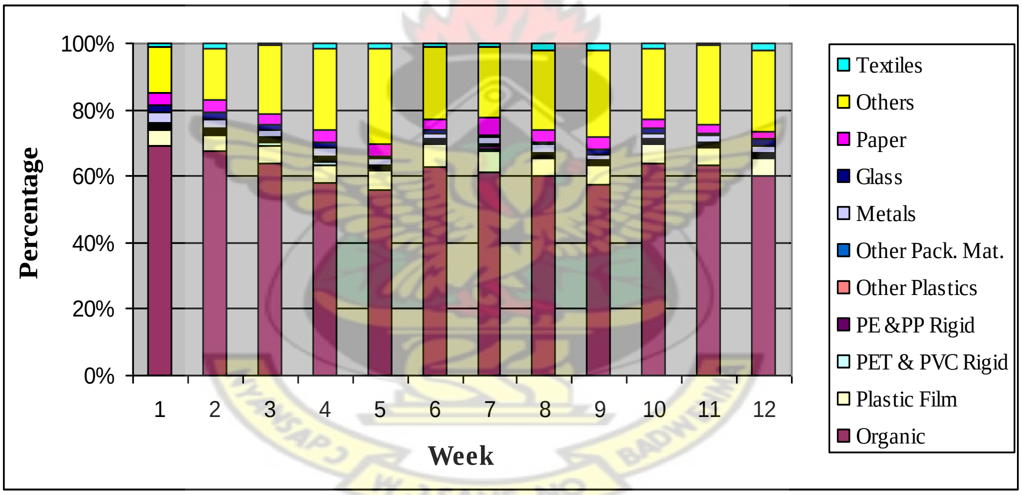

Figure 4.7 Weekly Composition of Waste in Asokwa

The percentage of organic was found to be the highest in all of the study areas. The percentage of organic waste on KNUST campus (69.2%) was found to be higher than that of Asokwa Sub-Metro (54.4%). This is similar to results from other studies in Ghana and internationally from developing countries that reported organic waste as the highest fraction of MSW. The waste composition result of this study is compared with results from other studies in urban areas in Ghana in Table 4.18.

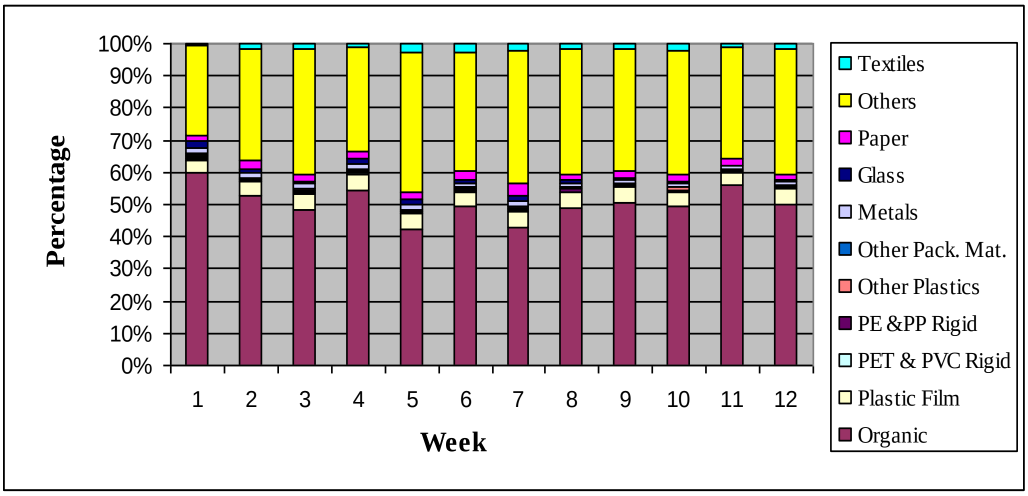

Figure 4.8 Weekly Composition of Waste in Atonsu

Ketibuah et al., (2004) reported that, in Bantama Sub- Metro in Kumasi, the bulk of household waste was organic waste with an overall average of 55% from the three residential classes of areas. The 1st Class areas had the highest fraction of Organic waste (71%) whilst the 2nd and 3rd Class areas had 56% and 48% respectively.

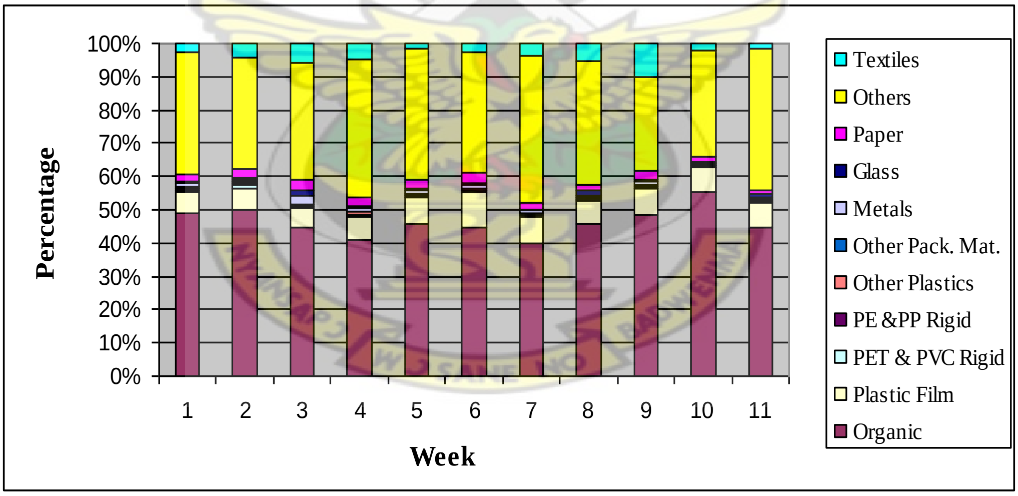

Figure 4.9 Weekly Composition of Waste in Ahinsan

Kotoka, (2001) reported 43.87% of Greens/vegetables/fruits from household waste in high income areas of Kumasi. This figure, however, is lower than what was obtained in this study due to the difference in the definition of organic waste. Organic waste defined in this study includes food wastes and yard waste while Kotoka (2001) reported "Greens/vegetables/fruits" and did not record food waste as organic and the definition of "greens" is also unclear.

Table 4.18 Household Waste Composition from KNUST, Asokwa Sub-Metro and Other Urban Areas in Ghana

Material	Area				
	Asokwa Sub-Metro	KNUST	Bantama Sub-Metro[1]	Accra, 2005[2]	Accra, 2008[3]
Organic, %	54.4	69.2	55	60	63
Plastics, %	6.8	7.3			10
Plastic/rubber, %			7	8	
Metals, %	1.7	2.6	2	3	2
Glass, %	1.1	1.3	1	2	2
Paper/cardboard, %	2.8	4.4	7	8	6
Textiles, %	1.8	1.8	1	2	5
Others/inert, %	31.4	13.4	29	13	12

[1]Ketibuah et al., 2004, [2]Fobil et al., 2005, [3]Owusu-Ansah, 2008

Table 4.19 Waste Composition from KNUST, Asokwa Sub-Metro and Other Urban Areas in Some Developing Countries

Material	Area				
	Asokwa Sub-Metro	KNUST	Guadalajara, Mexico [1]	Gabarone, Botswana[2]	Greater Paramaribo, Suriname [3]
Organic, %	54.4	69.2	52.9	67.9	56.8
Plastics, %	6.8	7.3	9.2	4.5	11
Metals, %	1.7	2.6	1.5	6.2	2.5
Glass, %	1.1	1.3	4.1	6.4	5.8
Paper/cardboard, %	2.8	4.4	10.5	12.5	6.8
Textiles, %	1.8	1.8		1.3	
Others/inert, Miscellaneous%	31.4	13.4	21.8	1.2	17.3

[1] Bernache-Perez et al., 2001, [2]Bolaane and Ali, 2004, [3] Zuilen, 2006

On the international scene, 68% of waste by weight is putrescible in Gabarone, Botswana, (Bolaane and Ali, 2004), 53% is putrescible in Guadalajara, Mexico, (Bernache-Perez et al., 2001), 58% is putrescible by weight in Guangzhou, China, (Chung and Poon, 2001), 66% of household waste is organic in Siem Reap, Cambodia (Parizeau et al., 2006) and 60% of household waste is organic in Greater Paramaribo, Suriname (Zuilen, 2006). Palczynski (2002) also indicated that, on as-delivered (wet basis), MSW from Accra, Ibadan, Dakar, Abidjan, and Lusaka show putrescible organic content ranging from 35-80% (generally toward the higher end of this range).

The second highest component of the waste stream in the study areas was the other waste with varying compositions for different areas generally based on the type of housing and fuel for cooking, because it mostly consist of soil, ash and charcoal. In the case of plastics, the percentage composition from this study is similar to that reported from Bantama Sub-Metro and is marginally lower than results obtained in Accra (Table 4.18). The amounts of paper observed in this study are generally lower than those reported in other studies in reference to Table 4.18 and 4.19. The glass, metal and textile materials were found to be lowest in all the areas studied with percentage composition below 3%.

The results of the weekly composition of waste suggest that the amounts of individual materials found in the waste stream are not static from week to week. This implies that an extended period of analysis is required to adequately quantify the amounts of specific materials if collection programmes are to be designed to collect those materials.

4.2.2 Waste Generation Rate

Waste generation in the context of this study is defined as the quantity of waste set out by a household for collection. The actual amounts of waste generated is difficult to quantify since most households divert some wastes mainly through burning, use of organic waste as compost for the backyard gardens and sale of some post-consumer materials to itinerant buyers. Therefore, actual households' waste generation rates may be higher than the amount collected. The per capita waste generation rate was calculated for each of the study areas using the total amount of waste collected from each household and the number of persons in the households. The number of persons in each household was calculated from the answers provided in a questionnaire survey conducted prior to the start of the project.

4.2.2.1 Waste Generation Rate: KNUST Campus

The average waste generated per person per day from KNUST staff residencies are given in Table 4.20. The average per capita waste generation from the senior staff area is higher than that from the junior staff area.

Table 4.20 Per Waste Generation Rate: KNUST

AREA	AVERAGE waste/kg/person/day	STANDARD DEVIATION waste/kg/person/day	RANGE	
			MIN	MAX
SENIOR STAFF	0.39	0.06	0.3	0.49
JUNIOR STAFF	0.26	0.05	0.2	0.39
OVERALL	0.30	0.05	0.23	0.39

The waste generated in a week from a household is found to be approximately 12kg on the average from household on KNUST campus. The average weekly waste generation is shown in Figure 4.10. A paired t-test analysis on the means of the daily per capita waste generated from the senior staff and junior staff suggest that a statistically significant difference exist between them (p=0.000) at 5% significance level (test results in Appendix F3.C).

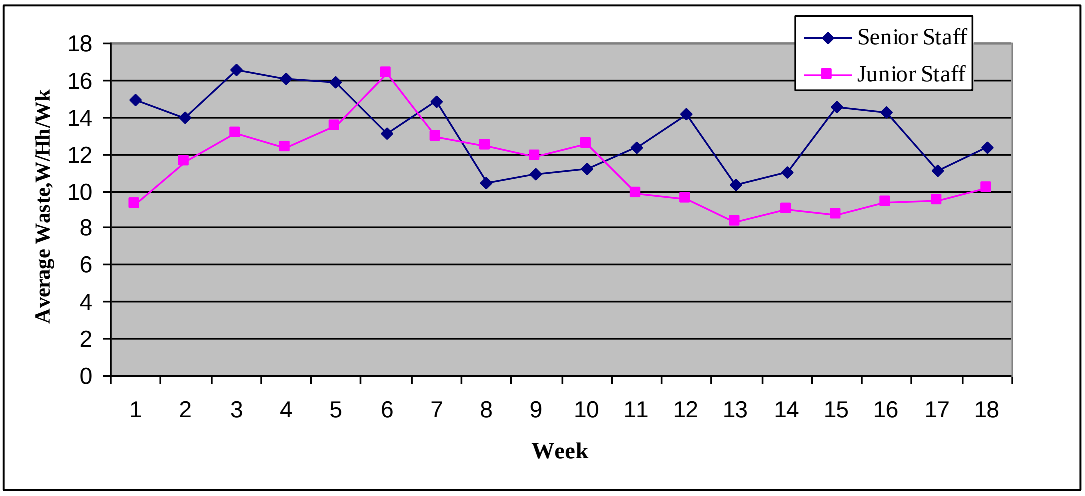

Figure 4.10 Average Household Waste Generated Weekly: KNUST

4.2.2.2 Waste Generation Rate: Asokwa Sub-Metro

The per capita waste generation rate for the selected areas in the Asokwa Sub-Metro is shown in Table 4.21. In Figure 4.11, the trend in weekly waste generation is shown.

Table 4.21 Per Capita Waste Generation Rate: Asokwa Sub-Metro

AREA	AVERAGE waste/kg/person/day	STANDARD DEVIATION waste/kg/person/day	RANGE	
			MIN	MAX
ASOKWA	0.63	0.06	0.49	0.71
ATONSU	0.52	0.08	0.31	0.6
AHINSAN	0.27	0.05	0.2	0.33
OVERALL	0.49	0.04	0.39	0.56

A paired t-test analysis on the means of the daily per capita waste generated from multiple pair comparisons among the three selected areas in the Asokwa Sub-Metro suggest that a statistically significant difference exist between them (p=0.000) at 5% significance (test results in Appendix F3.D-F3.F).

It can be observed from the results that the average waste generated per person per day was highest for Asokwa, followed by that of Atonsu and finally that of Ahinsan.

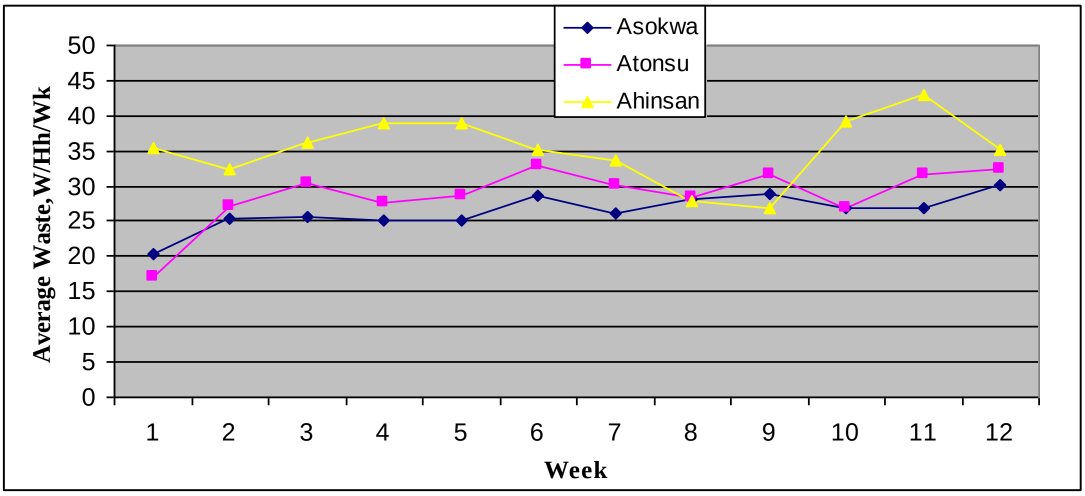

Figure 4.11 Average Household Waste Generated Weekly in Asokwa Sub-Metro

This supports the position that higher income areas have higher per capita waste generation rates than lower income areas from other studies. In Ghana, Opoku (1999) reports waste generation rate of 0.28 - 0.47 kg/cap/d in middle income households and 0.24 - 0.29 kg/cap/d in low income areas of Kumasi which does not vary much from the results obtained in this study. Kotoka (2001) found the average waste generation rate for high income communities in Kumasi to be 0.94kg/cap/day. This is higher than results obtained for high income area in this study. This may be attributed to the differences in the methods used in collecting data on household waste in the two studies. Average waste generation rates of 0.462 kg/cap/d, 0.380 kg/cap/d and 0.285 kg/cap/d were reported for high income, middle income and low income areas respectively in Accra (Fobil, 2005). Owusu-Ansah (2008) also report waste generation rates of 0.7kg/cap/d, 0.32kg/cap/d and 0.37kg/cap/day for high income, middle income and low income communities respectively with an average for the three areas of 0.35kg/cap/d in Accra. The above reports from Accra suggest that per capita waste generation rates are higher in Kumasi than in Accra.

In some other parts of the developing world, reported average waste generation rates are 0.362kg/cap/d in Dar es Salaam, Tanzania (Kaseva et al., 2002);

0.33kg/cap/d in Gaborone, Botswana (Bolaane and Ali, 2004), 0.47 ± 0.06kg/cap/d in Greater Paramaribo, Suriname (Zuilen, 2006) and 0.25kg/cap/d in Cittagong, Bangladesh (Sujauddin et al., 2008). Beede and Bloom (1995) assert that it appears that even the poorest individuals within a country generate on daily bases per capita of 0.3 – 0.4 kg of MSW. It can, therefore, be said that the average waste generation rate obtained in this study is comparable with results from other studies.

4.2.2.3 Waste Generation Rate and Household Size

The number of persons in a household was correlated with waste generation rate (kg/Hh/d and kg/cap/d) in order to establish the influence of household size on waste generation rate. The correlation depicted in Figure 4.12 and 4.13 shows that there is in general a weak positive relationship (r = 0.3955 – KNUST; r = 0.3891 - Asokwa Sub-Metro) between number of persons in a household and the waste household generation rate (kg/Hh/d). Household size corresponds with an increase in the total daily household waste generation rate. This compares with results obtained by Sujauddin et al. (2008) who found generation of HSW (kg/Hh/day) to be positively correlated with family size (r = 0.236).

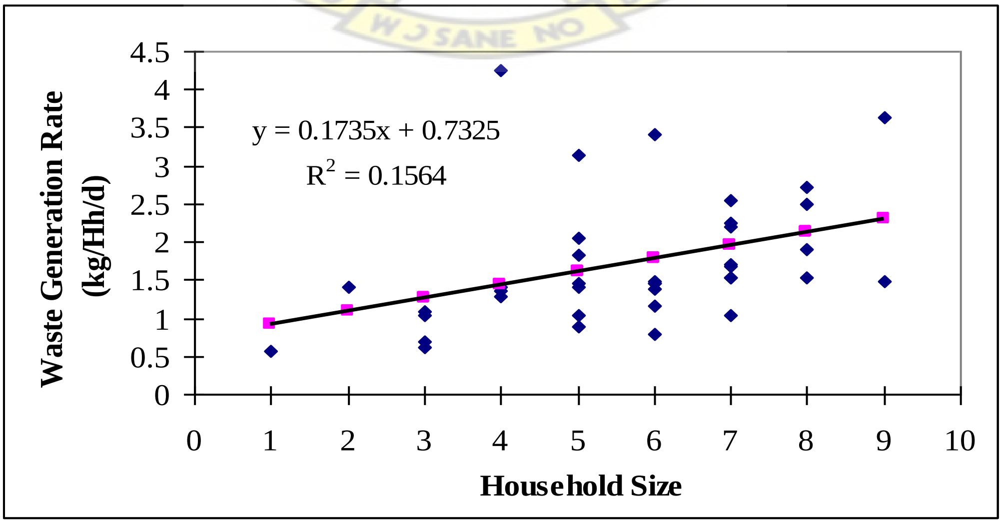

Figure 4.12 Relation between Household Size and Total Household Waste Generation Rate: KNUST

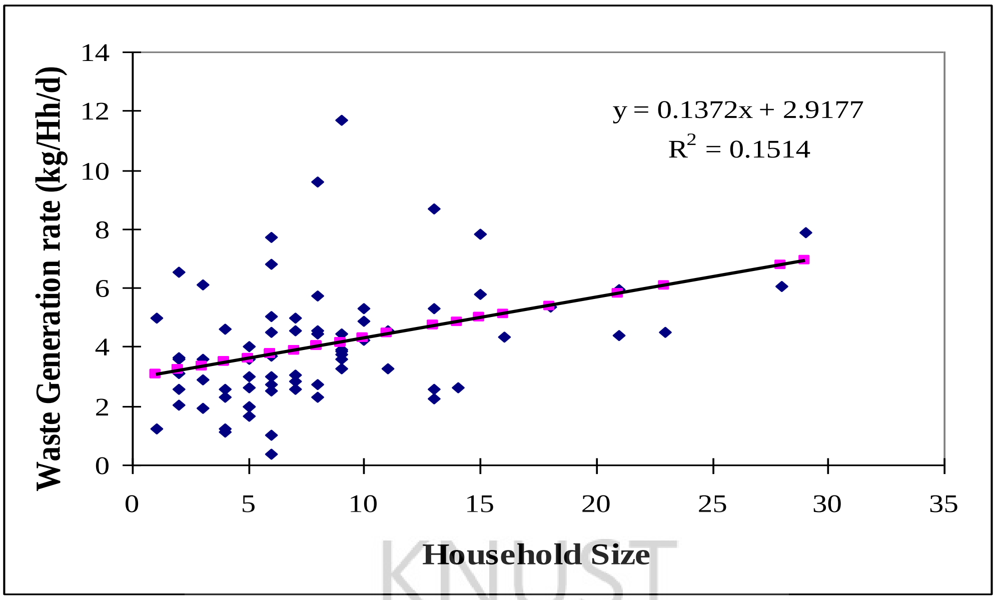

Figure 4.13 Relation between Household Size and Total Household Waste Generation Rate: Asokwa Sub-Metro

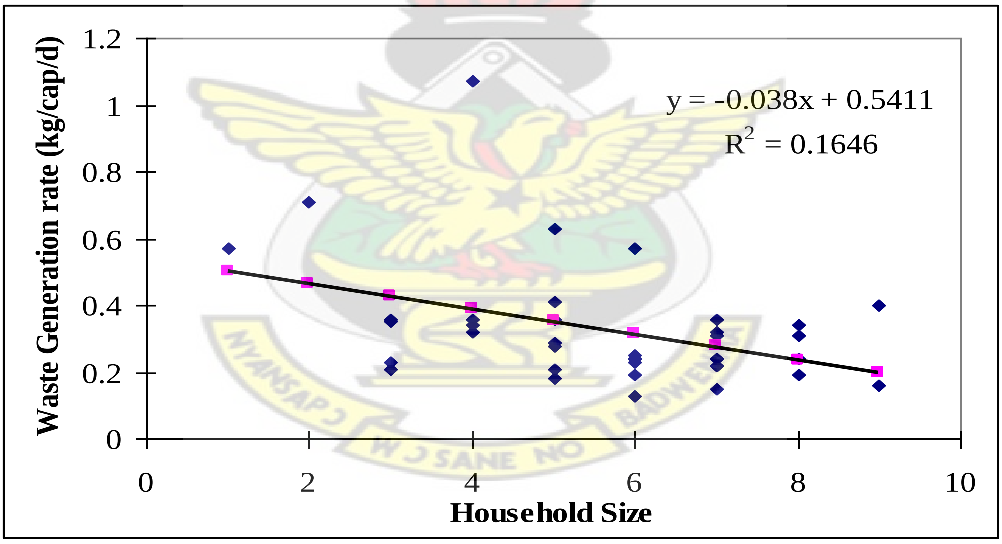

Figure 4.14 Relation between Household Size and Per Capita Waste Generation Rate: KNUST

The correlation depicted in Figure 4.14 and 4.15 shows that there is a moderate ({r = 0.4058} – KNUST, {r = 0.4579 – Asokwa Sub-Metro}) negative relationship between the number of persons in a household and the per capita waste generation rate.

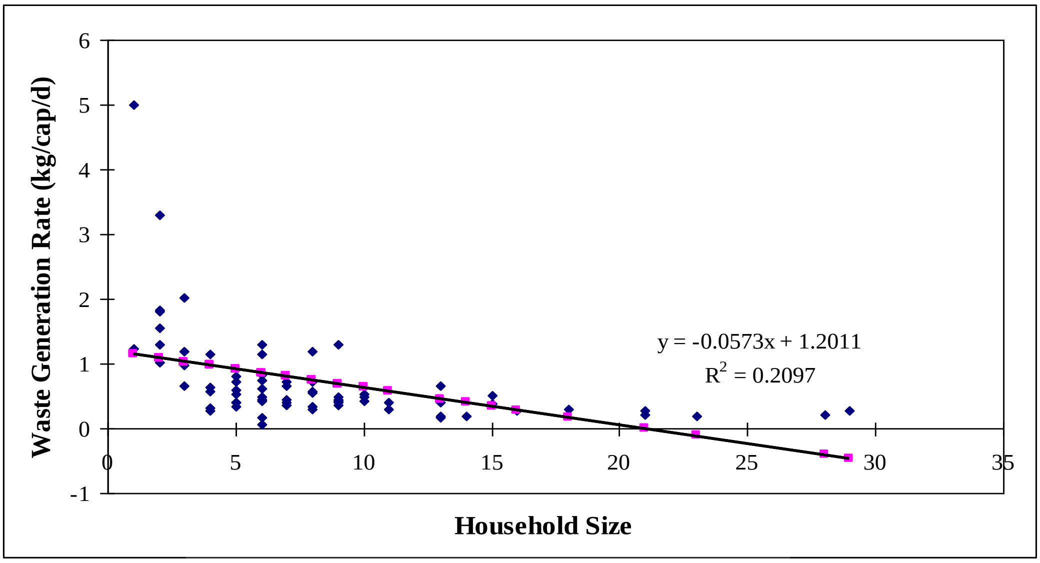

Figure 4.15 Relation between Household Size and Per Capita Waste Generation Rate: Asokwa Sub-Metro

This means that the number of persons in a household has a discernible influence on household waste generation rate. A poor negative relation has been found by other researchers between household size and per capita waste generation rate (Bolaane and Ali, 2004; Zuilen, 2006; Parizeau et al., 2006; Owusu-Ansah, 2008).

4.2.2.4 Total Household Waste in Kumasi

It has been revealed that MSW generation is positively associated to population size (Beede and Bloom, 1995). It is commonly accepted that waste generation grows approximately proportional to a country's population. Beede and Bloom (1995) further estimate that a one percent increase in population is associated with a 1.04 percent increase in MSW. The amount of waste generated per capita times the population determines the amount of MSW available for disposal. Based on the acquired data the yearly HSW produced in Kumasi can be estimated. The population of Kumasi in the year 2008 is estimated to be 1,791,916, with a population growth rate of 5.47% (GSS, 2005). With an average per capita waste generation rate of 0.49kg/cap/d and population of 1,791,916 for year the 2008, the total HSW generated in Kumasi is estimated to be 320,484.2 tonnes. The daily estimated HSW in Kumasi is 878.04tonnes. The waste management department of KMA record the total waste collected from the metropolis in 2008 to be 371,568.75 tonnes (refer to Appendix F3.H). The amount of waste collected annually, if 85% collection is achieved as reported by KMA, can be estimated to be 272,411.55 tonnes. Therefore, it can be estimated that HSW constituted approximately 75% of MSW in Kumasi.

The population of Kumasi is projected for the next ten years using the equation:

$$P_n = P_0 \times (1 + r)^n \qquad 4\text{-}1$$

Where: P_n - population in nth year, P_0: initial, r - population growth rate (%), n - number of years

Assuming a yearly increment of population of current population growth rate (5.47%) is constant, as well as the per capita generation rate of HSW the amount of HSW to be generated in Kumasi is estimated for the next 10 years. The trend in expected HSW generation rate is shown in Figure 4.16 (Data points are presented in Appendix F3.G).

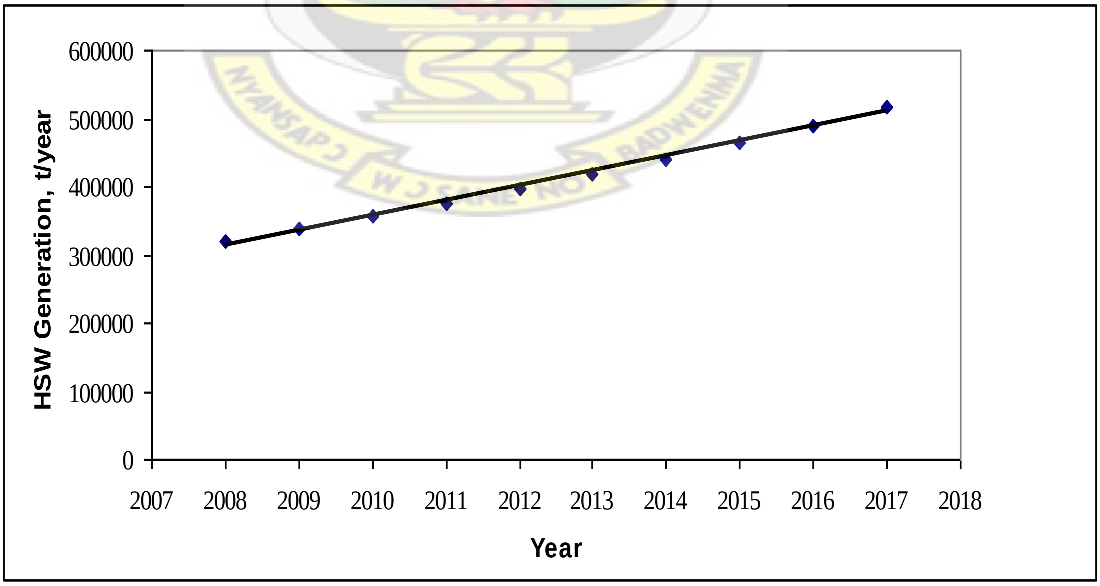

Figure 4.16 Annual HSW Generation for Kumasi

A 61.5% increase of the present estimated HSW generation in Kumasi is expected after 10 years with an annual HSW of 517,567.62 tonnes.

4.3 HOUSEHOLD'S WASTE SEPARATION EFFICIENCY AND LEVEL OF COMPLIANCE

4.3.1 Level of Compliance and Separation Efficiency: KNUST Campus

4.3.1.1 Participation and Set-Out Rate: KNUST Campus

The number of households from the senior staff areas that participated in the project was 25 out of the 40 targeted households, 10 houses on the selected street were vacant at the time of the project execution and 5 households opted out of the project. At the junior staff area 28 households participated in the project 4 houses in the selected block were vacant. Therefore a total of 53 households agreed to participate in the project. The number of bins left by each household for collection was recorded and the percentages calculated as the set-out rate. On the average 67.6% and 80.5% of households from senior staff and junior staff areas separated waste into the three categories requested for respectively over the 18 weeks of analysis. Details of weekly set-out rates can be found in appendices F4.A and F4.B. Most households setting out two bins indicated they were not comfortable with the plastic bag provided for the collection of plastic wastes, they preferred a bin instead due to storage difficulties.

4.3.1.2 Level of Compliance: KNUST Campus

The descriptive statistics of the level of Compliance of households to separate waste as required is presented in Table 4.22 – 4.24. Details of weekly household's level of compliance is presented in Appendices F3.A – F3.C

Table 4.22 Level of Compliance by Households in Placing Organic Wastes in Bin Designated for Organic Wastes

	Senior Staff			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	35.49	43.85	19.99	0.67
Standard deviation, %	8.62	6.83	6.56	1.53
Min, %	21.74	25	4.17	0
Max, %	52.17	52	30.43	4
	Junior Staff			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	27.7	45.8	25.07	1.43
Standard deviation, %	5.22	7.85	6.12	1.85
Min, %	18.52	28.57	14.81	0
Max, %	35.71	62.96	39.29	3.85
	Overall			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	31.36	44.86	2.69	1.09
Standard deviation, %	5.13	5.55	5.23	1.2
Min, %	25.49	30.61	11.76	0
Max, %	41.18	52	35.29	3.85

Table 4.23 Level of Compliance by Households in Placing Plastic Wastes in Bag Designated for Plastic Wastes

	Senior Staff			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	31.94	5.04	30.2	32.82
Standard deviation, %	8.11	4.74	7.69	8.18
Min, %	16.67	0	15	20
Max, %	47.06	13.33	40	47.62
	Junior Staff			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	33.41	3.62	35.81	27.17
Standard deviation, %	7.47	3.88	9.21	12.2
Min, %	18.18	0	13.64	168.182
Max, %	45.85	12.5	52.38	
	Overall			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	32.84	4.19	33.47	29.51
Standard deviation, %	5.59	3.12	5.73	6.8
Min, %	24.44	0	21.43	22.73
Max, %	43.18	9.3	41.3	50

Table 4.24 Level of Compliance by Households in Placing Residual Wastes in Bin designated for other Wastes

	Senior Staff			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	12.02	15.29	38.84	33.85
Standard deviation, %	4.34	7.02	12.95	11.26
Min, %	5	0	15	14.29
Max, %	21.74	30	66.67	52.17
	Junior Staff			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	10.05	14.4	49.63	25.92
Standard deviation, %	6.22	8.28	11.09	5.25
Min, %	0	4	19.23	18.52
Max, %	20	38.46	65.38	36
	Overall			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	11.02	14.83	44.6	29.55
Standard deviation, %	3.94	5.52	6.29	5.78
Min, %	4.17	4.35	34.04	18.75
Max, %	19.57	29.79	54.17	39.58

It can be observed from Table 4.22 that on the average sorting of organic waste was fair, only 1.09% of households overall had contaminants in their organic waste bin above 50% by weight.

The percentage of households that had contaminants above 50% in the bag provided for plastic wastes on the average was 29.51%. This indicates a lower level of compliance for separating plastic wastes than organic wastes. The level of compliance for the separation of other wastes was comparable to that for plastic wastes; an average of 29.55% of households had contaminants above 50% in the bin for other wastes.

4.3.1.3 Separation Efficiency: KNUST Campus

On the average the percentage of organic that was analyzed from the bin provided for organic waste was 93.31%. The distribution of the percentage of organic waste analyzed from the organic bin from the senior and junior staff areas and for both is depicted in Figure 4.17

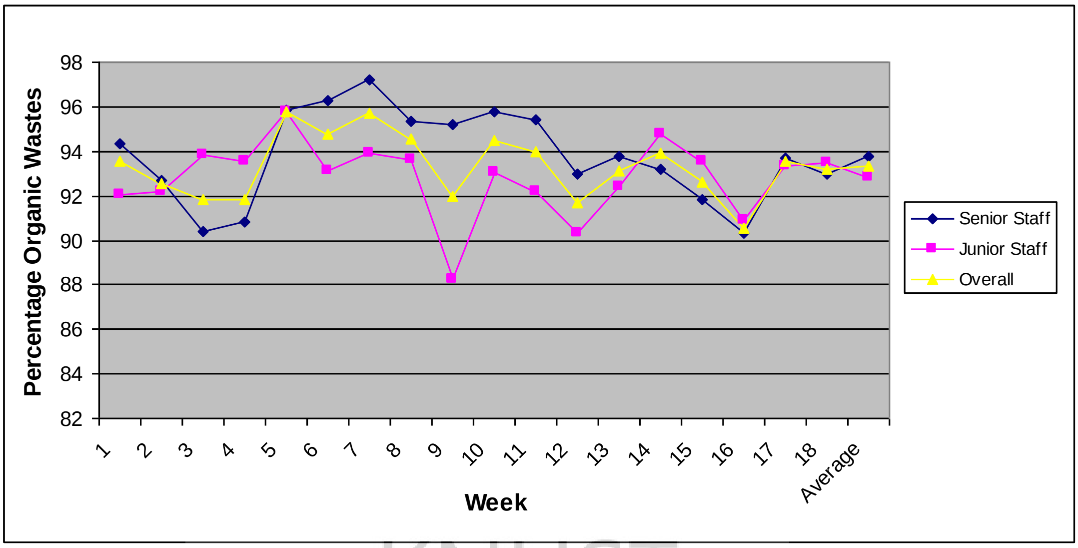

Figure 4.17 Percentages of Organic Wastes in Bin Designated for Organic Wastes: KNUST

Over the entire project period of 18 weeks, the separation efficiency for organic waste from both senior and junior staff areas was well above 80%. This is a good indication that organic wastes with minimum contamination could be collected for composting or other organic waste treatment methods from staff residencies on KNUST campus. The separation efficiency for plastic waste was on the average 49.9%. As shown in Figure 4.18, the separation efficiency of plastic wastes was on the average between 37% and 64% over the project period, with values from junior staff households higher than those from senior staff households. On the average the percentage of wastes in the bin provided for other wastes that was properly separated was 56.18% with the junior staff households having a higher average of 61.5% than the senior staff household with 50.29%. The average separation efficiency over the entire project period was maintained between 51 and 66% as shown in Figure 4. 19.

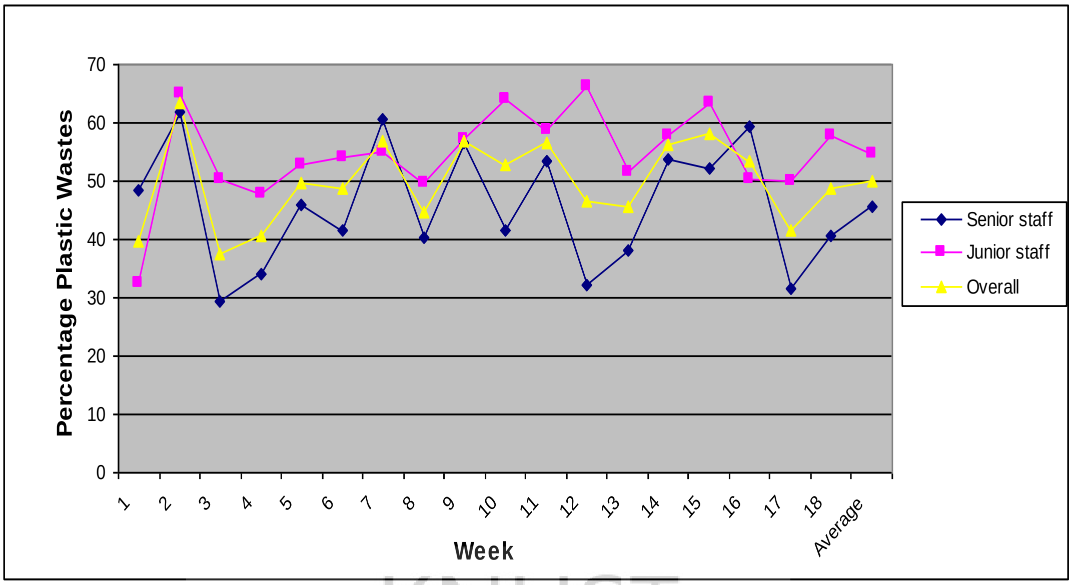

Figure 4.18 Percentage of Plastic Wastes in Bag for Plastics Wastes: KNUST

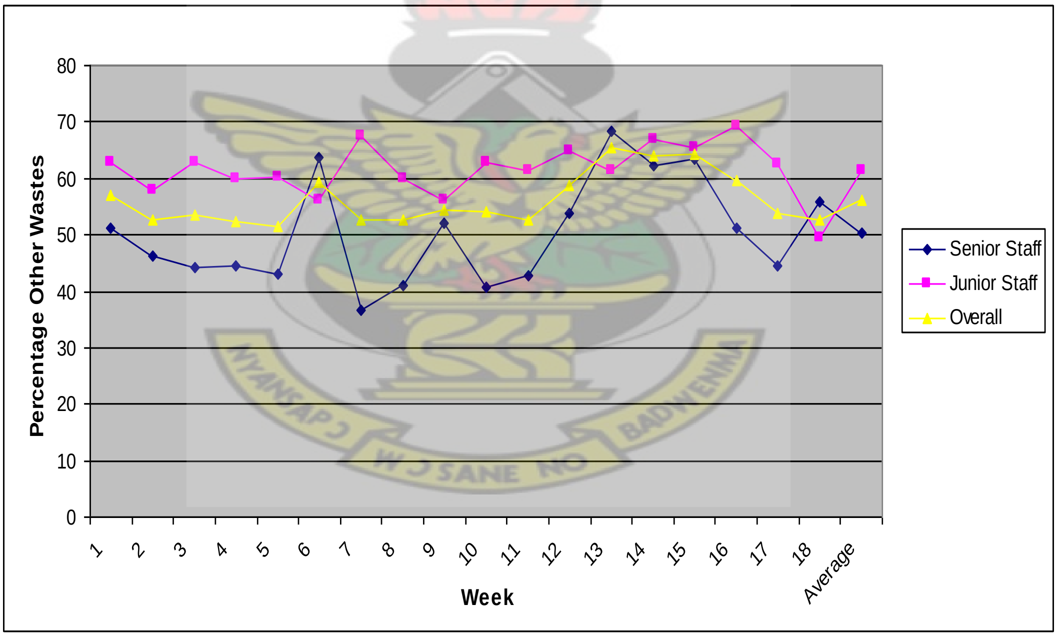

Figure 4.19 Percentage of Other Wastes in Designated Bin: KNUST

4.2.1.4 Level of Contamination: KNUST Campus

The average percentage of contaminants in the bin designated for organic wastes were 6.45%, 7.3% and 6.69% for senior staff, junior staff and both areas (overall) respectively. As indicated from Figure 4.20, the major contaminant in the organic waste bin was plastic film, followed by other wastes with rigid PE & PP rigid plastics being the least. The average overall percentage of contaminants in the plastic wastes bag was 50.1%, however the average percentage of contaminants was 54.7% and 45.33% for senior staff households and junior staff households respectively. Organic wastes accounts for the higher amounts of contaminants with textiles being the least as shown in Figure 4.21

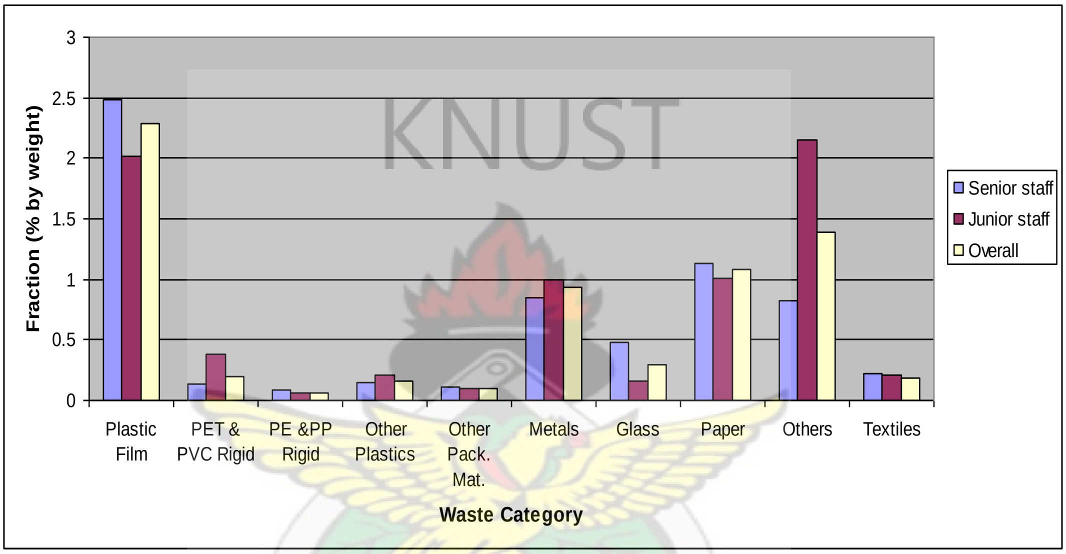

Figure 4.20 Percentage of Contaminants in Bin Designated for Organic Wastes: KNUST

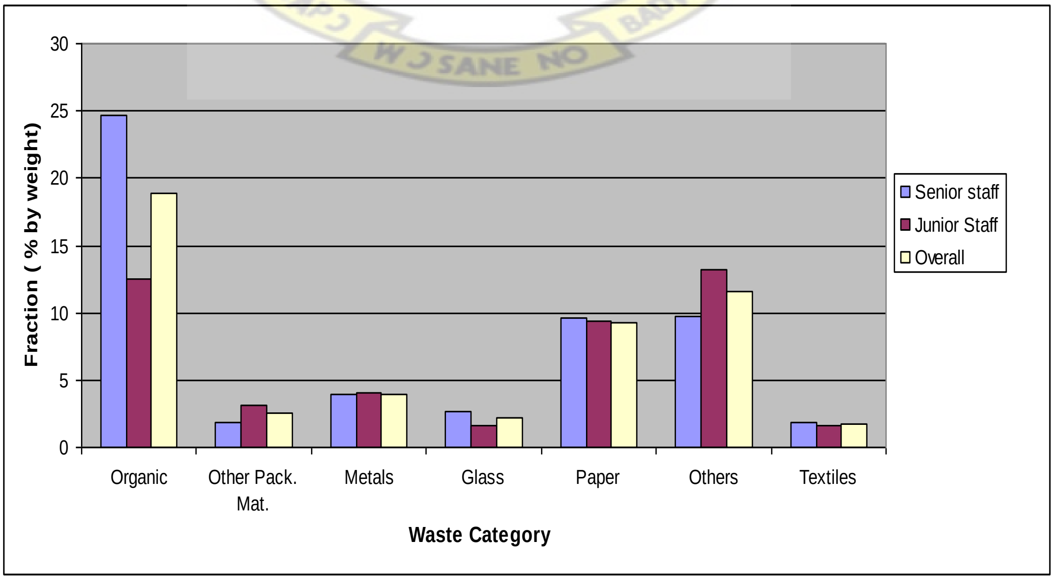

Figure 4.21 Percentage of Contaminants in Bag Designated for Plastic Wastes: KNUST

Contaminants in the bin for other wastes on the average constituted 43.83% of the waste analyzed from that bin. Senior staff households had a higher contaminant composition of 49.71% compared to 38.53% from the junior staff households on the average. Organic waste, mainly leftover food, peels of fruits and vegetables, was the predominant contaminant with plastic film following as can be observed in Figure 4.22. The least contaminant was rigid PET & PVC plastics.

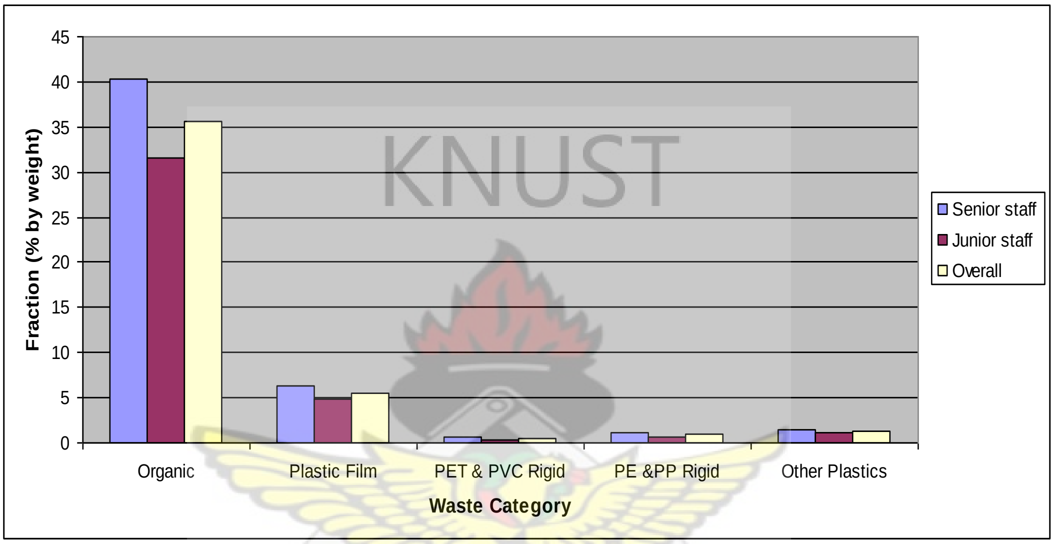

Figure 4.22 Percentage of Contaminants in Bin Designated for Other Wastes: KNUST

Although it was presumed that senior staff members had more experience with waste separation so the level of compliance and separation efficiency would be higher from their households this was not the case. Junior staff households' level of compliance and separation efficiency was higher for all the waste categories. This could be partially due to the apathy and skeptism expressed by household heads in senior staff households to the success of waste separation schemes in Ghana. Most of them also wanted to be sure that waste separated had outlets for processing and were not going to be mixed up and disposed of after analysis hence compost boxes were placed at a visible place on the selected street for households to see what was happening to the organic wastes collected. Most household heads from the junior staff areas had no previous knowledge of waste separation at source but were more willing to separate their waste once they thought it was beneficial to do so. It is also noted that, the household head may not be directly responsible for handling waste in their households, therefore their knowledge and experience in source separation scheme may not result in high levels of compliance, but it is assumed that they play an oversight role in their households such that if they are interested in the SS scheme could ensure their household's compliance.

4.3.2 Separation Efficiency and Level of Compliance: Asokwa Sub-Metro

4.3.2.1 Participation and Set-Out Rate: Asokwa Sub-Metro

The total number of households that participated in the SS study in the Asokwa Sub-metro was 76 out of the targeted 103. In Asokwa households on the selected streets that agreed to participate in the study were 34. In Atonsu 35 households agreed to participate in the study but one household took the bins but did not set it out for collection and was not accessible due to the presence of wild dogs. In Ahinsan getting households to participate in the study was very difficult. 29 households agreed initially to participate in the study on the selected street but only 8 of them accepted the bins for separation of their waste. Most household withdrew because of the anticipation of neighbours putting faecal matter in their bins due to inadequate toilet facilities in the neighbourhood. On the average 88.7%, 86.2% and 88.6% of households from Asokwa, Atonsu and Ahinsan separated waste into the three requested for respectively over the 12 weeks of analysis. Details of weekly set-out rates can be found in appendices F4.C-F4.E

4.3.2.2 Level of Compliance: Asokwa Sub-Metro

The level of compliance for organic waste in each area is shown in Table 4.25

Table 4.25 Level of Compliance by Households in Placing Organic Wastes in Bin Designated for Organic Wastes: Asokwa Sub-Metro

	Asokwa			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	5.7	23.06	57.07	14.18
Standard deviation, %	3.9	7.99	7.68	5.68
Min, %	0	8.82	42.42	3.03
Max, %	12.12	39.39	67.65	21.21
	Atonsu			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	8.37	13.76	50.29	27.57
Standard deviation, %	2.89	4.83	7.53	7.44
Min, %	3.03	3.23	37.5	15.63
Max, %	13.33	18.75	62.5	36.36
	Ahinsan			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	3.41	16.07	42.53	37.99
Standard deviation, %	8.08	9.78	18.71	17.75
Min, %	0	0	12.5	12.5
Max, %	12.5	14.29	75	75

The above results show that on the average 5.7%, 8.37% and 3.41% of households from Asokwa, Atonsu and Asokwa respectively put only organic waste in the organic bin. Results show that, 23.06%, 13.76% 16.07% respectively had up to 10% contaminants with the major component in the organic bin being organic. Also, 57.07%, 50.29% and 42.53% of households from the three areas respectively had contaminants between 10% and 50% in the organic bin with the major component being organic. Furthermore, 14.18%, 27.57% and 37.99% of households from Asokwa, Atonsu and Ahinsan had contaminants above 50% in the organic bin. This results show that the majority of households from the three areas had contaminants up to 50% in the organic bin i.e. the degree of compliance on the average was fair for all the areas.

The results in Table 4.26 show that on the average 11.51%, 14.3% and 2.27% of households from Asokwa, Atonsu and Asokwa respectively put only plastic waste in the plastic bin. Results show that, 5.6%, 2.87% 1.14% of households respectively had up to 10% contaminants with the major component in the plastic bin being plastics. Also, 28.42%, 24.8% and 23.86% of households from the three areas respectively had contaminants between 10% and 50% in the plastic bin with the major component being plastic. Furthermore, 54.7%, 58.03% and 72.73% of households from Asokwa, Atonsu and Ahinsan had contaminants above 50% in the plastic bin.

Table 4.26 Level of Compliance by Households in Placing Plastic Wastes in Bin Designated for Plastic Wastes

	Asokwa			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	11.51	5.6	28.42	54.47
Standard deviation,%	5.33	4.34	8.62	11.64
Min, %	3.13	0	9.38	31.03
Max, %	19.35	12.5	44.83	7.88
	Atonsu			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	14.3	2.87	24.8	58.03
Standard deviation,%	3.82	2.8	6.02	4.9
Min, %	9.38	0	18.18	50
Max, %	19.35	9.38	35.29	64.52
	Ahinsan			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	2.27	1.14	23.86	72.73
Standard deviation,%	5.06	3.77	10.39	12.27
Min, %	0	0	12.5	50
Max, %	12.5	12.5	50	87.5

These results show that the majority of households from the three areas had contaminants above 50% in the plastic bin i.e. the degree of compliance on the average was poor for all the areas.

The results in Table 4.27 show that on the average 18.33%, 22.42% and 11.36% of households from Asokwa, Atonsu and Asokwa respectively put only other wastes in the 'others' bin. Also, 11.15%, 12.76% and 12.5% of households respectively had up to 10% contaminants in the 'others' bin. Furthermore, 36.41%, 36.03% and 58.6% of households from the three areas respectively had contaminants between 10% and 50% in the 'others' bin.

Table 4.27 Level of Compliance by Households in Placing Other Wastes in Bin Designated for Other Wastes

	Asokwa			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	18.33	11.15	36.41	34.11
Standard deviation,%	4.53	5.41	7.28	4.38
Min, %	9.38	3.03	18.75	28.13
Max, %	24.24	21.88	46.88	41.18
	Atonsu			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	22.42	12.76	36.03	28.8
Standard deviation,%	6.69	5.77	5.43	7.07
Min, %	12.9	5.88	26.67	16.13
Max, %	34.38	25.81	44.12	41.94
	Ahinsan			
	Excellent	**Good**	**Fair**	**Poor**
Average, %	11.36	12.5	58.6	17.53
Standard deviation,%	8.76	9.68	14.85	12.57
Min, %	0	0	37.5	0
Max, %	25	25	87.5	42.86

Households from Asokwa, Atonsu and Ahinsan had 34.11%, 28.8% and 17.53% of contaminants above 50% in the 'others' bin. This results show that the majority of households from the three areas had contaminants up to 50% in the 'others' bin i.e. the degree of compliance on the average was fair for all the areas. This could be because of households may be avoiding separation therefore just dropping materials into the others bin. Details of weekly household's level of compliance is presented in Appendices F3.D – F3.F

4.3.2.3 Separation Efficiency: Asokwa Sub-Metro

The separation efficiency of waste from the three bins is depicted in Figure 4.23 to 4.25. The average percentage of organic waste in the bin designated for organic waste was 74.3%, 60.02% and 59.56% from Asokwa, Atonsu, and Ahinsan respectively. This shows that the separation efficiency for organic waste was highest in the Asokwa, followed by Atonsu with Ahinsan having the least with sorting efficiency being above 50% each week.

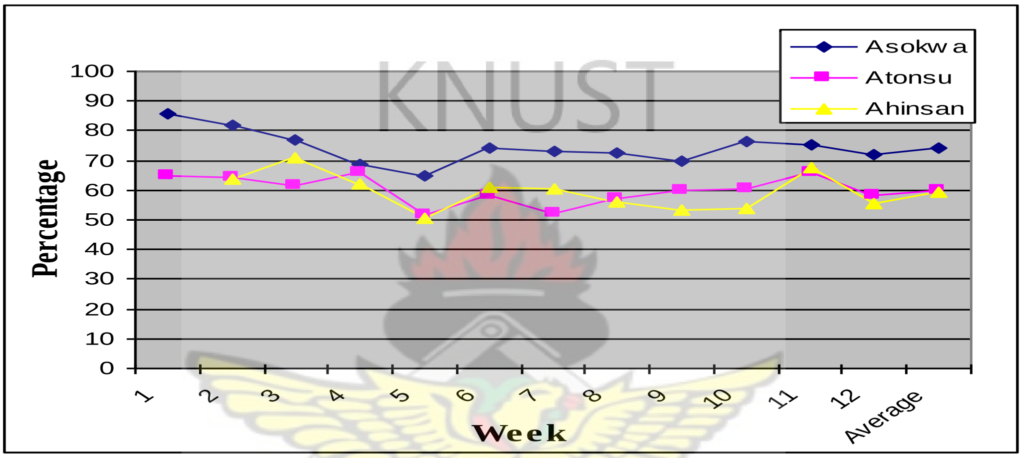

Figure 4.23 Percentage organic waste in bin designated for organic waste: Asokwa Sub-Metro

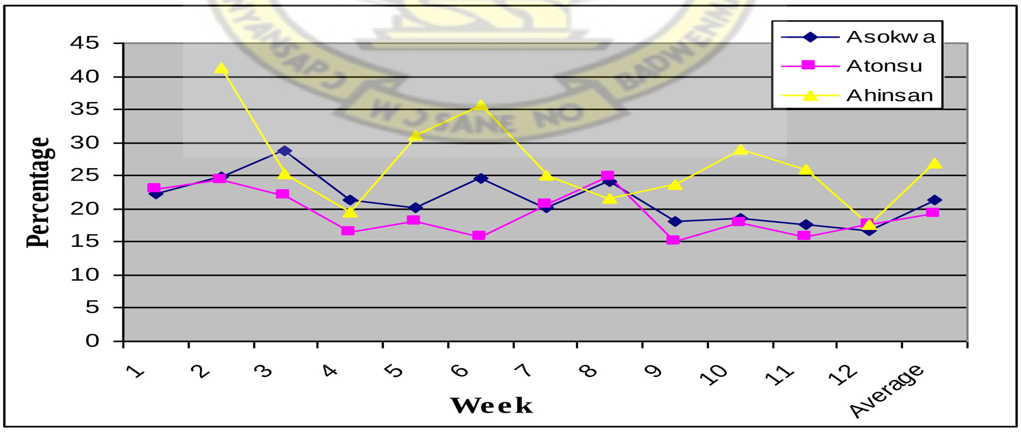

Figure 4.24 Percentage Plastic Waste in Bin Designated for Plastic Waste: Asokwa Sub-Metro

It can be deduced that the level of recovery of organic waste if collected separately could be quite high. The separation efficiency for organic waste from this study is lower than that reported in other studies; 97.8% in Danang, Vietnam (Nguyen, 2005) and 96% in China (Ranninger et al., 2006). This may be attributed to the fact that the studies by Nguyen (2005) and Ranninger et al. (2006) separated waste into just two streams.

The average percentage of plastics in the plastics bin for Asokwa, Atonsu and Ahinsan was 21.42%, 19.26% and 26.92% respectively. Ahinsan had the highest percentage of plastics in the plastic bin, followed by Asokwa, with Atonsu having the least. The average sorting efficiency for plastics was below 30% for all the areas.

The average percentage of others in the 'others' bin for Asokwa, Atonsu and Ahinsan was 51.19%, 59.57% and 62.41% respectively. Ahinsan had the highest percentage of others in the 'others' bin, followed by Atonsu, with Asokwa having the least. The separation efficiency, on the average, for other wastes was above 50% for all the areas.

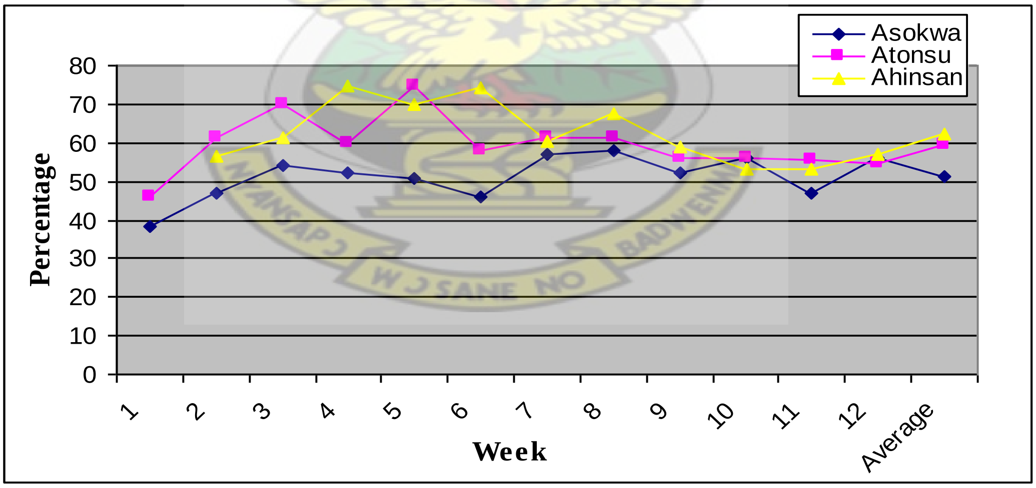

Figure 4.25 Percentage Other Wastes in Bin Designated for Other Wastes: Asokwa Sub-Metro

4.3.2.4 Level of Contamination: Asokwa Sub-Metro

The contaminants in the organic bin have been aggregated into two major categories; 'others' and plastics. The level of contamination in the organic bin is shown in Figure 4.26 for the three areas.

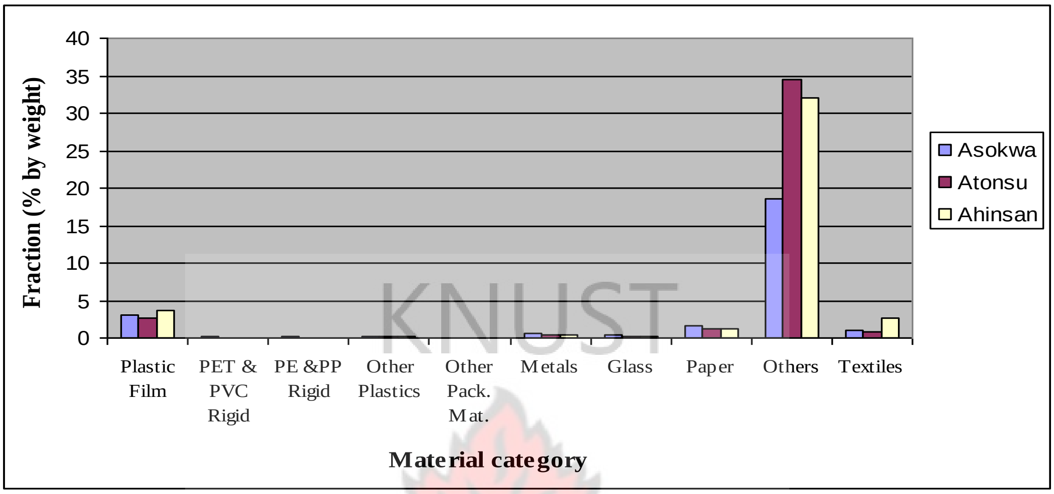

Figure 4.26 Percentages of Contaminants in Bin Designated for Organic Wastes: Asokwa Sub-Metro

In Asokwa, of the 25.7% of contaminants in the organic bin, 22.26% was made up of other components and 3.44% plastics on the average. In Atonsu, of the 39.98% of contaminants on the average, 37.1% was made up of other wastes and 2.88% Plastics. In Ahinsan, of the 40.44% contaminants in the organic bin 36.52% was made up of other wastes and 3.92% plastics.

The level of contamination in the plastic bin is shown Figure 4.27 for the three areas

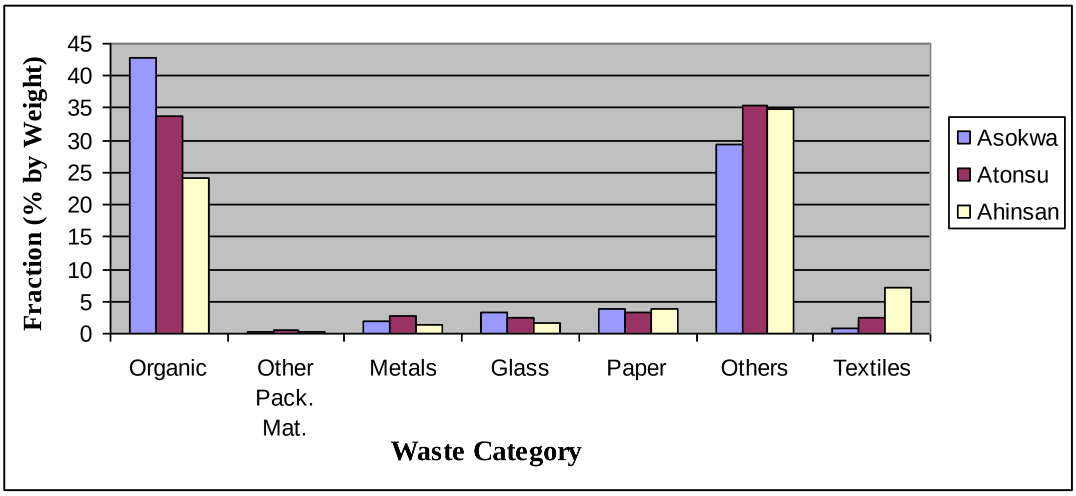

Figure 4.27 Percentage of Contaminants in Bin Designated for Plastic Wastes: Asokwa Sub-Metro

The contaminants in the Plastic bin have been aggregated into two major categories; organic and others. In Asokwa, of the 78.58% of contaminants in the plastic bin, 42.8% was made up of organic waste and 35.78% others on the average. In Atonsu, of the 80.74% of contaminants on the average, 33.84% was made up of organic wastes and 46.9% others. In Ahinsan, of the 73.08% contaminants in the plastics bin 24.27% was made up of organic wastes and 48.81% others

The level of contamination in the others bin is shown in Figure 4.28 for the three areas

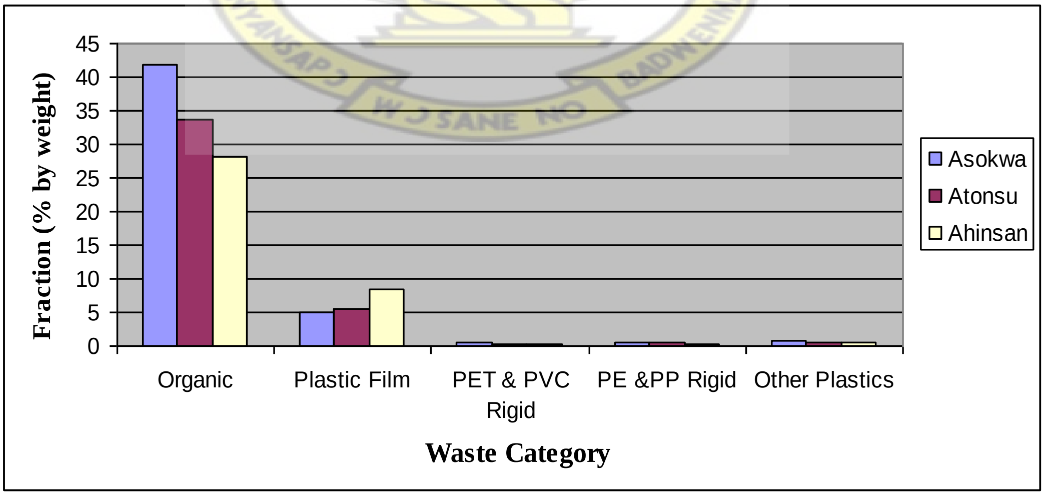

Figure 4.28 Percentage of Contaminants in Bin Designated for Other wastes: Asokwa Sub-Metro

The contaminants in the 'others' bin have been aggregated into two major categories: organic and plastics. In Asokwa, of the 48.81% of contaminants in the others bin, 41.95% was made up of organic waste and 6.84% plastics on the average. In Atonsu, of the 40.43% of contaminants on the average, 33.72% was made up of organic wastes and 6.71% plastics. In Ahinsan, of the 37.59% contaminants in the plastics bin 28.28% was made up of organic wastes and 9.31% others.

4.4 RELATIONSHIPS BETWEEN HOUSEHOLD'S AND RESPONDENT'S CHARACTERISTICS AND SOURCE SEPARATION EFFICIENCY

4.4.1 Relationship between Selected Respondent Characteristics

Cross tabulations of certain characteristics of respondents from both KNUST staff residencies and Asokwa Sub-Metro were made in order to identify the relationship between them.

4.4.1.1 Knowledge of Recycling Relative to Level of Education of Respondent

It is widely envisaged that individuals with high level of education are likely to have knowledge of recycling and its benefits. Recycling here refers to the processing of post-consumer materials into useful products. It can be deduced from Table 4.28 that majority of respondents who claim to know about recycling of waste have had education up to the secondary and tertiary level. Perhaps, it can be accepted that education has a positive influence on the knowledge of recycling. Interestingly, all the respondents who have had no formal education, although a small number, also have knowledge of recycling.

Table 4.28 Knowledge of Recycling Relative to Level of Education

Knowledge of Recycling	Level of Education, Count				
	None	Basic	Secondary	Tertiary	Total
Yes	4	9	38	35	86
No		3	7		10
Total	4	12	45	35	96

4.4.1.2 Knowledge of SS Relative to Level of Education of Respondent

Similar to the influence of the level of education of an individual on his/her knowledge of recycling, it is supposed that the higher the level of education of an individual the higher the probability that they have knowledge of SS of HSW. In reference to Table 4.29 it can be said that most respondents with no knowledge of SS have had education up to the secondary and tertiary level. Therefore, a high level of education does not necessarily translate into knowledge of SS of HSW.

Table 4.29 Knowledge of SS Relative to Level of Education

Knowledge of Source Separation	Level of Education, Count				Total
	None	Basic	Secondary	Tertiary	
Yes	1	3	15	19	38
No	3	8	25	14	50
Total	4	11	40	33	88

4.4.1.3 Knowledge of Recycling Relative to Knowledge of SS

Source separation of waste is undertaken primarily to facilitate successful recycling of waste materials. It can be seen from Table 4.30 that a high number of respondents (39 out of 98) who know of recycling also know about SS. But a higher number of respondents (47 out of 98) who know of recycling do not know of SS. It is not surprising that only one respondent who claims not to know of recycling has knowledge of SS.

Table 4.30 Knowledge of SS Relative to Knowledge of Recycling

Knowledge of SS	Knowledge of Recycling		
	Yes	No	Total
Yes	39	1	40
No	47	11	58
Total	86	12	98

4.4.1.4 Concern for Safe Waste Disposal Relative to Gender of Respondent

In reference to Table 4.31, out of 74 respondents who are concerned for safe disposal of waste collected from their homes 41(representing 55%) are females as against 33 males (representing 45). This shows that the concern for safe disposal of waste is similar among both males and females.

Table 4.31 Concern for Safe Disposal of Waste Relative to Gender

	Gender		
Concern for safe disposal of waste	**Male**	**Female**	**Total**
Yes	33	41	74
No	1	11	12
Don't know	4	7	11
Total	38	59	97

4.4.1.5 Concern for Safe Waste Disposal Relative to Age

Generally, concern for safe waste disposal is high among respondents; 74 out of 98. Relative to the number of respondents in each age category, it can be said that the concern for safe waste disposal is almost evenly distributed among age groups.

Table 4.32 Concern for Safe Disposal of Waste in Relation to Age

	Age						
Concern for safe disposal of waste	**<26**	**26-34**	**35-44**	**45-55**	**55-59**	**≥60**	**Total**
Yes	15	12	17	21	2	7	74
No	3		2	1	2	5	13
Don't know	2	1	3	4	1		11
Total	20	13	22	26	5	12	98

4.4.1.6 Concern for Safe Waste Disposal Relative to Level of Education of Respondent

More than 50% of respondents from each group of level of education are concerned about how safe waste collected from their homes is disposed. Relatively respondents with no formal education have the least concern for safe disposal of HSW whilst those with a maximum level of basic education have the highest concern.

Table 4.33 Concern for Safe Disposal of Waste Relative to Level of Education

	Level of Education				
Concern for safe disposal of waste	**None**	**Basic**	**Secondary**	**Tertiary**	**Total**
Yes	2 (50%)	11(85%)	30 (75%)	23 (79%)	66
No	2	1	5	2	10
Don't know		1	5	4	10
Total	4	13	40	29	86

Early studies show that demographic factors are significant determinants of waste control practices (Corral-Verdugo, 2003). The four most often reported demographic variables in studies on recycling behaviour are gender, age, income, and education. This section focuses on the interrelationships between the socio-demographic characteristics (age, education and household size) of households and their SS efficiency for organic, plastic and other waste. The Level of education of household members was ranked as: 1 – None, 2 – Basic, 3 – Secondary and 4 – Tertiary. The weighted mean level of education for a household was calculated by multiplying the number of persons in each rank with the weight of the rank equivalent to the rank number then summing them up and then diving the total by the household size. The weighted mean of the households was also computed in a similar way with the ranks defined as follows: **1**: 0-12, **2**:13-19, **3**: 20-30, **4**: 31-40, **5**: 41-50, **6**: 51-70, **7**: 71 and above.

4.4.2 Relationship between Household's Level of Education and Source Separation Efficiency

The relationship between households weighted mean level of education and SS efficiency of organic, plastic and other wastes are shown in Figures 4.29 – 4.31

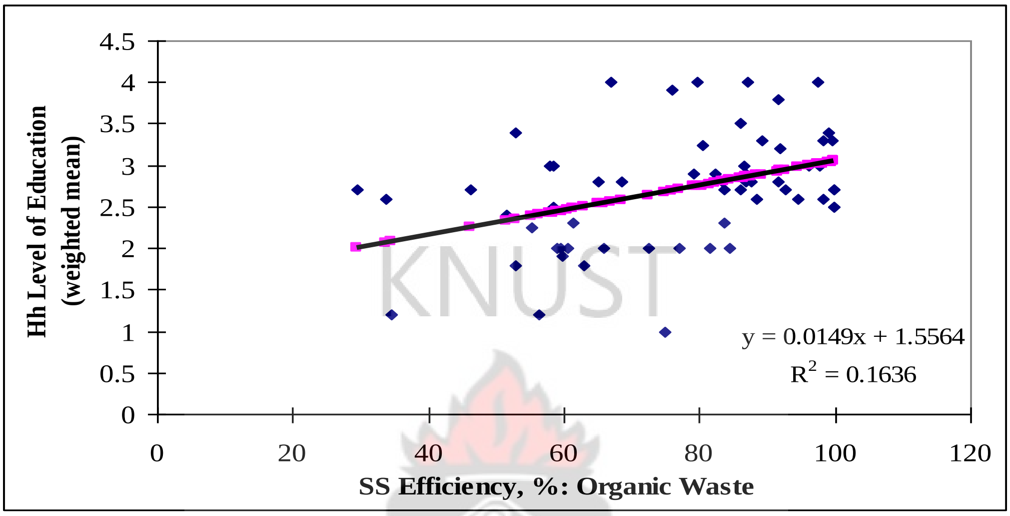

Figure 4.29 Household's Level of Education Related to SS Efficiency of Organic Waste

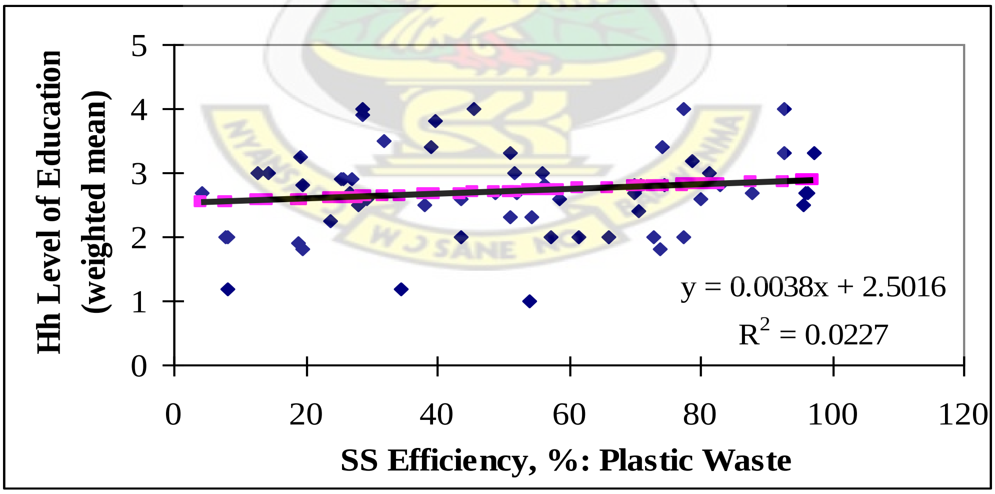

Figure 4.30 Household's Level of Education Related to SS Efficiency of Plastic Waste

The regression results presented in Figure 4.29 - 4.31 show that a weak positive relationship exist between the mean household level of education and the SS efficiency of organic and plastic waste (R: Organic waste = 0.4045), (R: (Plastic waste) = 0.1506). However there seem to be a very weak negative relationship between the mean household level of education and SS efficiency of other waste (R (Others) = 0.0001).

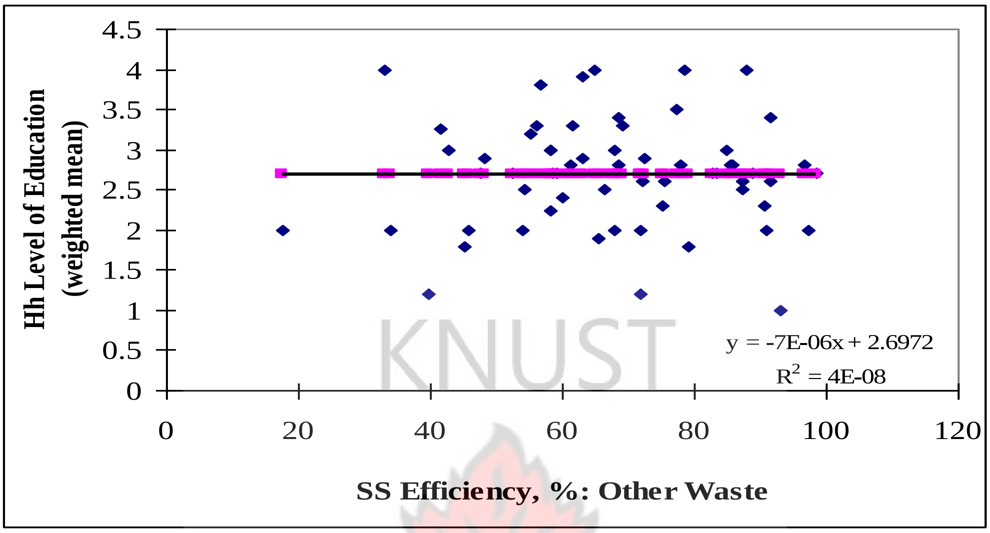

Figure 4.31 Household's Level of Education Related to Source Separation Efficiency of Other Waste

The results obtained shows that the household with higher education are more likely to identify materials for designated bins. It is easier for households, irrespective of level of education, to put waste into the bin designated for other waste since it required less identification of specific materials.

4.4.3 Relationship between Householder's Age distribution and SS Efficiency

The relationship between householders' age distribution and SS efficiency of organic, plastic and other wastes are shown in Figures 4.32 – 4.34**.** The regression results presented in Figure 4.32 - 4.34 show that a weak negative relationship exist between the mean household age and the SS efficiency of organic, plastic and other waste (R (Organic waste) = 0.1427; R (Plastic waste) = 0.0269; R (Others) = 0.1872).

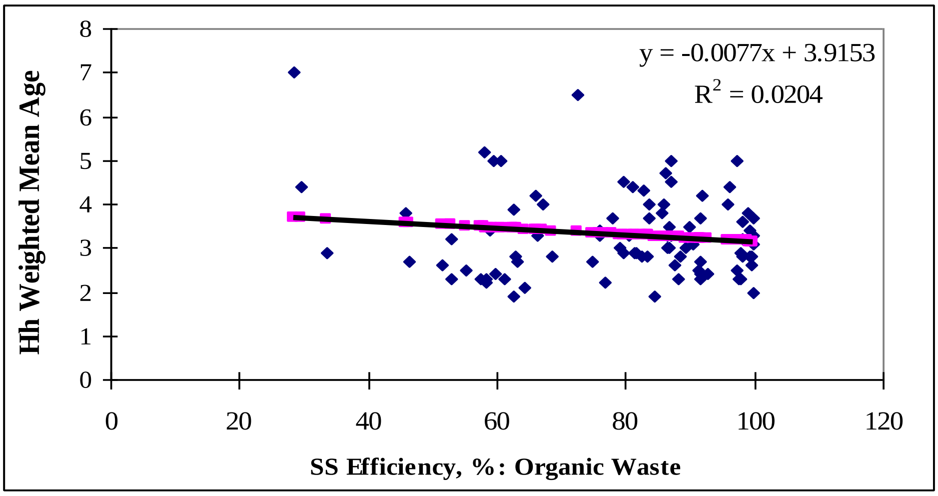

Figure 4.32 Household's Weighted Mean Age Related to SS Efficiency of Organic Waste

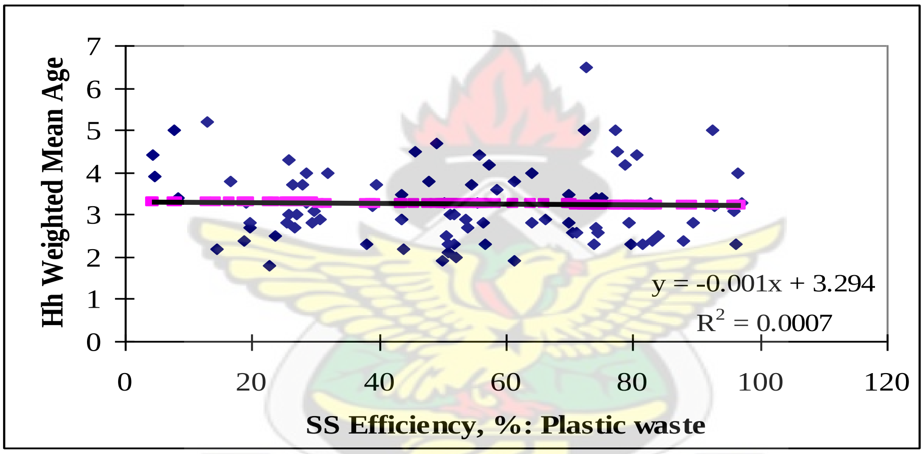

Figure 4.33 Household's Weighted Mean Age Related to SS Efficiency of Plastic Waste

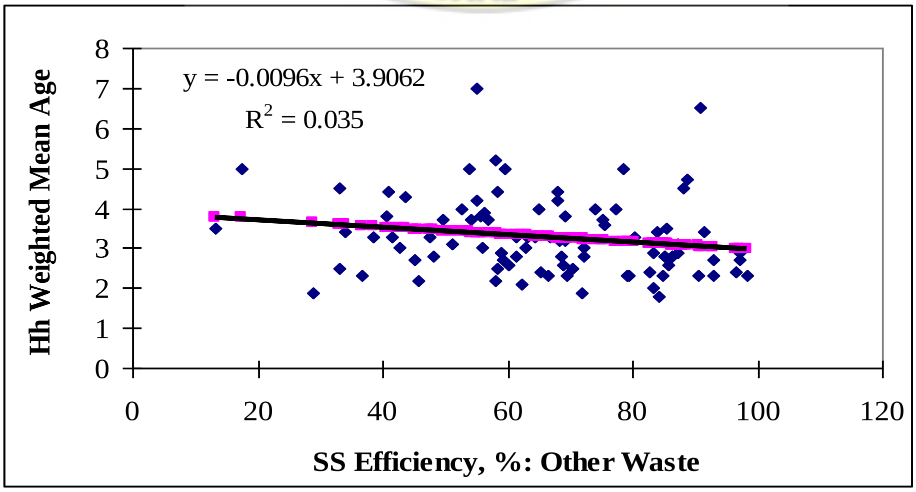

Figure 4.34 Household's Weighted Mean Age Related to SS Efficiency of Other Waste

4.4.4 Relationship between Household's Size and SS Efficiency

The relationship between household Size and SS efficiency of organic, plastic and other wastes are shown in Figures 4.35 – 4.37

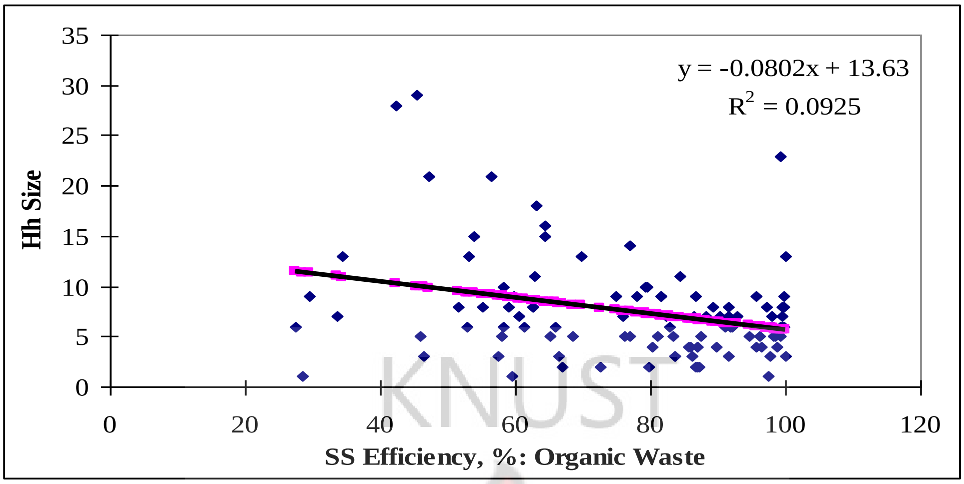

Figure 4.35 Household's Size Related to SS Efficiency of Organic Waste

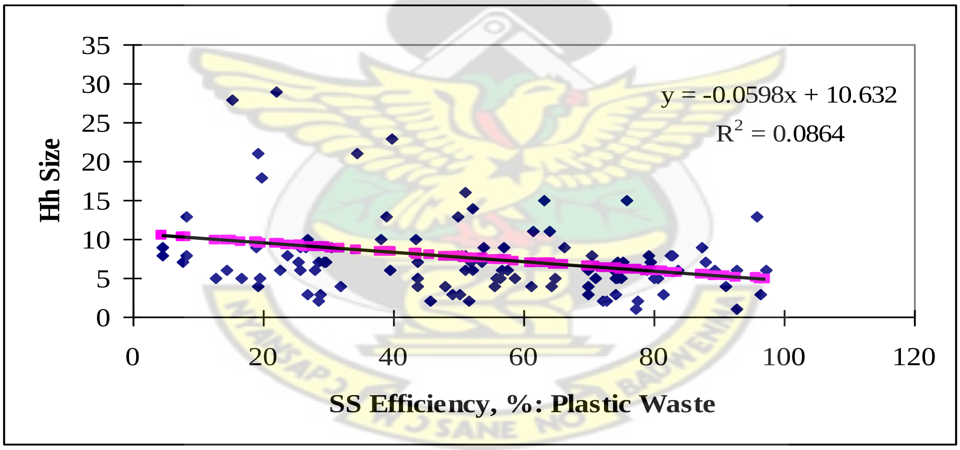

Figure 4.36 Household's Size Related to SS Efficiency of Plastic Waste

The regression results presented in Figure 4.35 - 4.37 show that a weak positive relationship exist between the household size and the SS efficiency of other waste (R (Others) = 0.0360). However there seem to be a weak negative relationship between the household size and SS efficiency of organic and plastic waste (R (Organic waste) = 0.3041, R (Plastic waste) = 0.2939)

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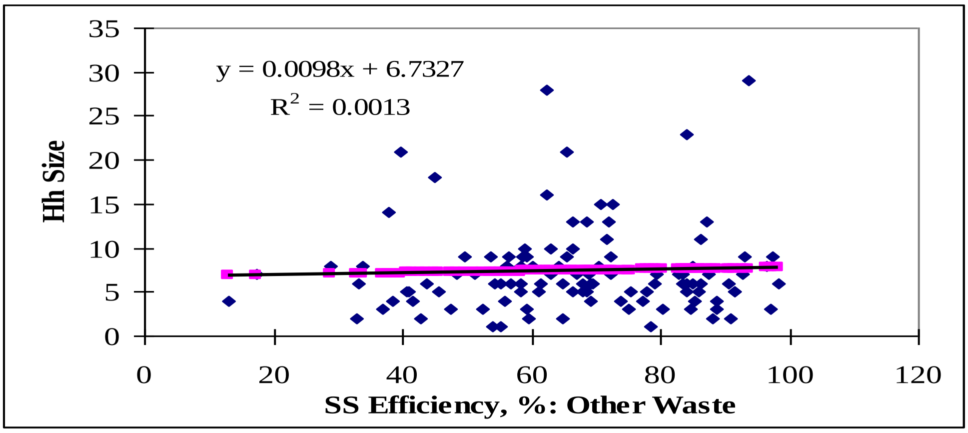


Figure 4.37 Household's Size Related to SS Efficiency of Other Waste

In general it can be concluded that although there exist some relationships between household socio demographic characteristic and the SS efficiency of organic, plastic and other wastes, the relationships are not strong enough to be suitable for predictive purposes. However, these relationships and observations from the study are useful for the design of SS schemes e.g. by identifying target groups and materials as well as appropriate approaches for different groups of population.

4.5 OPTIMIZATION OF ISWM AND WASTE TREATMENT OPTIONS FOR WM IN KUMASI

There are various options for recovering resources (energy and /or materials) from the HSW streams. However, some questions that can arise in selecting waste recovery options include: How much waste can be recovered? Are the quantities generated feasible for recovery? What are the economic benefits or costs of selected waste treatment options? In this section an attempt is made to address some of these questions in relation to plastic recycling, composting and incineration of HSW generated in Kumasi with results from the study carried out in the Asokwa sub-metro.

4.5.1 Optimization Results

The optimum solution of the developed model are presented and compared with the current case of sending all household waste to the landfill. The cost of landfilling all collected waste is estimated to be GH¢ 9184778.68 for the reference year of 2010.

4.5.1.1 Optimum Solution

The optimum cost of running the said SWM system was found to be GH¢6,518,659 per annum. The decision variables obtained to achieve the optimum solution are depicted in the waste flows shown in Figure 4.38.

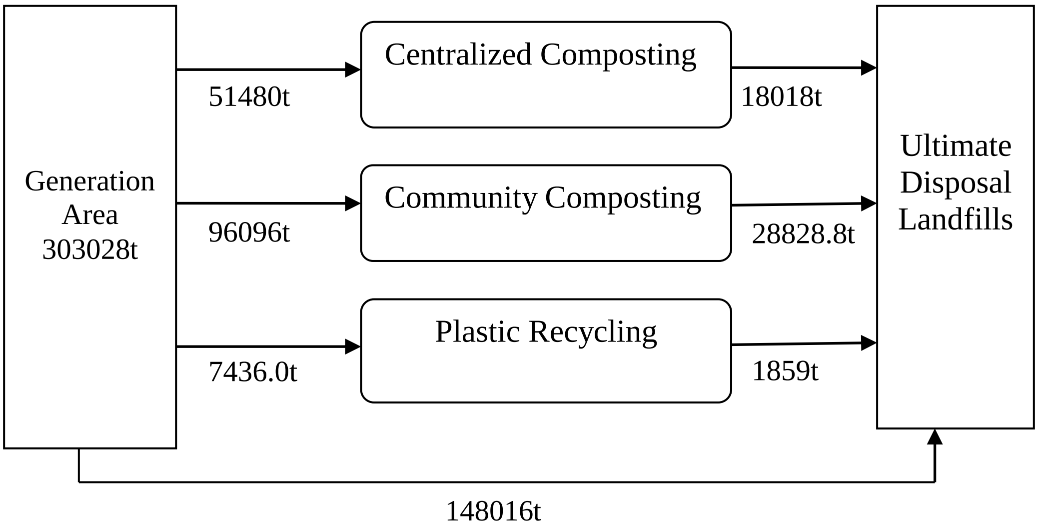


Figure 4.38 Waste Flows in the Optimal Waste Treatment Case

In this case all the treatment options are utilized in the ISWM system, which implies that:

1. A total of 148016 tonnes of waste should be transported from generation area *i* to landfill *m*
2. A total of 51480 tonnes of waste must be transported from generation area *i* to centralized composting plant *j*
3. A total of 858 tonnes of waste must be transported from generation area *i* to each community composting plants *k* (i.e. 858 x 112 = 96096 tonnes of waste is transported to all community composting plants).
4. Similarly, a total of 371.80 tonnes of waste must be transported from waste generation area *i* to all the 20 plastic recycling plants m (i.e. 371.80 x 20=7436.0 tonnes of waste are transported to each plastic recycling facility).

4.5.2.2 Sensitivity Analysis

A. Scenario 1 (Inclusion of cost of land for centralised composting and community composting)

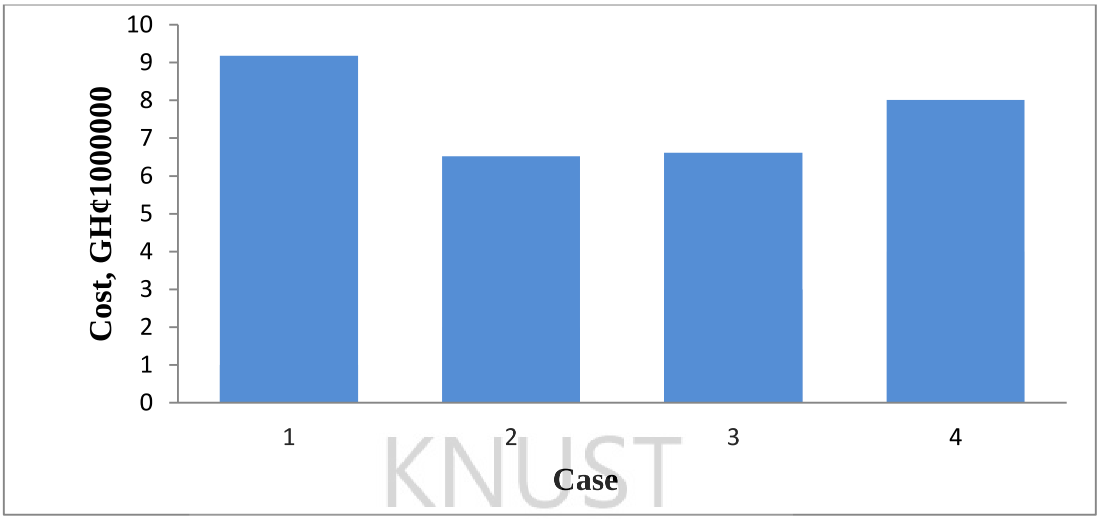
The optimal solution to the optimization was obtained assuming that the municipality already has acquired land to accommodate the centralized and community composting plants. The model is tested to observe the effect of land cost for these facilities on the optimal solution. The optimum cost solution in this case was found to be GH¢6611666. However, the waste flows to the various treatment facilities remained the same as the previous case.

B. Scenario 2 (No revenue from compost sales)

Previous studies on composting suggest that there are bottlenecks associated with the marketability of compost produced from MSW. According to Drechsel et al. (2004), from the perspective of waste management, composting is principally reducing waste volume and transport costs. Compost production therefore, should be targeted at the largest scale possible especially if composting plants are sited close to waste generation source, thereby reducing transportation costs. In this scenario, the optimal solution is sought for the model assuming there are no compost sales. The optimum cost of the WM system obtained in this case is GH¢8,006,508. The waste flows however changed. No waste is to be sent to the centralized composting plant. The waste flows in this scenario are as shown below:

W_{im}	W_{ij}	W_{jm}	W_{ik}	W_{km}	W_{in}	W_{nm}
199496	0	0	858	257.4	371.8	92.95

In this scenario, the optimum cost of waste treatment increases drastically although it is still less than the cost of sending all waste to the landfill. The comparisons of optimum cost of treating waste under the above discussed scenarios are shown in Figure 4.38.



Legend for Cases

1. All waste is treated at the landfill
2. Optimal solution
3. Scenario 1(Inclusion of land costs for centralized and community composting plants)
4. Scenario 2 (No revenues from compost sales)

Figure 4.39 Cost Comparisons for Waste Treatment Cases

It is observed from the cost comparisons that subjecting collected household waste to centralized or/and community composting and plastic recycling before landfilling, under the assumptions made in this study, reduces the cost of the WM as compared to landfilling all the waste collected.

C. Scenario 3 (Increasing capital cost for centralized composting)

The capital cost estimates for this study were based on best available data that could be obtained from literature and discussions with experts in the industry. This cost may vary depending on the changing equipment and construction costs. Therefore the effect of changing capital cost on the optimal system cost is explored. The result of this case is shown in Figure 4.40.

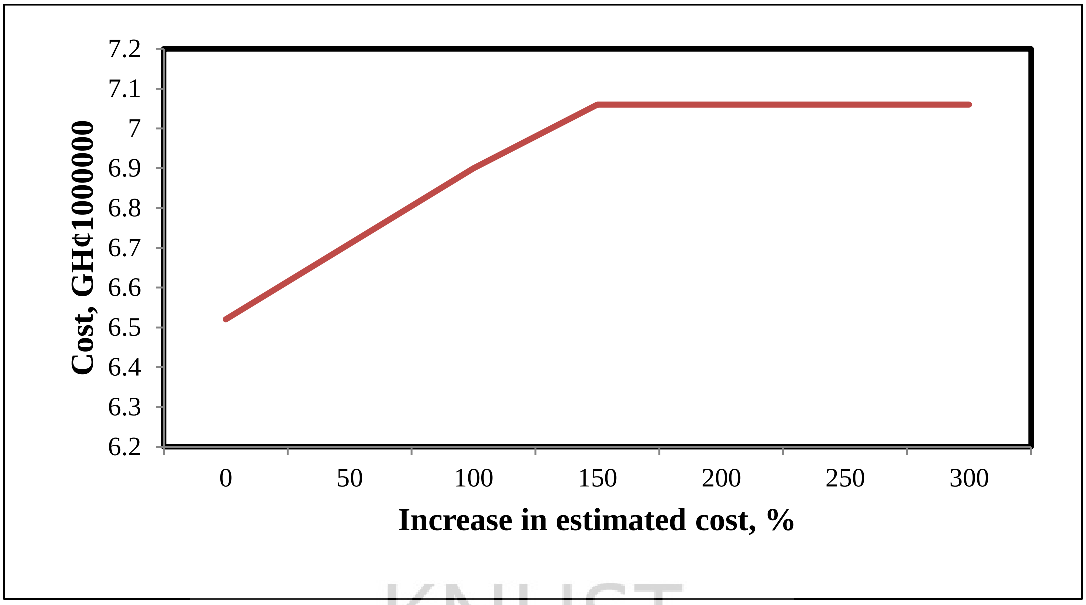


Figure 4.40 Total System Cost Change with Increase in Cost for Centralized Composting

It is observed that the cost of waste treatment increases drastically as the capital cost of centralized composting increases. The system waste flow remains unchanged until the percentage increase in cost gets to about 150 and more, where centralized composting is not considered in the options for waste treatment and more waste is then sent to the landfill (refer to Appendix G6.A). This means that within the limits of the modelling assumptions when the capital cost of centralized composting exceeds GH¢12.3/t centralized composting is not an economic option for treating part of the household solid waste in Kumasi.

D. Scenario 4 (Increasing capital cost for community composting)

Likewise the effect of changing capital cost on the optimal system cost is explored for community composting plants. This is presented in Figure 4.41, where it can be observed that the system increases with increasing percentage change in capital cost of the community composting plant up to about 500 percent increase. The system cost then reduces slightly and remains constant at the point where community composting is not included in the waste options (refer to Appendix G6.B).

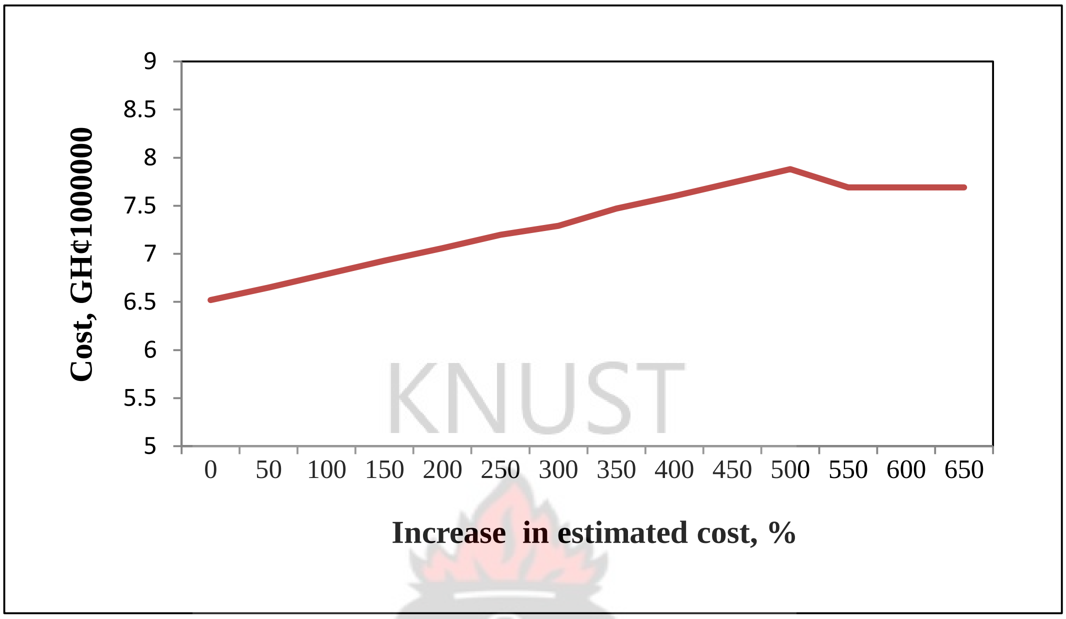


Figure 4.41 Total System Cost Change with Increase in Cost for Community Composting

This also implies community composting is not an economically viable option for handling HSW in Kumasi when the capital cost exceeds GH¢16.74/t within the limits of the modelling assumptions.

E. Scenario 5 (Increasing Capital Cost for Plastic Recycling)

Similarly the effect of percentage increase in capital cost of plastic recycling on the optimum system cost was investigated. The result presented in Figure 4.42 show that the waste flow in the system does not change with increasing cost until the percentage increase gets to about 450 percent after which any further increase results in plastic recycling not been included in the waste treatment options (refer to Appendix G6.C). This implies that plastic recycling is economically viable under the modelling assumptions if the capital cost is less than GH¢151.36/t.

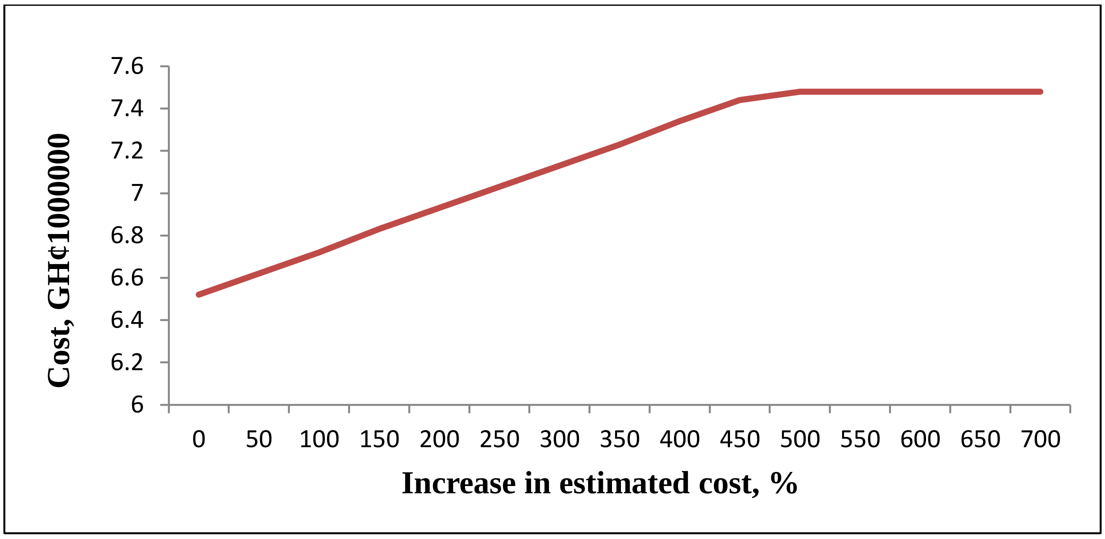


Figure 4.42 Total System Cost Change with Increase in Cost for Community Plastic Recycling Composting

It can be inferred from the optimization process and sensitivity analysis that an integrated waste management system for Kumasi including centralized composting, community composting, plastic waste recycling and landfilling could reduce the cost of WM in Kumasi. Rathi (2005) also observed that community participation in waste management provides the least cost option for managing waste in Mumbai, India. It is observed that more waste is sent to the landfill as cost for the various treatment options exceed certain thresholds. The inclusion of community level waste treatment options will create more jobs therefore addressing unemployment needs in the city. Composting will become more viable if markets for compost are well developed or if the cost of collection and landfilling increases substantially. This agrees with observations made by Renkow and Rubin, (1996). Options for marketing compost can be adopted from lessons learnt from experiences in Dhaka (Zurbrügg et al, 2002) where sale of compost could be delegated to a known fertilizer selling company, the involvement of agricultural extension officers to help farmers utilize the compost well and appreciate its value as well as setting up demonstration farms where the compost could be used. Community composting and plastic recycling however depend on the participation of community members. The attitudes and habits of community members with much education, policy measures and law enforcement can evolve to support community level waste treatment options. In this study only economic costs are considered, however of sustainable integrated waste management, environmental and social cost must be investigated. This leaves room for further research to address environmental and social costs and benefits of establishing IWM system for Kumasi.

4.5.2 Incineration as a Waste Treatment Option in Kumasi

One option of utilizing MSW is energy recovery through incineration. Incineration of MSW does not completely eliminate, but does significantly reduce, the volume of waste to be landfilled. The reductions are approximately 75 percent by weight and 90 percent by volume (Rand et al., 2000). In order to evaluate the feasibility of energy recovery as an integral part of SWM system it is of great importance to determine the energy content or calorific value (CV) of the solid waste, which is defined as the number of heat units involved when unit mass of material is completely burned. The energy content of any material, such as solid waste, is a function of many parameters, namely, physical composition of the waste, moisture content and ash content (Abu-Qdais and Abu-Qdais, 2000). There are several experimental and empirical approaches available for determining the CV of MSW. For this study two models (below) have been used, of which the parameters (composition of waste) were available.

1. $E = 23\{F + 3.6 (PA)\} + 160 (PL)$ (Khan and Abu Ghrarah, 1991 as cited in Abu-Qdais and Abu-Qdais, 2000) 4-2

Where:

E = energy content of MSW, Btu/lb (Btu/lb = 2.326 kJ/kg)

PL = percentage of plastic by weight

F = percentage of food waste by weight

PA = percentage of paper waste by

The calculated energy content is:

E = 23{0.544 + 3.6 (0.028)} + 160 (0.068) = 25.7104Btu/lb =59.8024kJ/kg = 0.598MJ/kg

Total Energy content of HSW in Kumasi = 59.8024kJ/kg x 272412000kg

E = 16.3×10^6MJ

2. E = Σ(Amount of each waste component in 100 kg x Effective calorific value of each component) x total amount of generated waste (Andersson et al., 2001 as cited in Zuilen, 2006) 4-3

Energy generated from waste incineration for each 100 kg of HSW is presented in Table 4.35 below

Table 4.34 Energy Generated from Waste Incineration for Each 100 kg of HSW

Waste Categories	Effective Calorific Values (MJ/kg) (1)*	Amount of Each Waste component in 100kg (kg) (2)	Estimated Energy content of HSW in Kumasi (MJ/100kg) (1x2)
Plastic	40.7	6.8	276.76
Paper	15.2	2.8	45.56
Food/ Garden Waste	6.35[1]	54.4	345.44
Textiles	13.5	1.8	24.3
Rest	6	31.4	188.4
Total Estimated Energy content			880.46

*Source: Andersson et al. (2001) as cited in Zuilen (2006), [1]Average of values for food (6.6) and garden (6.1) since the two were collected as organic in the study

It can be deduced from table 4.35 that the total energy content of HSW is estimated to be 8.8 MJ/kg. This is lower than values obtained by Fobil et al. (2005) who reported a calorific value of 16.75-16.95 MJ/kg for MSW in Accra. According to Rand et al. (2000), the average calorific of the waste must be at least 7 MJ/kg and annual amount of waste for incineration should not be less than 50,000 metric tons and weekly variations in the waste supply to plant should not exceed 20% to justify incineration. Both methods show that different energy contents HSW in Kumasi. In the first method only the main components are included in the calculations. The second method made use of the heating value of almost every component present in the waste making the amount of energy produced more reliable. The energy content of the HSW estimated by the second method suggests that incineration could be considered to manage the HSW in Kumasi based on its energy value. There are, however, other criteria to be considered before incineration could be considered as a sustainable way of managing HSW.

It is clear that plastic, paper and food generate the most energy per kg. The plastic fraction in waste stream generates quite high energy. For that reason, more energy can be extracted from waste that contains a larger percentage of plastic fractions. A downside to the large energy production from plastic and paper is that they also have the largest amounts of emission to the environment. Both fractions emit the greatest amounts of carbon dioxide and nitrous oxide which are well known greenhouse gases (Andersson et al., 2001 as cited in Zuilen, 2006). Due to the high moisture content and low heat production, food produce a small amount of energy from incineration but due to the high percentage in the waste stream the net energy is still high.

Rand et al. (2000) argued that MSW incineration could be considered as a sustainable SWM option if only the following criteria are fulfilled:

1. A mature and well-functioning waste management system has been in place for a number of years
2. Solid waste is disposed of at controlled and well operated landfills
3. The supply of combustible waste will be stable and amount to at least 50,000 metric tons/year
4. The lower calorific value must on the average be at least 7MJ/kg, and must never fall below 6MJ/kg in any season
5. The community is willing to absorb the increased treatment cost through management charges, tipping fees, and tax-based subsidies
6. Skilled staff can be recruited and maintained
7. The planning environment of the community is stable enough to allow a planning horizon of 15 years.

Factors cited by UNEP and IETC (1996) as basis that make incineration difficult or inadvisable in many developing countries include:

1. The high capital and operating costs involved, relative to national income levels, and the comparatively low cost of sanitary landfilling. The typical capital investment for a mass burn waste incinerator ranges from US$ 50 million to US$ 280 million depending on its capacity, making it the most costly SWM option available (Platt, 2004 as cited in Zuilen, 2006). Further, the net cost per ton to burn wastes is at least twice the cost of controlled landfilling, and many times of recycling and composting strategies (Platt, 2004 as cited in Zuilen, 2006). Incinerators often require foreign financing to build and maintain.

2. It is difficult to incinerate wastes in many developing countries due to their high moisture and low energy content. Evaluation of energy recovery for MSW in Accra revealed that only 40 % of the available energy of the waste stream is recoverable because of the high moisture content of the waste (Fobil et al. (2005).
3. In addition, the technical infrastructure required to maintain incineration facilities, including their pollution control equipment, is generally not currently available in developing countries. The elements of infrastructure that are often lacking include highly trained personnel, constant availability of technologically advanced testing and repair facilities, and a well functioning system for ensuring the quick availability of spare parts.

It may be concluded that, incineration may not be an immediate option that should be considered for managing HSW in Kumasi. Since, most of the suggested pre-requisites for incineration to be sustainable have not yet been met.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter concludes the thesis by highlighting the most important findings from the study. Recommendations for practical design consideration for instituting organized SS and ISWM in the study area as well as suggestions for future research are also presented in this chapter.

5.1 CONCLUSIONS AND RECOMMENDATIONS FROM STUDY RESULTS

Although the pilot waste separation at source project was of limited duration and size, the types of households/areas involved were typical of many areas in Kumasi.

5.1.1 Household Waste Composition and Waste Generation Rates

5.1.1.1 KNUST

Organic waste dominates the waste stream obtained from staff residencies on KNUST campus. Other waste was the next highest component. The third highest component is plastic. The rest are paper, metals, textiles and glass successively. The overall per capita waste generation rate obtained for the selected staff residencies on KNUST campus was 0.3kg/person/day. A generation rate of 0.39kg/person/day and 0.26kg/person/day was obtained for the senior staff and junior staff areas respectively. These generation rates were found to be statistically different for the two areas at 5% level of significance. Household size was found to be positively correlated (r = 0.3955) to the average household waste generated daily and negatively correlated with per capita waste generation(r = 0.4058).

5.1.1.2 Asokwa Sub-Metro

Waste composition from the three classes of areas was predominantly organic, followed by other wastes (ashes, sand, diapers, shoes, composite materials, batteries, bulbs etc.). Plastic waste was the third most abundant material in the waste from all the areas. Other materials; paper, metals, glass and textiles are available in varying quantities from the three areas. The overall composition of materials in the HSW in Asokwa sub-metro is organic - 54.4%, others – 31.4%, plastic – 6.8%, paper – 2.8%, metals – 1.7%, textiles - 1.8%, and glass – 1.1%.

Waste generation rate (kg/person/day) for the three areas of 0.63%, 0.52% and 0.27% for first, second and third class areas respectively. The difference in these generation rates for the three areas was found to be statistically significant at 5% level of significance when compared pair wise. The overall household solid waste generation rate for the Asokwa sub-metro was found to be 0.49kg/person/day. Household size was found to be positively correlated (r = 0.3891) to the average household waste generated daily and negatively correlated with per capita waste generation(r = 0.4579).

Waste composition and generation rate from the two study areas are similar to results obtained from other studies. It is estimated (based on results from this study and information from WMD-KMA) that HSW constitutes 75% of MSW collected in Kumasi for the year 2008. An increase of 61.5% of the present estimated HSW generation in Kumasi is expected in ten years when HSW generation rate is projected with current per capita generation rate and assuming constant annual population growth rate. It may be concluded that irrespective of the informal recovery of materials from the waste stream a considerable amounts of recyclable materials are still found in the waste stream. High waste diversion rates could be achieved if the organic fraction is considered for treatment in addition to plastics, metals and paper.

5.1.2 Household's Waste Separation Efficiency and Level of Compliance

Household's Potentials for SS of HSW is expressed in the separation efficiency and level of compliance. The results of the study show that there is a clear difference in the effectiveness of households to separate different waste materials at source. Comparing the separation efficiency for the three waste streams highlights this.

5.1.2.1 KNUST

The level of compliance of households in separating waste is an indication that participating households had an excellent ability to differentiate organic wastes from other wastes and properly separated them with only 1.09% having contaminants above 50% in their organic waste bin. The level of compliance in separating plastic waste and other wastes was poorer than for organic wastes. The separation efficiency for plastic wastes and other wastes was also on the average slightly around 50%. Separation efficiency for organic waste between 50% and 90% for all the areas respectively shows that the separate collection of organic waste could be most successful. Majority of households had up to 50% of contaminants in the organic bin though. The separation efficiency for plastics was between 15% and 40% for all the areas. More than 50% of households had contaminants above 50% in the plastics bin. The most contaminated plastics were the films as they are used to wrap food that soils it and makes it difficult for recycling. The separation efficiency for other waste was between 40% and 75% for all the areas. More than 50% of all households had up to 50% of the waste placed in the others bin being others. From the separation efficiency and level of compliance of households it can be concluded that waste separation at source of organic waste could be successful with sustained communication with households as to their performance.

5.1.2.2 Asokwa Sub-Metro

Contaminants above 50% in the organic bin were recorded for household in the Asokwa sub-metro, 14.18%, 27.57% and 37.99% of households from Asokwa, Atonsu and Ahinsan respectively. These results show that the majority of households from the three areas had contaminants up to 50% in the organic bin i.e. the degree of compliance on the average is fair for all the areas. The percentage of organic waste that was found in the organic bin was 74.3%, 60.02% and 59.56% from Asokwa, Atonsu, and Ahinsan respectively. The level of compliance in separating plastics was low in all the three areas. 54.7%, 58.03% and 72.73% of households from Asokwa, Atonsu and Ahinsan had contaminants above 50% in the plastic bin. The level of compliance reflects in the separation efficiency for plastic wastes. The average percentage of plastics in the plastics bin for Asokwa, Atonsu and Ahinsan was 21.42%, 19.26% and 26.92% respectively. 34.11%, 28.8% and 17.53% of households from Asokwa, Atonsu and Ahinsan had contaminants above 50% in the others bin. The average percentage of others in the 'others' bin for Asokwa, Atonsu and Ahinsan was 51.19%, 59.57% and 62.41% respectively. It is suggested that future source separation of household waste could consider separation into two waste streams; organics and others since the separation efficiency and level of compliance for separating plastic waste was low.

5.1.3 Factors That Will Promote or Limit Successful Implementation of Source Separation

5.1.3.1 Existing Household Waste Management Methods

Currently, most households in the first class area have house to house waste collection services and are willing to pay for a reliable waste collection service. Households in the second class area dispose off their waste at a communal site but are willing to participate in house to house collection services if the service will be reliable. House to house waste collection in the third class area is not advised due to the complex household structure, lack of space to place bins and unwillingness of households to pay for waste collection services. Households from all the areas undertake some level of waste recovery by reusing items that they could have thrown away and selling items to itinerant buyers. 59%, 65% and 75% of households in the first, second and third class areas respectively reuse post consumer items. 45%, 50% and 37.5% from the first, second and third class areas respectively sell items to itinerant buyers. This they did mainly for monetary gains. A waste separation at source that ensures that households directly get monetary rewards for their recyclables is likely to succeed. Therefore, future organized SS schemes that require separation into different bins in households could target households in the first class area and those in second class areas where access routes are available.

5.1.3.2 Awareness and attitudes of Respondents of Waste Management, Recycling and Source Separation

It was realised that most respondents who have had secondary and tertiary education are aware of recycling. On the other hand, respondents who are not aware of SS also have had secondary or tertiary education. The results indicate that most of respondents are aware of recycling but only few know that SS promotes recycling.

The attitude of households to WM was explored by assessing their concern for safe and acceptable disposal of waste. It can be concluded that majority of households (74 out of 98) are concerned that waste collected from their homes be disposed of in an acceptable manner. Most households in the Asokwa do not know the final disposal of waste collected from their homes. There is the need to raise the awareness of households and citizens in Kumasi in general to arouse their interest in supporting waste management programs that will be beneficial to them. It is recommended that information dissemination on waste management status of the city be made, on regular basis, to citizens to make them aware of the costs of managing waste.

5.1.3.3 Relationships between Household Socio-Demographic Characteristics and Source Separation efficiency

A positive but weak relationship was found between household's weighted mean level of education and SS efficiency for organic and plastic waste {R (Organic waste) = 0.4045, R (Plastic waste) = 0.1506}, indicating that households with higher education achieved higher separation efficiencies for organic and plastic waste. However there seem to be a very weak negative or no relationship between the mean household level of education and SS efficiency of other waste (R (Others) = 0.0001).

A weak negative relationship was found to exist between the mean household age and the SS efficiency of organic, plastic and other waste (R (Organic waste) = 0.1427; R (Plastic waste) = 0.0269; R (Others) = 0.1872). This indicates that household with younger persons on the average separated their waste as required well than households with older persons. A very weak positive relationship was found to exist between the household size and the SS efficiency of other waste (R (Others) = 0.0360). However there seem to be a weak negative relationship between the household size and SS efficiency of organic and plastic waste (R (Organic waste) = 0.3041, R (Plastic waste) = 0.2939).

5.1.3.4 Considerations for Design of Source Separation Programs in Kumasi

I. Mandatory versus Voluntary Source Separation Programmes

It is generally accepted that making SS mandatory would increase participation in programs. Although, it is also perceived that mandatory recycling may tend to produce a negative attitude towards SS, and may cause some persons to resist the program whenever possible (Zuilen, 2006), respondents from this study show a strong support for making SS mandatory.

II. Types of Material to be Recycled and Separation Methods

It is recommended that subsequent waste separation schemes conducted on house to house basis, could consider separation into two fractions with a bin maintained for organic wastes and another bin for the rest of the waste in first and second class areas. Households in these areas could be advised to keep selected recyclables and sell them to itinerant buyers as most households were willing to sell to them or send them to collection points within their communities for some cash incentive. Communal collection of organic and selected recyclable waste could be investigated in third class areas as well.

III. Provision of Container

Provision of free bins has been mentioned as an important incentive for households to participate in organized SS. Results from this study show that very few households, less than 40% in the Asokwa sub-metro and less than 60% from KNUST, are willing to provide bins for separating their HSW at source. Hence provision of free bins must be an integral part of any organized SS scheme in

Kumasi. Central collection of recyclable wastes could also be considered since a high percentage of respondents are willing to patronize such a collection arrangement.

IV. Collection Frequency and Collection Day

Most households in Asokwa sub-metro are comfortable with collection twice a week of all waste fractions since they were not used to regular collection. Households on KNUST campus having a daily collection services advocate for daily collection. This shows that a collection scheme for the separate collection of waste fractions in households must correspond to the service that they are used to or be better.

Taking the response of households into account, when a separation scheme is designed to provide a reliable and consistent collection service and free bins backed up with good communication over 50% of residents in all classes of areas are likely to participate in the scheme. There is the need to educate people on the resource value of waste and to provide them with concrete evidence of the use of collected materials to increase the level of compliance in future SS programmes.

5.1.4 The integration of Waste Treatment Options in Kumasi

5.1.4.1 Integration of treatment options

It may be concluded from the results of the optimization solution that centralized composting, community composting and plastic waste recycling if included in the waste management system in Kumasi could reduce the annual system cost substantially. This could also decrease the amount of wastes that need to be landfilled thereby extending the lifespan of the landfill. The high portion of biodegradable waste (food waste) in the household waste stream is a good measure for compost production. Community composting and plastic waste recycling is recommended for further investigation. Pilot community plants could be set up and monitored. Results from the performance of these pilot plants could then be used to plan and design plants for other communities incrementally for the city. Composting of mixed waste at the landfill site could be carried out. The CDM could be explored as a financing option for the composting plant. The compost produced could be used as daily cover, if proper landfilling operations are to be carried out in order to capture the landfill gas. Other marketing strategies like those employed in other developing could countries could also be explored to address the bottlenecks associated with the marketing of compost.

5.1.4.2 Incineration

Energy recovery through combustion of waste is being considered by local authorities to manage the increasing quantities of waste generated. The calculation from this study showed that household waste has a calorific value of 8.8 MJ/kg of waste which might justify the energy generation from incineration (minimum value 7MJ/kg of waste). This energy content is quite high despite the high moisture and inert content of HSW in Kumasi. Considering other factors such as the high investment costs and lack of capacity to adequately manage the toxic ash and emissions demonstrate that the combustion of waste may not be a promising waste management technique for Ghana.

5.1.5 Contribution to Knowledge from Study

This research seeks to contribute scientific knowledge to the development of appropriate schemes for resource recovery from MSW in developing countries. This study is one of the few that have been conducted in Ghana relating willingness of households to separate their SW at source to actual separation efficiencies and level of compliance. The results of all aspects of this study are expected to be useful to municipal authorities, WM companies, the government and researchers. This research's findings also have important practical and policy implications for understanding waste character and decision-making regarding SS (customary and organized) of household waste. This study has also contributed to the knowledge base in the area of separation at source of HSW in an urban city of a developing country. The approach taken in this study expresses the advantage gained by integrating engineering and social science, where engineering knowledge of characteristics and flow of household waste and social knowledge of households and or individuals characteristics, awareness, and perceptions about WM and SS are integrated to gain useful information for the design of successful SS programs. Households' participation and separation potential, coupled with waste generation rate and composition could provide invaluable information for planning waste separation schemes for households on KNUST campus and Kumasi. This study represents an attempt towards a better planning and management of HSW. It demonstrates how the application of system analysis tools could provide useful information on the system performance to support informed decision making in the area of SWM.

5.2 RECOMMENDATIONS FOR FUTURE STUDIES

The results from this study are useful in understanding the performance of households in participating in organized SS in Kumasi. However, whether or not waste separation at source will be implemented depends not only on households, but also on other external factors. Some external factors include subsidies from the government, market opportunities and revenues from recovered materials, capital, operating and maintenance costs for collecting and transporting separated wastes. Hence there is need for further studies in order to develop and implement successful SS and waste recovery programs to contribute to solving the increasing problems of SWM that have plagued our cities. Some suggestions for future studies are presented as follows:

1. Instituting an all year round waste characterization studies for all generation sectors (households, markets, institutions, commercial establishments) is recommended. This would enable contribution of waste from these sectors to the total waste that must be handled to be calculated.
2. It will be necessary to conduct research on collection methods for separate waste collection, as in the type of vehicles, collection routes and containers that will make separate collection reasonable.
3. Research on separate collection of recoverable waste streams at communal sites/neighbourhood depots is recommended since most households are used to sending collected household waste to communal dumps or containers.
4. The contribution of various stakeholders to formal and informal reuse and recycling and the effect of these recovery activities on the entire solid waste management system also need further investigations.

5. Local industry demand for recyclables as well as the potential for waste trade internationally needs to be investigated to evaluate the market that exists for recyclables.
6. Establishing pilot community composting and plastic waste recycling plants is recommended to assess their feasibility to reduce the amount of waste that must be transported to the landfill.
7. Although municipal authorities in Ghana are more concerned with the costs of managing waste it is necessary to evaluate the environmental implications of MSWM. Since environmental cost are necessary in evaluating MSWM in the context of sustainable development. It points to the need for carrying out further research in the direction of estimating environmental costs of WM for Kumasi and in Ghana as a whole.

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APPENDICES

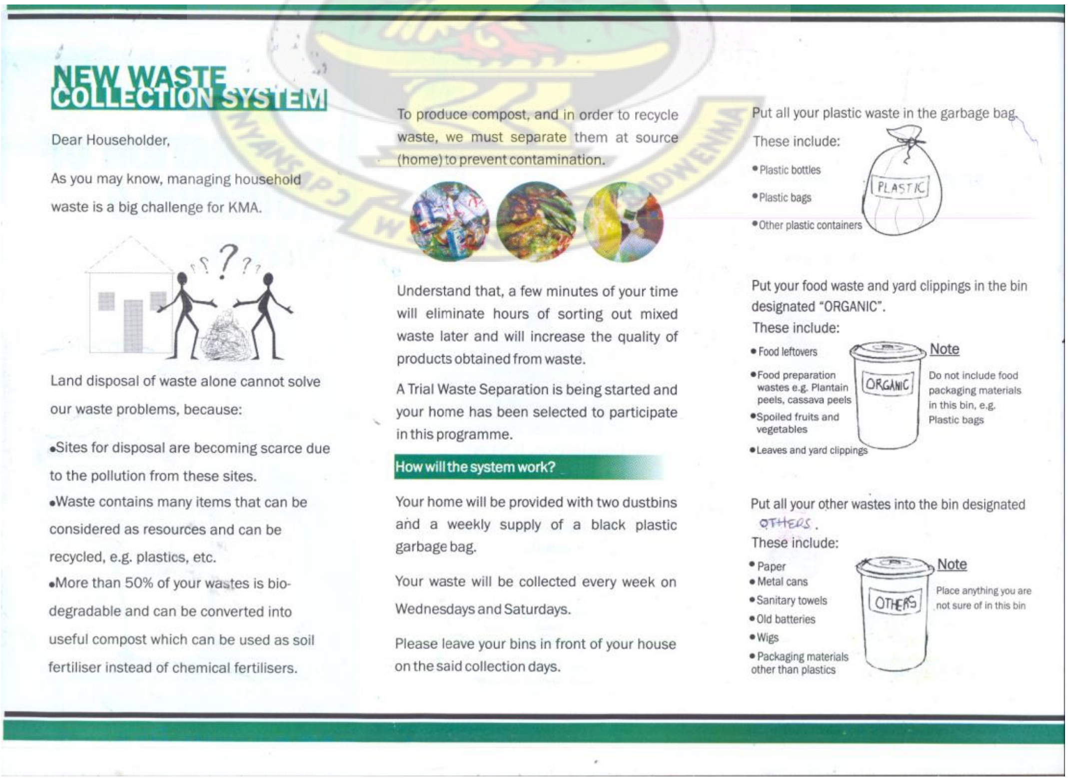
APPENDIX A: INFORMATION ON THE KMA

Appendix A1: Localities that fall under the various Classes in the Kumasi Metropolis according to the KMA

1st Class	2nd Class	3rd Class
Adiebeba	Adoato	Aboabo
Adiembra	Adum	Abrepo
Ahodwo	Adumanu	Adukrom
Asokwa	Amakom	Ahinsan
Bomso	Atonso	Amanfrom
Danyame	Anwomaso	Ampabame
Mbrom	Apiri	Anomanye
Odeneho Kwadaso	Aprade	Apatrapa
West Nhyaeso	Asafo	Apeadu
	Asebi	Aprabon
	Ash Town	Asawase
	Asuoyeboah	Asokore Mampong
	Atasomanso	Atafoa
	Bantama	Atwima Amanfrom
	Boadi	Ayeduase
	Bohyen	Ayigya
	Bompata	Breman
	Buokrom Estate	Buokrom
	Daban	Dakodwom
	Dichemso	Deduako/Kodiekrom
	Edwenase	Denchembuoso
	Fanti New Town	Dompoase
	Fankyenebra	Duase
	Gyinyase	Emena
	Kentinkrono	Kaase
	Kotei	Kokode
	Kwadaso	Konkromoase
	Manhyia	Kronom
	New Tafo	Kyirapatre
	North Suntreso	Makro
	Nsenie	Mpatasie
	Nzema	Moshie Zongo
	Ohwimase	Nwamase
	Pankrono	Nyankyereniase
	Patase	Oduom
	Santasi	Oforikrom
	Sepe Dote	Ohwim
	Suame	Old Tafo
	South Suntreso	Pakuso
		Sawaba
		Sepe Owusu Ansah
		Sepe Aprampram
		Sepe Tinpon
		Sokoban
		Tanoso
		Twumduase,Yenyawso

APPENDIX B: INFORMATION AND EDUCATION MATERIALS

Appendix B1: Brochure Distributed During KNUST Study



Appendix B2: Stickers Pasted on Bins during the KNUST Study


DROP OTHER WASTE
HERE

Appendix B3: Handbill Distributed to Households Prior to Distribution of Bins in the Asokwa Sub-Metro

Appendix B4: Brochure Distributed During the distribution of Bins in the Asokwa Sub-Metro

APPENDIX C: QUESTIONNAIRES

Appendix C1: Questionnaires Administered Prior to Distribution of Bins - KNUST Campus

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI
DEPARTMENT OF CHEMICAL ENGINEERING
HOUSEHOLD QUESTIONNAIRE SURVEY

This research aims at investigating household's handling of solid wastes and resource recovery from these wastes. Solid waste management is a very pertinent issue facing municipal and local authorities all over Ghana. Due to population growth and the changing lifestyles of Ghanaians, the amounts of waste generated has increased drastically over the years. The composition has also changed from predominantly biodegradable materials to include appreciable amounts of non-biodegradable materials. In view of the above developments, land filling of waste is not enough to solve the problems of solid waste management. Recovery of materials from these wastes has been proposed by many researchers. To develop schemes to recover materials from waste, the view of all stakeholders involved in the generation and handling of waste must be sought. Your view as a stakeholder is very important in order to develop a scheme for resource recovery that will be suitable to you.

Your participation is voluntary and the data collected will be treated with utmost confidentiality. The data collected will be computerized without personal information and the results presented as group data.

This study is being conducted by Asase Mizpah Ama Dziedzorm (Miss), a PhD student at the Chemical Engineering Department, KNUST, Kumasi under the supervision of Dr. Moses Mensah and Dr. S.K. Amponsah.

Thank you for your cooperation and participation in this important exercise.

Area: ………………………. Date: ……………

House No. …………………. Type of housing:………………………………………….

PART 1- ABOUT YOURSELF

1. To which age group do you belong?

Under 26 yrs ☐[1] 35-44 yrs ☐[3] 55-59 yrs ☐[5]

26-34 yrs ☐[2] 45-54 yrs ☐[4] 60 yrs and above ☐[6]

2. Are you? Male ☐[1] Female ☐[2]

3. What is your highest level of education? ………………………………

4. What is your Occupation? ……………………………………………..

5. Are you? Single ☐[1] Married ☐[2]

6. In your household, are you the?

Father ☐[1] Mother ☐[2] Child ☐[3] Other ☐[4]

PART 2- ABOUT YOUR HOUSEHOLD

7. How much is your household's average monthly income?

Less than 1 million cedis ☐[1] 2-5million cedis ☐[3] above 10 million cedis ☐[5]

1-2 million cedis ☐[2] 5-10 million cedis ☐[4]

8. How many people make up your household?

………….

9. How many of your household members fall within the following age groups?
1. 0-12 ……………….
2. 13-19 ……………....
3. 20-30 ……………….
4. 31-40 ……………….
5. 41-50 ……………….
6. 51-70 ……………….
7. 71 and above …………

10. What are the levels of education of your household members?
1. Primary school ………………
2. Incomplete secondary education ………………
3. Complete secondary education . ..……………
4. Professional education ………………
5. Technical education ………………
6. Incomplete tertiary education ………………
7. Tertiary education ………………
8. None

PART 3- HOUSEHOLD WASTE DISPOSAL

11. How do you dispose your daily household wastes?

Individual Bin ☐[1] Communal container ☐[2] Other ☐[3]

12. How many refuse bins do you have in your house? …………………………………..

13. How often do you dispose off your wastes?
………………………………………….

14. Are there some particular wastes that you do not put in the bins? Yes ☐[1] No ☐[2]

15. If yes, what are they? ………………….

16. If yes to Q14, Why?

we burn them ☐[1] we bury them ☐[2] we reuse them at home ☐[3] we sell them to itinerant buyers ☐[4]

Other ☐[5] Specify other …………………………………………………………………..

17. What type of waste does your household reuse (can indicate more than one)?

Glass ☐[1] Plastic bottles ☐[3] Plastic bags ☐[5] Paper ☐[7]

Cardboard ☐[2] Compostables ☐[4] Metal cans ☐[6] Other ☐[8]

18. Which of the following types of solid waste does your household sell to itinerant buyers?

Glass ☐[1] Plastic bottles ☐[3] Paper ☐[5]

Cardboard ☐[2] Compostables ☐[4] Other ☐[6]

PART3- ATTITUDES AND OPINIONS ABOUT WASTE MANGEMENT AND RECYCLING

19. Who collects your waste for final disposal? ……………………………………………….

20. Do you know where the collected waste is taken for ultimate treatment and disposal when it leaves your premise / neighbourhood?

Yes ☐[1] Don't know ☐[2]

21. If you know about the ultimate treatment / disposal of your waste, are you concerned whether this is done in an environmentally safe and acceptable manner?

Yes ☐[1] No ☐[2] Don't know ☐[3]

22. What is your opinion about the current situation of the disposal of solid waste in your neighbourhood?

Satisfactory ☐[1] Unsatisfactory ☐[2] No opinion/don't know ☐[3]

23. What do you consider the most urgent problem related to the disposal of solid waste in your neighbourhood?

1. Personal health ☐
2. Littering of solid waste in the neighbourhood ☐
3. pollution of living area ☐
4. other ☐

24. Why do you sell items to itinerant buyers? ....
……………………………………………………………………………………………

25. If you do not already sell things to itinerant buyers, will you be willing to do so if you are

asked to? Yes☐1 No☐2
26. Have you heard about recycling before? Yes ☐1 No ☐2
27. How did you hear about it? Literature ☐1 Media ☐2 Other ☐3 Specify other ………………………………………………..
28. Do you think recycling is a good option for managing your waste? Yes☐1 No ☐2
29. Have you heard about or witnessed source separation before (putting different waste materials into different bins at the house or collection point)? Yes☐1 No☐2
30. How did you hear about it or where did you witness it? ………………………………………………………………………………………………
31. Would you be prepared to separate your waste when given extra receptacles for the purpose of recycling? Yes☐1 No☐2
32. If No, Why are you not interested in separating your waste at source? Inconvenient/ no time ☐1 Storage/handling problems ☐3 Not interested ☐5 Too much effort ☐2 No need for separation at source ☐4 Other ☐6 Specify other ………………………………………………………………………………………………
33. If Yes, Why are you willing to separate your waste at source? Promotes collection of clean recyclables ☐1 Reduces waste going to landfills ☐3 Save natural resources ☐2 Other ☐4 Specify Other ……………………………………………………………………………………..
34. Do you think it should be made mandatory for every household to separate their waste at source? Yes ☐1 No ☐2
35. How many receptacles will you be willing to accommodate? …………………
36. If you are not provided with receptacles but asked to separate your waste would you be willing to buy your own receptacles? Yes ☐1 No☐2
37. Would you be willing to send some of your separated waste to a deposit site in your area if you are asked to do so? Yes☐1 No☐2
38. Would you be willing to send some of your separated waste to a deposit site in your area, if you will be paid some money for it? Yes☐1 No☐2
39. Any comments? …………………………………………………………………………………………………… …………………………………………………………………………………………………… …………………………………………………………………………………………………… …………………………………………………………………………………………………… …………………………………………………………… …………………………………………………………………………………………………… ………………

Appendix C2: Follow Up Questionnaire - KNUST Campus

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

DEPARTMENT OF CHEMICAL ENGINEERING

HOUSEHOLD FOLLOW UP

Hello, my name is Mizpah, a postgraduate student at the Chemical Engineering Department, KNUST. About three months ago, separate collection of household waste was introduced in your area on a pilot basis. I would like to know your concerns and comments on the performance of this waste collection system. Your answers to the few questions below would help in developing a system the best suits your community.

Thank you for your cooperation in taking time to answer these questions in order to help find solutions to the waste management problems that have plague our nation..

Area: ……………………….	Date: ……………
House No. ………………….	
PART 1- ABOUT YOURSELF	
1. To which age group do you belong? Under 26 yrs ☐1 35-44 yrs ☐3 55-59 yrs ☐5 26-34 yrs ☐2 45-54 yrs ☐4 60 yrs and above ☐6	
2. Are you? Male ☐1 Female ☐2	
3. In your household, are you the? Father ☐1 Mother ☐2 Child ☐3 Other ☐4	
PART 2- ABOUT YOUR HOUSEHOLD	
4. How many of your household members travelled for more than 3 days within the last three moths? ………….	
5. Please can you specify the period of travel ……………………………………………………………………………………………………… ……	

PART 3- HOUSEHOLD PARTICIPATION IN WASTE COLLECTION SCHEME
6. Is your household participating in the current waste collection scheme? Yes ☐1 No ☐2
If No, to Q. 6 , Why? Inconvenient/ no time ☐1 Storage/handling problems ☐3 Not interested ☐5 Too much effort ☐2 No need for separation at source ☐4 Other ☐6 Specify other …………………………………………………………………………………………
8. If you are participating in the scheme, do you have any difficulty in identifying in which bin to place any particular waste material? Yes ☐1 No ☐2 Please specify material ……………………………………………………………………………….
9. Do you empty your any of your bins in between the collection days i.e. Wednesday & Saturday? Yes ☐1 No ☐2
10. Are there some particular wastes that you do not put in the bins? Yes ☐1 No ☐2
11. If yes, what are they? …………………
12. If yes to Q10, Why? we burn them ☐1 we bury them ☐2 we reuse them at home ☐3 we sell them to itinerant buyers ☐4 Other ☐5 Specify other ………………………………………………………………..
13. Are you satisfied with the information provided for the collection Scheme? Yes ☐1 No ☐2
14. After participating in this collection scheme do you think it should be maintained and adopted throughout KNUST Campus? Yes ☐1 No ☐2
15. If no to Q14, why? ………………………………………………………………………………………… ………………………………………………………………………………………………… ………………..
PART3- SUGGESTIONS FOR IMPROVING THE COLLECTION SCHEME
Please your comments and suggestions for the implementation of separate collection of household waste ………………………………………………………………………………………………… ………………………………………………………………………………………………… ………………………………………………………………………………………………… ………………

Appendix C3: Questionnaires Administered Prior to Distribution of Bins - Asokwa Sub-Metro

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

DEPARTMENT OF CHEMICAL ENGINEERING

HOUSEHOLD QUESTIONNAIRE SURVEY

This research aims at investigating household's handling of solid wastes and resource recovery from these wastes. Solid waste management is a very pertinent issue facing municipal and local authorities all over Ghana. Due to population growth and the changing lifestyles of Ghanaians, the amounts of waste generated has increased drastically over the years. The composition has also changed from predominantly biodegradable materials to include appreciable amounts of non-biodegradable materials. In view of the above developments, land filling of waste is not enough to solve the problems of solid waste management. Recovery of materials from these wastes has been proposed by many researchers. To develop schemes to recover materials from waste, the view of all stakeholders involved in the generation and handling of waste must be sought. Your view as a stakeholder is very important in order to develop a scheme for resource recovery that will be suitable to you.

Your participation is voluntary and the data collected will be treated with utmost confidentiality. The data collected will be computerized without personal information and the results presented as group data.

This study is being conducted by students from the Chemical Engineering Department, KNUST- Kumasi under the supervision of Dr. Moses Mensah.

Thank you for your cooperation and participation in this important exercise. For further inquiries please contact Mizpah Asase on the following number: 0244712350

Area: ………………………. Date: ……………
House No. …………………. Type of housing: ……………………………………….
PART 1- HOUSEHOLD WASTE DISPOSAL
1. How do you dispose your household wastes? Individual Bin (house to house collection) ☐1 Communal dump site ☐2 Other ☐3 Specify Other ………………………….
2. How many refuse bins do you have in your household? …………………………………..
3. If compound house: How many bins are used by each household in the house? ………………………
4. How often do you dispose off your wastes? ………………………………………….
5. Do you burn some items that you regard as waste? Yes ☐1 No ☐2 Specify ………………………………………………………………..
6. Do you bury some items you regard as waste? Yes ☐1 No ☐2 Specify ………………………………………………………………..
7. Do you give out some items you don't use? Yes ☐1 No ☐2 Specify ………………………………………………………………..
8. Do you reuse some items in your house? Yes ☐1 No ☐2 Specify ………………………………………………………………..
9. Do you sell some unwanted items to itinerant buyers? Yes ☐1 No ☐2 Specify ………………………………………………………………..
PART 2- ATTITUDES AND OPINIONS ABOUT WASTE MANGEMENT AND RECYCLING
10. Who collects your waste for final disposal (company/authority)? ……………………………………………….
11. Do you know where the collected waste is taken for ultimate treatment and disposal when it leaves your premise / neighbourhood? Yes ☐1 No ☐2
12. If you know about the ultimate treatment / disposal of your waste, are you concerned whether this is done in an environmentally safe and acceptable manner? Yes ☐1 No ☐2 Don't know ☐3
13. What is your opinion about the current situation of the disposal of solid waste in your neighbourhood? Satisfactory ☐1 Unsatisfactory ☐2 No opinion/don't know ☐3
14. What do you consider the most urgent problem related to the disposal of solid waste in your neighbourhood? 1. Personal health ☐ 3. pollution of living area ☐ 2. Littering of solid waste in the neighbourhood ☐ 4. other ☐ Specify Other…………………………………………………………………………………………… …….

15. Why do you sell items to itinerant buyers? .... …………………………………………………………………………………………………
16. If you do not already sell things to itinerant buyers, will you be willing to do so if you are asked Yes☐1 No☐2
17. Have you heard about recycling before? Yes ☐1 No ☐2
18. How did you hear about it? Literature ☐1 Media ☐2 Other ☐3 Specify other ………………………………………………..
19. Do you think recycling is a good option for managing your waste? Yes☐1 No ☐2
20. Have you heard about or witnessed source separation before (putting different waste materials into different bins at the house or collection point)? Yes☐1 No☐2
21. How did you hear about it or where did you witness it? …………………………………………………………………………………………………
22. Would you be prepared to separate your waste when given extra receptacles for the purpose of recycling? Yes☐1 No☐2
23. If No, Why are you not interested in separating your waste at source? Inconvenient/ no time ☐1 Storage/handling problems ☐3 Not interested ☐5 Too much effort ☐2 No need for separation at source ☐4 Other ☐6 Specify other …………………………………………………………………………………………………
24. Do you think it should be made mandatory for every household to separate their waste at source? Yes ☐1 No ☐2
25. How many receptacles will you be willing to accommodate? …………………
26. If you are not provided with receptacles but asked to separate your waste would you be willing to buy your own receptacles? Yes ☐1 No☐2
27. Would you be willing to send some of your separated waste to a deposit site in your area if you are asked to do so? Yes☐1 No☐2
28. Would you be willing to send some of your separated waste to a deposit site in your area, if you will be paid some money for it? Yes☐1 No☐2
PART 3 - ABOUT YOURSELF
30. To which age group do you belong? Under 26 yrs ☐1 35-44 yrs ☐3 55-59 yrs ☐5 26-34 yrs ☐2 45-54 yrs ☐4 60 yrs and above ☐6
31. Are you? Male ☐1 Female ☐2

32. What is your highest level of education? ………………………………

33. What is your Occupation? ……………………………………………….

34. Are you? Single ☐1 Married ☐2

35. In your household, are you the?

Father ☐1 Mother ☐2 Child ☐3 Other ☐4

Specify Other…………………………………………

PART 4 - ABOUT YOUR HOUSEHOLD

36. How much is your household's average monthly income?

Less than GH¢ 100 ☐1 GH¢ 200-500 ☐3 above GH¢1000 ☐5

GH¢100-200 ☐2 GH¢ 500-1000 ☐4

37. How many people make up your household?

………….

38. How many of your household members fall within the following age groups?

1. 0-12 ……………….
2. 13-19 ……………....
3. 20-30 ……………….
4. 31-40 ……………….
5. 41-50 ……………….
6. 51-70 ……………….
7. 71 and above …………

39. What are the levels of education of your household members?

1. Primary/JSS ………………
2. Secondary / Technical ………………
3. Vocational ………………
4. Tertiary/Professional ………………
5. None ………………

40. Any comments?

……………………………………………………………………………………………………
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Appendix C4: Follow Up Questionnaire – Asokwa Sub-Metro

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

DEPARTMENT OF CHEMICAL ENGINEERING

HOUSEHOLD FOLLOW UP

About 6 weeks ago, separate collection of household waste was introduced in your area on a pilot basis. We would like to know your concerns and comments on the performance of this waste collection system. Your answers to the few questions below would help in developing a system the best suits your community.

Thank you for your cooperation in taking time to answer these questions in order to help find solutions to the waste management problems that have plague our nation..

Area: ………………………. Date: ……………
House No. ………………….
PART 1- ABOUT YOURSELF
1. To which age group do you belong? Under 26 yrs ☐ 1 35-44 yrs ☐ 3 55-59 yrs ☐ 5 26-34 yrs ☐ 2 45-54 yrs ☐ 4 60 yrs and above ☐ 6
2. Are you? Male ☐ 1 Female ☐ 2
3. In your household, are you the? Father ☐ 1 Mother ☐ 2 Child ☐ 3 Other ☐ 4
PART 2- HOUSEHOLD PARTICIPATION IN WASTE COLLECTION SCHEME
4. Is your household separating their waste as proposed? Yes ☐ 1 No ☐\
5.If yes , What do you put in the red bin? .... What do you put in the yellow bin? ………………………… What do you put in the green bin? ………………………..
6. If No, to Q. 4, Why? Inconvenient/ no time ☐ 1 Storage/handling problems ☐ 3 Not interested ☐ 5 Too much effort ☐ 2 No need for separation at source ☐ 4 Other ☐ 6 Specify other ………………………………………………………………………………………………
7. If you are participating in the scheme, do you have any difficulty in identifying in which bin to

place any particular waste material? Yes ☐1 No ☐2 Please specify material …………………………………………………………………………………
8. Do you empty any of your bins between any of the collection days? Yes ☐1 No ☐2
9. Are there some particular wastes that you do not put in the bins? Yes ☐1 No ☐2
10. If yes, what are they? ………………….
11. If yes to Q8, Why? we burn them ☐1 we bury them ☐2 we reuse them at home ☐ 3 we sell them to itinerant buyers ☐4 Other ☐5 Specify other ………………………………………………………………..
12. Are you satisfied with the information provided for the collection Scheme? Yes ☐1 No ☐2
13. After participating in this collection scheme do you think it should be maintained and adopted throughout Kumasi? Yes ☐1 No ☐2
14. If no to Q14, why? ………………………………………………………………………………………… ………..
PART3- SUGGESTIONS FOR IMPROVING THE COLLECTION SCHEME
Please your comments and suggestions for the implementation of separate collection of household waste …………………………………………………………………………………………………… …………………………………………………………………………………………………… …………………………………………………………………………………………………… …………………………………………………………………………………………………… ………………………………………………………………

APPENDIX D: SORTING CATALOGUE AND DATA SHEET

Appendix D1: Material categories analyzed in the area

Categories	**Sub-categories**
Organic waste	Food waste and yard waste
Plastics	Rigid PET and PVC
	Rigid PE and PP
	Plastic films
	Other plastic waste
Paper and cardboards	Packaging
	Newspapers-magazines
	Office papers
	Other papers
	Cardboard packaging
	Other Cardboard
Glass	
Metals	
Textiles	
Others	Health care textiles (diapers, sanitary towels)
	Composite packaging materials (other packaging materials)
	Ink, paints, pastes, resins
	Batteries and accumulators, light bulbs
	Sand, ceramics, leather, Rubber
	Ash, charcoal, pieces of wood
	Other unclassified waste

Appendix D2: Data Sheet

WEEK/DATE: ……………………………………………

AREA/HSE #: ……………………………………………

ORGANIC BIN	Mon	Thurs
Total Organic		
Organic		
Plastic film		
PET & PVC rigid		
PE & PP rigid		
Other Plastics		
Metals		
Glass		
Paper		
Textiles		
Other Pack Mat.		
Others		

OTHERS BIN	Mon	Thurs
Total Others		
Metals		
Glass		
Paper		
Textiles		
Other Pack Mat.		
Others		
Organic		
Plastic film		
PET & PVC rigid		
PE & PP rigid		
Other Plastics		

PLASTIC BIN	Mon	Thurs
Total Plastic		
Plastic film		
PET & PVC rigid		
PE & PP rigid		
Other Plastics		
Organic		
Metals		
Glass		
Paper		
Other Pack Mat.		
Textiles		
Others		

APPENDIX E: PICTURES FROM STUDY

Appendix E1: Pictures from KNUST Study

A typical staff bungalow at Buroburo road (senior staff)

A typical staff bungalow at F-Line (junior staff)

Bins with stickers at the Junior Staff area

Delivery of Samples to the analysis site

A typical waste from F-Line (junior staff); note the presence of ash in the waste

Measuring the weight of a sample

Plastic waste contaminated with food waste

Appendix E2: Pictures from Asokwa Sub-Metro Study

Housing in the 1st Class Area: Asokwa

Housing in the 2nd Class Area: Atonsu

Housing in the 3rd Class Area: Ahinsan

Numbers on Participating Houses

Distribution of Bins to Households

Delivery of Collected Waste

Sorting of Waste Component

APPENDIX F: RESULTS

Appendix F1: Results from Preliminary Study and Calculation of Sample Size (KNUST-Campus)

House number	Waste collected, kg
F22	26.0
F10	7.6
F17	3.6
F58	9.7
F49	6.9
F66	9.9
F73	4.1
F45	6.1
C1	15.7
C2	2.1
B2	14.5
B3	10.6
B4	22.0
B6	4.2
B7	4.8
B8	11.3
B9	16.8
B10	26.1
B24	26.7
B25	9.5
B26	12.8
Fs1	6.8
Fs2	5.8
Fs3	5.0
Fs4	29.2
Fs5	11.7

Average moisture content 54.7% for junior staff area and 46.4% for senior staff area

Bulk Density: 314.3kg/m^3

Average waste, Household/week (x) – 11.9kg

Standard Deviation (σ) – 8.01

Relative standard deviation (s) – 0.67

Estimation of E as a percentage of the mean

% of *x*	**E**
5 % of x	0.595
10% of x	1.19
15% of x	1.785

Estimating n based on the formula: $n = \left[\frac{s.t}{e.x}\right]^2$ (Dahlén, 2005)

Degrees of freedom (n-1) = 26

Confidence level	**α/2**	**$t_{\alpha/2,n-1}$**	**n, e= 0.595**	**n, e= 1.19**	**n, e= 1.785**
90	0.05	1.706	529	133	59
95	0.25	2.056	768	192	86

Estimating n based on the formula:

$$n = \left[\frac{z_{\alpha/2}\sigma}{E}\right]^2$$

(Israel, 1992; DEFRA, 2004)

Confidence level	**α/2**	**$Z_{\alpha/2}$**	**n, e= 0.595**	**n, e= 1.19**	**n, e= 1.785**
90	0.05	1.645	492	123	55
95	0.25	1.96	698	174	78

Appendix F2: Waste Composition

Appendix F2.A Overall Waste composition for Staff areas

Material	Senior staff	Junior Staff	Total	%
Organic, kg	4478.35	3442.95	7921.3	69.19
Plastic Film, kg	319.85	325.2	645.05	5.63
PET & PVC Rigid, kg	26.4	23.95	50.35	0.44
PE &PP Rigid, kg	33.9	23.85	57.75	0.5
Other Plastics, kg	45	38.2	83.2	0.73
Other Pack. Mat., kg	34.6	31.5	66.1	0.58
Metals, kg	180.75	121.2	301.95	2.64
Glass, kg	109.35	43.35	152.7	1.33
Paper, kg	302.95	202.6	505.55	4.42
Others, kg	449.2	1013.5	1462.7	12.78
Textiles, kg	118.6	83.5	202.1	1.77
Total, kg	**6098.95**	**5349.8**	**11448.75**	

Appendix F2.B Overall Waste Composition for Asokwa Sub-metro

Material	Asokwa	Atonsu	Ahinsan	Total	%
Organic. Kg	6242.4	5687.55	1435.85	13365.8	54.39
Plastic Film, kg	559.05	535.95	231.05	1326.05	5.4
PET & PVC Rigid, kg	55.65	34.3	11.75	101.7	0.41
PE &PP Rigid, kg	53	50.95	9.1	113.05	0.46
Other Plastics, kg	49.15	55.8	15.2	120.15	0.49
Other Pack. Mat., kg	23.45	15.1	3.05	41.6	0.17
Metals, kg	223.05	164.5	31.5	419.05	1.71
Glass, kg	140.3	109.45	20.5	270.25	1.1
Paper, kg	341.15	269.15	72.45	682.75	2.78
Others, kg	2267.2	4257.75	1156.25	7681.2	31.26
Textiles, kg	141.05	193.9	118.2	453.15	1.84
Total, kg	10095.5	11374.4	3104.9	24574.8	100

Appendix F2.C Weekly Waste Composition Senior Staff

WEEK	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	285.25	16.2	2.75	2.9	1.45	2.45	8.8	5.9	13	21.65	1.55
2	289.55	28.25	0.95	1.7	1.35	3.1	20.6	5.25	12.95	16.5	7.65
3	297.95	21.7	1.35	2.15	2.6	2.55	9.9	12.55	21	42.15	2.7
4	325.65	20.15	0.75	3.25	1.8	2	24.25	4.85	10.2	30.25	6.9
5	349.3	19.3	2.15	1.45	1.8	2.15	9.95	4.5	15.1	25.4	10.85
6	276.75	18.95	1.75	1.4	2.95	2.2	10.15	5.2	24.85	29.1	13.85
7	276.5	16.9	1.6	1.4	2	2.05	8.1	5.05	12.05	19.95	3.7
8	221.05	15.5	2.15	1.85	2	2.1	8.6	2.55	11.3	13.55	8.05
9	227.95	15.5	0.8	3.3	2.85	2	9.4	4.2	23.25	22.95	6.5
10	236.75	14.3	0.55	1.75	0.95	1.75	7.4	5.65	12.9	16.35	3.25
11	217	15.25	1.25	1.7	2.7	2.1	9.15	4	14.3	14.95	2.1
12	231.7	19.4	1.15	1.4	3.25	1.4	7.75	4.15	17.8	32.8	8.1
13	172.05	15.55	1.3	2	3.1	1.3	7.3	8.15	16.25	39.65	8.3
14	199.55	15.05	1.15	1.55	2.9	0.85	8.2	3.35	20.85	25.95	3.7
15	196	17.1	1.8	3.15	5.2	1.7	7.8	10.05	23.85	32.1	8.6
16	230.3	18.75	1.75	1.05	4.1	2.5	8.75	11.45	17.95	19.4	5.4
17	221.25	13.5	1.55	0.4	1.4	1.5	8.25	3.45	10.7	22	8.5
18	223.8	18.5	1.65	1.5	2.6	0.9	6.4	9.05	24.65	24.5	8.9
Total, kg	**4478.35**	**319.85**	**26.4**	**33.9**	**45**	**34.6**	**180.75**	**109.35**	**302.95**	**449.2**	**118.6**
Average	248.8	17.77	1.47	1.88	2.5	1.92	10.04	6.08	16.83	24.96	6.59
Standard deviation	47.55	3.44	0.56	0.79	1.05	0.58	4.65	2.92	5.1	8.14	3.28
Overall Total	**6098.95**										
Percentage	**73.43**	**5.24**	**0.43**	**0.56**	**0.74**	**0.57**	**2.96**	**1.79**	**4.97**	**7.37**	**1.94**

Appendix F2.D Weekly Waste Composition Junior Staff

WEEK	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	150.6	14.9	1.2	0.85	2.65	1.6	7.15	1.25	9.35	46.35	1.5
2	187.7	24.4	1.1	2.1	1.15	3.3	6.8	2.7	12.7	68.5	3.95
3	212.35	18.25	1	1.3	0.6	1.5	7.15	3.7	11.7	78	5.75
4	210.95	16.4	0.6	1.4	1.3	2.1	6.3	1.2	11.9	60.7	5.4
5	222.5	18.2	0.9	1.6	2	0.85	6.05	1.75	12.45	64.3	5.55
6	278.55	29.65	3.2	1	1.4	7.5	11.4	2.4	20.2	63.75	4.15
7	216.05	18.3	0.5	1.5	2.4	1.45	5.9	2.9	14.3	76.35	5.95
8	196.75	18.15	0.55	1.9	1.85	1.1	6.2	3.2	14.7	66.25	5.3
9	198.3	16.4	8.5	3.15	1.85	1.9	7.5	3.3	12.65	62.35	4.25
10	214.2	16.45	0.7	1.6	1.55	1.1	7.95	4.45	9.65	76	7.5
11	174.95	18.6	0.6	0.9	3.45	1.8	7.15	2.3	9.35	50.5	4.7
12	190.35	17.15	0.45	0.9	4.2	0.95	8.6	1.7	9.7	43.35	7.4
13	161.35	16.6	0.5	0.5	2.55	1.2	5.9	1.65	7.15	39.6	3.8
14	169.3	15.15	1	1.4	2	1.25	5.05	1.4	6.05	30.3	4
15	152.7	15.5	0.35	0.7	2.05	0.7	4	2.4	8.2	35.95	3.3
16	163.95	15.8	1.2	1.2	2.15	1.3	6.95	1.8	12.45	48.95	5.4
17	164.15	14.25	0.9	0.6	2.25	1.3	5.8	0.85	8.35	58.1	3
18	178.25	21.05	0.7	1.25	2.8	0.6	5.35	4.4	11.75	44.2	2.6
Total, kg	**3442.95**	**325.2**	**23.95**	**23.85**	**38.2**	**31.5**	**121.2**	**43.35**	**202.6**	**1013.5**	**83.5**
Average, kg	191.28	18.07	1.33	1.33	2.12	1.75	6.73	2.41	11.26	56.31	4.64
Standard deviation, kg	31.71	3.75	1.9	0.63	0.84	1.56	1.6	1.08	3.28	14.47	1.57
Overall Total	**5349.8**										
Percentage	**64.36**	**6.08**	**0.45**	**0.45**	**0.71**	**0.59**	**2.27**	**0.81**	**3.79**	**18.94**	**1.56**

Appendix F2.E Weekly Waste Composition Asokwa

Week	Total	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	642.5	445.8	28.3	3.5	3.55	4.6	3.15	19.05	14.5	24.7	87.55	7.8
2	805.45	543.8	39.55	5.15	4.6	4.05	2.5	21	17.35	28.6	125.15	13.7
3	775.5	496.2	41.55	7.05	3.95	5.95	2.15	18.55	11.15	22.6	162.25	4.1
4	811.75	472.55	42.95	5.9	5.1	6.5	1.75	23	14.05	28.5	199.65	11.8
5	809	452.15	46.15	3.9	3.65	2.6	1.75	18.15	7	30.2	229.95	13.5
6	909.85	573.4	59.75	4.75	3.35	2.8	2.55	17.85	10.65	27.55	198.65	8.55
7	826.45	507.4	52.45	3.9	7.05	2.4	2.05	17.85	6.7	39.95	177	9.7
8	896.2	539.95	46.2	5.3	3.4	4.25	1.4	21.9	6.95	31.8	216.25	18.8
9	933.25	537.4	54.1	4.05	3.6	3.15	2.05	15.6	13.55	39	243.1	17.65
10	847.75	541.55	48.45	4.2	4.9	3.95	1.35	14.85	11.35	22.4	182.8	11.95
11	880.45	559.2	47	3.65	5.3	3.05	1.45	15.25	8.05	22.6	210.2	4.7
12	957.3	573	52.6	4.3	4.55	5.85	1.3	20	19	23.25	234.65	18.8
TOTAL, kg	**10095.45**	**6242.4**	**559.05**	**55.65**	**53**	**49.15**	**23.45**	**223.05**	**140.3**	**341.15**	**2267.2**	**141.05**
Average, kg	**841.29**	**520.2**	**46.59**	**4.64**	**4.42**	**4.1**	**1.95**	**18.59**	**11.69**	**28.43**	**188.93**	**11.75**
Standard deviation, kg	**84.46**	**44.74**	**8.13**	**1.05**	**1.08**	**1.39**	**0.57**	**2.59**	**4.12**	**6.07**	**46.08**	**5.04**
Percentage		**61.83**	**5.54**	**0.55**	**0.52**	**0.49**	**0.23**	**2.21**	**1.39**	**3.38**	**22.46**	**1.4**

Appendix F2.F Weekly Waste Composition Atonsu

Week	Total	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	544.25	325.4	22.35	1.5	4.65	2.85	1.85	10.1	9.95	10.9	150.95	3.75
2	879.1	463.05	37.9	3	3.85	3.75	2.1	14.85	8.3	22.6	305.3	14.4
3	1016.2	494.1	45.6	5.25	7.25	6.25	2.65	13.95	5.15	22.6	397.1	16.3
4	921.35	500.05	47	3.35	5.35	3.9	1.2	16.35	12.85	24.5	298.7	8.1
5	952.85	400.9	47.4	3.85	2.45	4.6	1.6	15.5	14.15	23.3	415.1	24
6	1088.85	538.6	49.9	3.55	5.05	3.3	1.45	16.75	12.1	24.5	403.85	29.8
7	1009	430.9	53.95	3.8	3.6	7.4	1.5	12.1	18	38.15	418.4	21.2
8	915.3	448.1	44.8	1.95	7.1	4.15	0.8	12.85	9.05	15.65	357.85	13
9	1051.9	532.9	49.05	2.2	2.7	5.5	0.6	16.5	5.9	21.25	398.9	16.4
10	896.65	444.45	40.45	2.25	2.7	7.35	0.55	11.3	4.4	20.7	342.3	20.2
11	1054.5	588.2	44.85	1.75	2.55	3.45	0.15	11.6	3.8	24.1	363.2	10.85
12	1044.45	520.9	52.7	1.85	3.7	3.3	0.65	12.65	5.8	20.9	406.1	15.9
TOTAL, kg	**11374.4**	**5687.55**	**535.95**	**34.3**	**50.95**	**55.8**	**15.1**	**164.5**	**109.45**	**269.15**	**4257.75**	**193.9**
Average, kg	**947.87**	**473.96**	**44.66**	**2.86**	**4.25**	**4.65**	**1.26**	**13.71**	**9.12**	**22.43**	**354.81**	**16.16**
Standard deviation, kg	**145.18**	**70.65**	**8.38**	**1.13**	**1.68**	**1.6**	**0.74**	**2.26**	**4.43**	**6.36**	**76.18**	**7.07**
Percentage		**50**	**4.71**	**0.3**	**0.45**	**0.49**	**0.13**	**1.45**	**0.96**	**2.37**	**37.43**	**1.7**

Appendix F2.G Weekly Waste Composition Ahinsan

Week	Total	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
2	283.75	139.45	17.9	0.95	2.1	1.3	0.4	2.9	1.55	5.75	104.1	7.35
3	259.85	129.6	17.35	1.7	0.4	2.15	0.55	2.3	0.4	7.1	87.1	11.2
4	288.55	128.55	17.1	0.85	0.6	1.4	0.2	8.45	4.4	9.4	100.3	17.3
5	312.1	127.3	21.85	1.85	0.6	2.85	0.75	2.65	1.45	8.7	129.55	14.55
6	311.9	142.75	24.5	1.6	1.2	1.25	0.4	2.4	2.55	8	121.9	5.35
7	280.9	125.95	28.9	1.05	0.7	1.4	0.05	2.75	1.55	8.85	102.85	6.85
8	270.25	107.6	21.55	1	0.9	1.55	0.15	2	0.9	4.9	119.95	9.75
9	224.1	102.1	16.3	1	0.4	0.25	0.1	1.65	2.85	4.65	83.35	11.45
10	215.2	104.05	16.75	1	0.8	0.7	0.05	2.3	1.45	5.55	60.9	21.65
11	313.75	173.65	23.2	0.4	0.95	1.05	0.1	1.55	0.75	4.8	100.95	6.35
12	344.55	154.85	25.65	0.35	0.45	1.3	0.3	2.55	2.65	4.75	145.3	6.4
TOTAL, kg	**3104.9**	**1435.85**	**231.05**	**11.75**	**9.1**	**15.2**	**3.05**	**31.5**	**20.5**	**72.45**	**1156.25**	**118.2**
Average, kg	**282.26**	**130.53**	**21**	**1.07**	**0.83**	**1.38**	**0.28**	**2.86**	**1.86**	**6.59**	**105.11**	**10.75**
Standard deviation, kg	**39**	**21.8**	**4.25**	**0.48**	**0.49**	**0.68**	**0.23**	**1.9**	**1.16**	**1.86**	**23.48**	**5.22**
Percentage		**46.24**	**7.44**	**0.38**	**0.29**	**0.49**	**0.1**	**1.01**	**0.66**	**2.33**	**37.24**	**3.81**

Appendix F3: Total Waste Collected from Households Each Week

Appendix F3.A Total Waste Collected from Households Each Week- KNUST

HOUSE #	HH Size	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
B-1	2	11.8	8.5	20.3	6.15	0.95	8.45	12.1	7.4	5.4	8	14.6	16	14.6	6.35	6.6	13.7	10.6	6.9
B-3	8	17.25	23.85	22.35	27.55	32.45	23.6	20.5	17.5	16	11	11.1	15.1	17.1	16.5	16.7	22.9	13.2	19
B-6	5	21.15	14.75	17.05	15.45	16	13.8	14.05	6.6	13	6.7	8.95	16.8	8.9	21.85	22.45	10	9.45	22.4
B-9	5	12.5	12.3	13.9	11.65	12.55	16.2	18.7	16.8	16	16	13	11	9.75	13.55	12.8	9.5	6.2	7
B-10	6	27.7	40.5	41.95	37.6	26.75	7.9	30.05	17.65	16	12	10.3	18.4	19.55	20.25	39.95	22.9	23.9	16.4
B-14	6	4.6	5.3	11	6.2	9.3	7.15	12	12.55	13	11	10.1	4.2	4.5	5.75	6.05	4.05	8.35	10.8
B-16	6	10.8	5.3	5.15	5.45	7.65	2.85	4.8	0.5	1.4	4.5	1.3		0.35	6.15	1.9	11.1	14.3	10.9
B-19	7	20	21.75	23.65	37.75	33.05	29.8	25.95	11.55	7.4	7.9	15.4	23.1	17.45	6.7	11.05	8.5	4.75	15.8
B-20	5	22.6	9.5	10.75	11.05	6.2	9.7	10.7	0.3	8.3									
B-21	6	11.1	11.8	11.2	14.3	13.8	7.1	12.15	10.7	12	8.7	6.3	10.2	10.2	5.35	11.85	8.4	5.15	12.7
B-23	3	9.2	2.9	10.3	7.75	2.75	3.65	4.2	4.4	1.2	2.5	1.5	1.9	3.85	2.1	3.15	8.15	2.8	5.3
B-25	6	8.45	7.85	12.6	9.9	9.45	16.1	10.15	8.8	8.4	9.3	12.3	14.9	10.35	11.8	8.75	14.1	11.5	7.85
Fs-8	1	6.35	2.1	4	3.9	3.9	1.95	2.55	6.8	7.5	1.9	4.5	1.2	1.5	1.85	14	4.95	0.85	1.5
Fs-9	4	24.35	30.75	29.2	27.9	45.4	27.2	33.2	23	30	26	29.3	26.2	21.45	20.85	35.3	43	34.5	30
Fs-10	3	11.7	9.1	5.5	8.4	5.15	10.5	7.9	5.5	5.3	15	9.9	6.75	3	5.8	5.5	8	7.35	6.05
Fs-11	5	18.85	17.35	25.35	26.95	28.75	23.9	18.35	16.55	15	28	37	33.2	12.45	20.45	22.15	25.1	13.6	12.4
F-24	4	10.85	12.25	11.9	6.55	6.2	16.1	8.55	13.7	9.8	7.3	5.95	9.3	7.25	6.15	6.9	9.1	6.95	8.3
F-25	7	13.85	12.35	15	16.85	13.6	17.5	11.4	10.85	9.7	11	6.6	9.1	8.25	9.05	14.8	10.6	11.3	10.9
F-26	8	5.4	10.5	15.9	9.8	10.95	10.4	16.1	9.45	8.6	8.5	9.85	9.85	9.15	14.8	9.6	14.2	9.2	10.8
F-27	7	11.9	13.8	10.4	14.95	13.65	17.8	10.15	6.8	11	8.7	9.35	10.7	9.05	14.2	12.8	13.5	14.2	11.6
F-28	4	10.8	10.95	10.65	11.45	6.05	9.9	10.5	12.85	8.1	16	11	6.95	10.1	5.15	6.2	10.8	4.75	9.5
F-30	7	12.4	15.2	17.7	16.65	14.7	18	17.2	10.25	17	17	14.8	15.3	15.3	13.5	12.55	14.4	15	21.4
F-31	9	5.05	14.6	11.95	13.3	6.7	14.2	5.45	8.85	13	11	14.8	10.8	9.25	7.9	8	8.35	11.5	12.9
F-33	8	17.15	23.65	22.65	21	29.65	30.6	24.7	26.95	17	12	10.5	13.6	12.7	12.25	10.25	10.3	10	9.25
F-42	3	6.35	5.55	6.35	6.3	12	6.65	7.6	5.2	2.4	4.3	2.2	3.9	4.3	5.9	2.6	2.55	2.05	1.5
F-43	5	4.45	14.45	8.5	11.1	5.05	11.5	3.4	8.8	15	11	10.1	17	8.35	10.95	12.2	9.5	9.9	11
F-46	7	7.65	7.35	6.85	5.85	17.5	8.65	5.8	5	4.4	7.5	5.1	7.15	6.9	5.7	7.15	7.15	7.6	

Appendix F3.A Continuation: Total Waste Collected from Households Each Week- KNUST

HOUSE #	HH Size	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
F-49	8	6.2	18.05	18.45	12.8	13.45	19.4	14.7	22.85	15	22	12.6	7.05	9.85	12.3	7.65	11	5.35	10.4
F-50	7	12.05	13.45	11.6	8.35	18	29.7	22.8	28.35	25	25	24.6	7.5	4.8	6.85	8.85	13.5	12.6	12.2
F-51	5	4.4	4.65	8.45	4.9	2.5	5.15	20.05	2.95	6.9	9.2	4.4	11.6	9.1	13.8	7.8	4.1	1.9	10.3
F-52	9	26.15	15.25	38.4	34.85	37.65	41.8	29.7	33.55	30	37	18.1	18.5	12.75	6.95	11.25	12.2	36.2	18.2
F-54	7	8.25	11	10.25	11.7	17	23.1	14.25	15.15	12	12	7.4	6.2	3.75	4.6	5.6	6.4	11.7	12.3
F-57	6	11.75	10.5	15	16.7	14.65	19.6	18.35	11.8	7.5	10	5.8	3	7.55	8.2	4.6	4.35	3.9	9
F-58	5	4.9	17.1	11.65	6.7	8.9	11.2	10.55	4.3	5.3	2.3	2.4	5.8	3.4	5.85	5.15	1.7	4.75	2.05
F-59	6	10.8	7.75	10.1	13.45	12.9	10.3	6.05	11.85	9.1	19	11.3	7.75	6.4	7	6.45	6.3	5.65	13.6
F-60	3	3.25	2.95	2.85	7.75	12.4	8.2	7.85	5.6	16	7.4	6.55	9.95	5.55	12.3	6.75	9.85	2.2	3.9
TOTAL	**213**	**443**	**479.5**	**552**	**529**	**552**	**570**	**521**	**441**	**437**	**444**	**402**	**409**	**338**	**364**	**410**	**420**	**374**	**398**
Ave W/HH/Wk		**11.7**	**12.62**	**14.5**	**13.9**	**14.5**	**15**	**13.7**	**11.6**	**12**	**12**	**11**	**11**	**9.14**	**9.83**	**11.1**	**11**	**10**	**11**
STDEV Waste/HH/Week		**6.61**	**7.8**	**8.59**	**9.09**	**10.4**	**8.9**	**7.84**	**7.56**	**7**	**7.5**	**7.3**	**6.9**	**4.9**	**5.3**	**7.98**	**7.5**	**7.7**	**6**
Ave HH size	**5.61**																		
W/Cap/Wk		2.1	2.3	2.6	2.5	2.6	2.7	2.4	2.1	2.1	2.1	1.9	1.9	1.6	1.7	1.9	2	1.8	1.9
W/Cap/Day		0.3	0.33	0.37	0.36	0.37	0.39	0.34	0.3	0.3	0.3	0.27	0.27	0.23	0.24	0.27	0.29	0.26	0.27
Ave W/Cap/Day		**0.3**																	

Appendix F3.B Total Waste Collected from Households Each Week- Asokwa Sub-Metro

HOUSE #	HH Size	1	2	3	4	5	6	7	8	9	10	11	12
1	3	29.2	29.6	19.7	26.4	38.45	30.05	22.4	31.3	7.8	23.45	22.15	26.4
2	3	13.45	11.7	7.55	7.75	7.85	40.4	9.7	11.65	10.9	17.1	10	15.55
3	7	31.3	28.1	33.1	23.8	28.55	42.3	26.8	24.95	39.1	33	48.35	61.45
4	4	20.2	17.05	55.9	30.95	37.25	38.45	29.35	36.8	17.65	40.05	31.1	32.45
5	9	37.9	21.7	19.45	12.75	16	15	16.2	35.45	34.15	41.65	37.4	42.75
6	10	22.6	33.85	28.8	35.15	39.8	34.05	54.35	24.5	34.6	25.4	6.5	15.5
7	5	21.05	17.2	19.85	12.85	3.55	8.5	3.9	43.7	11.6	5.2	7.55	13.45
8A	3	39.45	39.15	33.7	31.35	39.55	47.3	38.35	35.95	53.1	65.6	41.8	47.5
8B	16	25.55	27.5	22.5	31.05	17.95	28.65	25.8	35.3	29.3	34.1	43.35	45.5
8C	1	5.65	9.7	8.25	7.2	6.85	10.45	6.35	2.95	13.35	11.5	7	13.85
8D	7	16.35	12.5	23.25	35.9	17	20.55	25.7	18.5	19.1	16.05	8.7	23.95
8E	5	26.4	11.9	13.55	13.75	17.1	23.45	22.05	15.55	25.9	9.5	28.1	13.3
8F	6				4.85		6.9	20.5	22.3	22.2	25.2	23.3	26.55
9	5	16.8	23.85	33.7	35.15	35.4	24.15	39.55	31.15	29.65	28.05	2.65	4.2
10	6	44.3	65.9	34.15	55.95	58.95	47.8	73.7	55.45	66.05	8	24.95	38.25
11	5	29.9	37.25	32.15	25.8	31.7	19	23.95	25.8	23.4	25.3	26.8	36.8
13	4	6.05	13.9	23.45	13.6	11.45	26.85	5.95	13	20.25	27	30.05	22.3
14	3	3.65	15.85	6.15	15.3	4.65	16.8	20.75	31.6	26.3	39.9	46.45	15.95
16	7	8.75	10.65	20.15	25.65	19.35	29	24.35	22.5	16.45	7.5	15	19.15
17	7	4.2	15.85	24.5	14.85	24.7	16.9	20.5	19.1	33.2	26.2	28.65	28.5
18	8	65.7	84.3	78.9	64.6	49.05	55.75	65.45	74.95	84.4	51	61.75	68.45
19	2	23.05	41.5	46.7	40.4	35.8	53.3	40.2	46.7	64.8	49.2	54.75	55.75
20A	4	3.05	6.55	7.1	7.9	8.3	9.3	10.7	19.7	2.35	8.3	5	5.75
20B	2	18.2	18.15	16.65	18.7	21.1	23.45	22.95	21.45	16.6	4.35	15.65	18.75
20C	5	6.05	13.9	11.8	12.2	10.5	12.75	10.7	17.7	12.15	7.5	12.55	10
21B	4	4.15	4.55	4.1	5.5	8	27.2	7.8	6.6	7.6	6.65	7.35	16.75
23	15	29.35	42.85	47.35	68.15	54.55	78.5	51.5	49.8	58.05	71.5	55.2	49.65
24	5	5.6	10.3	27.9	9.25	10.25	4.95	8.4	12.6	15.85	15.05	25	22.05
25	10	23.4	37.7	37	42.2	37.05	27.95	22.8	32.2	26.4	35.8	51.75	73.55
26	9	6.4	36	8.95	26.6	37.35	37.55	30.3	28	45.1	47.75	29	42.75

Appendix F3.B Continuation: Total Waste Collected from Households Each Week- Asokwa Sub-Metro

HOUSE #	HH Size	1	2	3	4	5	6	7	8	9	10	11	12
36A	9		22.65	19.5	20.6	36.9	29.4	13.6	25.25	28.6	22.6	26.7	28.9
36B	6		31.65	26.45	26.5	30.25	34.9	19.7	29.6	33.45	27.65	45.05	39.95
36C	9	21.85	13.1	24.55	31.35	23.85	38.65	30.65	30.4	28.25	21.95	21.35	36.9
37	8	15.1	19.65	19.05	25	19.1	28.85	18.5	21.85	17.45	14.5	12.8	17.75
38	8	23.1	32.85	32.15	35.65	37.6	40.55	34.85	27.7	38.3	17.65	36.55	26.15
39	6	24.15	45.9	53.05	49.85	70.2	74.5	58.85	36.05	53.3	71.8	61.65	48.8
40	4	33.05	18.35	11.15	7.85	14	15.55	14.8	11.65	24.65	10.3	10.4	22.35
41	18	15.25	38.7	42.4	38.3	43.05	65.25	45.75	41.6	29.55	17.8	42.35	30.45
42A	6	19.75	25.8	21.55	14.4	14.9	52.45	24.95	25.4	33.25	19	38.2	19.9
42B	6	28.65	30.45	49.05	34.3	33.05	36.4	33.15	44.5	27.75	24.35	35.9	43.95
43B	11	5.7	28.1	22.65	29.85	17.8	33.9	27.15	26.5	29.3	15.5	17.65	21.25
44	2	19.45	15.85	15.3	18.95	17.55	22	26.85	30.45	18.1	19.95	32.3	24.85
45	2	9.9	10.8	11.6	11.2	20.65	23.1	13.45	10.3	11.2	12.6	23.45	14.75
46	9	36.3	67.2	80.2	74.3	85.5	109.95	134	80.25	93.5	63.25	77.15	80.3
47	11	32.3	41	40.35	37.95	33.7	26.6	19.75	18.65	38.5	14.8	38.9	38.5
48	6	2	3.35	1.65	2.15	2.05	1.95	3.55	1.45	6.2	2.95	2.95	1.65
49	13	33.7	57.35	87.8	60.15	78.6	56.8	68.75	55.2	77.4	33.75	55.05	67.35
50	5	5.5	27.35	18.6	14.1	25.25	25.75	20.75	15.15	30.4	17.95	16	34.55
51A	8	0	58.35	23.9	55.75	47.95	49.85	34.35	39.45	40.95	43.65	47.9	38.75
51B	2	8.25	14.15	33.5	10.95	13.8	19.75	62.65	30.95	28.55	26.4	27.35	26.05
51C	6	4.4		13.3	22	24.75	12.75	3.75		1.85	0.65	1.3	
52A	9	17.95	17.55	37.65	22.9	19.4	20.75	13.7	17.5	34.55	20.25	31.5	21.5
52B	6	8.7	31.1	19.8	8.95	11.45	10.85	17.3	11.65	23.65	17.05	16.1	34.05
53	6	20	23.65	25.85	27.55	13	13.75	23.9	18.15	39.6	16.75	16.05	12.25
54	14	14.8	16.75	9.95	15.25	11.25	16.8	16.6	20.25	29.6	17.1	22.15	29.95
55	8	8.95	12.45	20.55	15.6	14.35	9.6	14.95	17.4	3.8	25.4	26.45	22.6

Appendix F3.B Continuation: Total Waste Collected from Households Each Week- Asokwa Sub-Metro

HOUSE #	HH Size	1	2	3	4	5	6	7	8	9	10	11	12
56A	10	9.8	35.1	27.65	14.65	27.8	46.25	39.4	65.4	39.5	39.1	37.15	27.35
56B	7	33.3	13.65	38.55	31.1	31	18.55	26.1	25.35	36.9	50.3	52.55	27.35
56C	3	16.35	13.7	18.75	18.55	12.05	38.5	7.35	18.75	31.3	67.05	33.95	26.85
57	21	26.65	50.8	43.3	40.25	31.65	42.05	38.1	21.75	33.15	48.15	55.15	69.5
58	13	12.2	2	21.05	18.55	15.9	12.05	8.6	14.95	18.6	14.1	19.6	32.4
60	1	12.15	33	60.85	32.8	31.05	21.05	41.15	38.95	39.65	34.7	37	38
73	21		37.8	23.1	39.9	37.45	39.35	31.35	37.6	15.25	19	26.35	31.7
75	13		40.15	60.5	30.95	42.35	35.15	39.05	17.8	34.6	23.1	42.35	43.45
76	29		44.5	34.95	50.9	56.7	57.3	47.95	73.85	60.35	35.9	58.8	87.5
77	23		24.1	18.3	47.25	43.9	43.6	37.55	15.45	25.4	16.85	27.85	47.05
81	15		41.65	28.25	38.6	50.6	49.05	44.25	48.45	31.65	48.75	54.15	11.6
82	13		8.95	9.4	12.55	15.35	15.05	13.65	16.6	19.25	17	25.3	43.5
83	28		32.7	37.35	48.7	40.05	41.25	40.15	39.25	35.7	42.3	55.3	52.6
TOTAL	**592**	**1121.15**	**1890.5**	**2010.45**	**1957.45**	**1985.9**	**2253.45**	**2054.1**	**2024.55**	**2139.1**	**1910.1**	**2166.35**	**2286.55**
Ave W/HH/Wk		**18.69**	**27.01**	**28.72**	**27.57**	**28.37**	**31.74**	**28.93**	**28.51**	**30.13**	**26.9**	**30.51**	**32.2**
STDEV Waste/HH/Week		**12.58**	**16.89**	**17.78**	**16.43**	**17.46**	**18.96**	**20.53**	**16.46**	**18.43**	**17.11**	**17.14**	**18.46**
Ave HH size	**8.34**												
W/Cap/Wk		**2.7**	**3.3**	**3.4**	**3.3**	**3.4**	**3.8**	**3.5**	**3.5**	**3.6**	**3.2**	**3.7**	**3.9**
W/Cap/Day		0.39	0.47	0.49	0.47	0.49	0.54	0.5	0.5	0.51	0.46	0.53	0.56
Ave W/Cap/Day		**0.49**											

Appendix F3.C t-Test: Paired Two Sample for Means (Waste Generated, kg/cap/day): KNUST

	Senior Staff	*Junior staff*
Mean	0.38833333	0.257778
Variance	0.003885	0.002665
Observations	18	18
Pearson Correlation	0.236413	
Hypothesized Mean Difference	0	
df	17	
t Stat	7.810649	
P(T<=t) one-tail	2.52E-07	
t Critical one-tail	1.739606716	
P(T<=t) two-tail	5.05E-07	
t Critical two-tail	2.109816	

Appendix F3.D t-Test: Paired Two Sample for Means (Waste Generated, kg/cap/day): Asokwa and Atonsu

	Asokwa	*Atonsu*
Mean	0.629167	0.518333
Variance	0.003499	0.005779
Observations	12	12
Pearson Correlation	0.881094	
Hypothesized Mean Difference	0	
df	11	
t Stat	10.43484	
P(T<=t) one-tail	2.41E-07	
t Critical one-tail	1.795885	
P(T<=t) two-tail	4.82E-07	
t Critical two-tail	2.200985	

Appendix F3.E t-Test: Paired Two Sample for Means (Waste Generated, kg/cap/day): Asokwa and Ahinsan

	Asokwa	*Ahinsan*
Mean	0.641818	0.268182
Variance	0.001736	0.001576
Observations	11	11
Pearson Correlation	0.12913	
Hypothesized Mean Difference	0	
df	10	
t Stat	23.06951	
P(T<=t) one-tail	2.65E-10	
t Critical one-tail	1.812461	
P(T<=t) two-tail	5.29E-10	
t Critical two-tail	2.228139	

Appendix F3.F t-Test: Paired Two Sample for Means (Waste Generated, kg/cap/day k): Atonsu and Ahinsan

	Atonsu	*Ahinsan*
Mean	0.537273	0.268182
Variance	0.001622	0.001576
Observations	11	11
Pearson Correlation	0.421873	
Hypothesized Mean Difference	0	
df	10	
t Stat	20.75469	
P(T<=t) one-tail	7.47E-10	
t Critical one-tail	1.812461	
P(T<=t) two-tail	1.49E-09	
t Critical two-tail	2.228139	

Appendix F3.G Estimated Population and Annual HSW Generation for Kumasi

	Population	**Waste generation (t/yr)**
2008	1791916	320484.17
2009	1889934	338014.66
2010	1993313	356504.06
2011	2102347	376004.83
2012	2217346	396572.29
2013	2338635	418264.8
2014	2466558	441143.88
2015	2601479	465274.45
2016	2743780	490724.96
2017	2893864	517567.62

Appendix F3.H Monthly Waste Collection Service Coverage – 2008 (KMA- Waste Management Department

MONTH/ COMPANY	TONNAGE(METRIC TONNES)											
	KWML	**WASTEGROUP**	**MESKWORLD**	**ABC**	**ZOOMLION**	**ANTHOCO**	**OSBON**	**SAK-M**	**FREKO**	**KMA**	**PRIVATE**	**TOTAL**
JANUARY	4,306.58	1,554.00	5,508.99	1,323.30	14,470.02	48.98	3,312.60	217.86	1,270.92	825.80	315.22	**33,154.27**
FEBRUARY	7,900.06	707.56	6,411.57	1,279.94	10,670.36	110.24	203.68	657.53	715.02		371.44	**29,027.40**
MARCH	3,316.05	632.75	6,154.06	1,316.26	17,620.84	432.48	301.00	855.22	558.20		293.33	**31,480.19**
APRIL	7,319.45	598.34	3,532.81	894.73	15,009.29	367.46	156.99	835.62	556.89		472.10	**29,743.68**
MAY	9,118.78	727.72	3,254.15	576.84	7,777.68	334.80		1,148.16	544.66	285.58	668.60	**24,436.97**
JUNE	1,679.30	3,382.50	9,686.24	1,041.62	22,893.07	614.92		1,144.98	601.60	349.45	650.32	**42,044.00**
JULY	2,157.30	1,208.76	5,669.69	1,153.32	17,536.37	1,161.48		1,074.94	582.22	129.88	608.72	**31,282.68**
AUGUST	1,544.28	1,154.68	7,157.67	1,147.86	12,112.91	1,602.88		830.08	530.41	58.28	612.92	**26,751.97**
SEPTEMBER	1,692.00	960.32	7,865.69	1,280.22	16,252.36	316.40		1,118.22	472.10	210.22	529.67	**30,697.20**
OCTOBER	13,589.74	886.10	3,523.78	1,423.64	15,462.89	1,265.90		1,360.05	701.86	140.28	761.48	**39,115.72**
NOVEMBER	4,514.14	630.76	3,669.44	1,215.84	10,518.71	1,074.08		1,178.80	629.66	226.94	578.74	**24,237.11**
DECEMBER	11,492.88	458.50	2,865.98	1,250.64	9,560.96	767.58		1,347.96	728.86	25.94	1,098.26	**29,597.56**
TOTAL	**68,630.56**	**12,901.99**	**65,300.07**	**13,904.21**	**169,885.46**	**8,097.20**	**3,974.27**	**11,769.42**	**7,892.40**	**2,252.37**	**6,960.80**	**371,568.75**

Appendix F4: Weekly Level of Compliance

Appendix F4.A Weekly Level of Compliance for Organic Waste: KNUST

	SENIOR STAFF				JUNIOR STAFF				OVERALL			
Week	**Excellent**	**Good**	**Fair**	**Poor**	**Excellent**	**Good**	**Fair**	**Poor**	**Excellent**	**Good**	**Fair**	**Poor**
1	50	25	25	0	32	36	32	0	40.82	30.61	28.57	0
2	28	52	16	4	29.63	48.15	22.22	0	28.85	50	19.23	1.92
3	28	44	24	4	25.93	51.85	18.52	3.7	26.92	48.08	21.15	3.85
4	32	52	12	4	22.22	48.15	29.63	0	26.92	50	21.15	1.92
5	36	40	24	0	18.52	62.96	14.81	3.7	26.92	51.92	19.23	1.92
6	32	52	16	0	23.08	50	23.08	3.85	27.45	50.98	19.61	1.96
7	50	45.83	4.17	0	33.33	48.15	18.52	0	41.18	47.06	11.76	0
8	41.67	41.67	16.67	0	32.14	42.86	25	0	36.54	42.31	21.15	0
9	32	40	28	0	25.93	40.74	29.63	3.7	28.85	40.38	28.85	1.92
10	52.17	34.78	13.04	0	21.43	50	28.57	0	35.29	43.14	21.57	0
11	40.91	40.91	18.18	0	33.33	40.74	25.93	0	36.73	40.82	22.45	0
12	35	45	20	0	32.14	46.43	17.86	3.57	33.33	45.83	18.75	2.08
13	39.13	39.13	21.74	0	22.22	51.85	25.93	0	30	46	24	0
14	33.33	50	16.67	0	35.71	39.29	25	0	34.62	44.23	21.15	0
15	30.43	47.83	21.74	0	22.22	55.56	18.52	3.7	26	52	20	2
16	21.74	47.83	30.43	0	28.57	28.57	39.29	3.57	25.49	37.25	35.29	1.96
17	30.43	43.48	26.09	0	33.33	40.74	25.93	0	32	42	26	0
18	26.09	47.83	26.09	0	26.92	42.31	30.77	0	26.53	44.9	28.57	0
Average, %	**35.49**	**43.85**	**19.99**	**0.67**	**27.7**	**45.8**	**25.07**	**1.43**	**31.36**	**44.86**	**22.69**	**1.09**
Standard deviation	**8.62**	**6.83**	**6.56**	**1.53**	**5.22**	**7.85**	**6.12**	**1.85**	**5.13**	**5.55**	**5.23**	**1.2**
Min	**21.74**	**25**	**4.17**	**0**	**18.52**	**28.57**	**14.81**	**0**	**25.49**	**30.61**	**11.76**	**0**
Max	**52.17**	**52**	**30.43**	**4**	**35.71**	**62.96**	**39.29**	**3.85**	**41.18**	**52**	**35.29**	**3.85**

Appendix F4.B Weekly Level of Compliance for Plastic Waste: KNUST

	SENIOR STAFF				JUNIOR STAFF				OVERALL			
Week	**Excellent**	**Good**	**Fair**	**Poor**	**Excellent**	**Good**	**Fair**	**Poor**	**Excellent**	**Good**	**Fair**	**Poor**
1	40	0	30	30	18.18	0	13.64	68.18	28.57	0	21.43	50
2	36.84	5.26	26.32	31.58	32	8	40	20	34.09	6.82	34.09	25
3	16.67	0	38.89	44.44	33.33	0	37.04	29.63	26.67	0	37.78	35.56
4	29.41	11.76	17.65	41.18	24	4	48	24	26.19	7.14	35.71	30.95
5	22.22	5.56	27.78	44.44	28.57	0	52.38	19.05	25.64	2.56	41.03	30.77
6	27.78	11.11	27.78	33.33	22.22	7.41	29.63	40.74	24.44	8.89	28.89	37.78
7	33.33	6.67	40	20	34.78	4.35	34.78	26.09	34.21	5.26	36.84	23.68
8	23.81	0	28.57	47.62	45.83	0	33.33	20.83	35.56	0	31.11	33.33
9	30	0	40	30	26.92	0	42.31	30.77	28.26	0	41.3	30.43
10	23.53	5.88	29.41	41.18	40	4	44	12	33.33	4.76	38.1	23.81
11	30	0	40	30	33.33	8.33	29.17	29.17	31.82	4.55	34.09	29.55
12	42.11	5.26	21.05	31.58	37.5	12.5	29.17	20.83	39.53	9.3	25.58	25.58
13	47.06	0	29.41	23.53	40.74	7.41	29.63	22.22	43.18	4.55	29.55	22.73
14	30	10	40	20	37.04	0	37.04	25.93	34.04	4.26	38.3	23.4
15	45	10	15	30	39.13	4.35	39.13	17.39	41.86	6.98	27.91	23.26
16	33.33	13.33	26.67	26.67	28	0	44	28	30	5	37.5	27.5
17	35.29	5.88	29.41	29.41	38.1	4.76	23.81	33.33	36.84	5.26	26.32	31.58
18	28.57	0	35.71	35.71	41.67	0	37.5	20.83	36.84	0	36.84	26.32
Average, %	**31.94**	**5.04**	**30.2**	**32.82**	**33.41**	**3.62**	**35.81**	**27.17**	**32.84**	**4.19**	**33.47**	**29.51**
Standard deviation	**8.11**	**4.74**	**7.69**	**8.18**	**7.47**	**3.88**	**9.21**	**12.2**	**5.59**	**3.12**	**5.73**	**6.8**
Min	**16.67**	**0**	**15**	**20**	**18.18**	**0**	**13.64**	**12**	**24.44**	**0**	**21.43**	**22.73**
Max	**47.06**	**13.33**	**40**	**47.62**	**45.83**	**12.5**	**52.38**	**68.18**	**43.18**	**9.3**	**41.3**	**50**

Appendix F4.C Weekly Level of Compliance for Other Waste: KNUST

	SENIOR STAFF				JUNIOR STAFF				OVERALL			
Week	**Excellent**	**Good**	**Fair**	**Poor**	**Excellent**	**Good**	**Fair**	**Poor**	**Excellent**	**Good**	**Fair**	**Poor**
1	8.7	21.74	26.09	43.48	0	16	48	36	4.17	18.75	37.5	39.58
2	13.64	18.18	31.82	36.36	0	7.69	65.38	26.92	6.25	12.5	50	31.25
3	12	24	40	24	8	4	64	24	10	14	52	24
4	13.64	18.18	27.27	40.91	12	8	52	28	12.77	12.77	40.43	34.04
5	8.33	12.5	50	29.17	16	16	36	32	12.24	14.29	42.86	30.61
6	8.7	17.39	39.13	34.78	11.54	7.69	57.69	23.08	10.2	12.24	48.98	28.57
7	8.7	13.04	26.09	52.17	7.41	25.93	44.44	22.22	8	20	36	36
8	5	30	15	50	3.85	19.23	57.69	19.23	4.35	23.91	39.13	32.61
9	18.18	9.09	50	22.73	11.54	15.38	46.15	26.92	14.58	12.5	47.92	25
10	9.52	14.29	33.33	42.86	14.81	7.41	59.26	18.52	12.5	10.42	47.92	29.17
11	13.04	13.04	34.78	39.13	4	12	60	24	8.33	12.5	47.92	31.25
12	13.64	4.55	40.91	40.91	4	20	48	28	8.51	12.77	44.68	34.04
13	9.52	19.05	52.38	19.05	15.38	38.46	19.23	26.92	12.77	29.79	34.04	23.4
14	19.05	0	66.67	14.29	20	8	40	32	19.57	4.35	52.17	23.91
15	14.29	19.05	38.1	28.57	16	8	52	24	15.22	13.04	45.65	26.09
16	10	15	45	30	16	16	48	20	13.33	15.56	46.67	24.44
17	8.7	17.39	56.52	17.39	16	12	52	20	12.5	14.58	54.17	18.75
18	21.74	8.7	26.09	43.48	4.35	17.39	43.48	34.78	13.04	13.04	34.78	39.13
Average,%	**12.02**	**15.29**	**38.84**	**33.85**	**10.05**	**14.4**	**49.63**	**25.92**	**11.02**	**14.83**	**44.6**	**29.55**
Standard deviation	**4.34**	**7.02**	**12.95**	**11.26**	**6.22**	**8.28**	**11.09**	**5.25**	**3.94**	**5.52**	**6.29**	**5.78**
Min	**5**	**0**	**15**	**14.29**	**0**	**4**	**19.23**	**18.52**	**4.17**	**4.35**	**34.04**	**18.75**
Max	**21.74**	**30**	**66.67**	**52.17**	**20**	**38.46**	**65.38**	**36**	**19.57**	**29.79**	**54.17**	**39.58**

Appendix F4.D Weekly Level of Compliance for Organic Waste: Asokwa Sub-Metro

	ASOKWA				ATONSU				AHINSAN			
Week	**Excellent**	**Good**	**Fair**	**Poor**	**Excellent**	**Good**	**Fair**	**Poor**	**Excellent**	**Good**	**Fair**	**Poor**
1	9.09	39.39	42.42	9.09	13.33	10	53.33	23.33				
2	9.09	27.27	60.61	3.03	9.38	18.75	50	21.88	0	25	25	50
3	12.12	21.21	51.52	15.15	9.38	12.5	62.5	15.63	25	0	62.5	12.5
4	0	22.58	64.52	12.9	6.06	15.15	57.58	21.21	0	25	37.5	37.5
5	3.13	15.63	62.5	18.75	3.03	12.12	48.48	36.36	0	12.5	12.5	75
6	6.45	19.35	64.52	9.68	9.38	9.38	50	31.25	12.5	0	75	12.5
7	3.13	28.13	53.13	15.63	9.68	3.23	51.61	35.48	0	25	25	50
8	0	30.3	48.48	21.21	9.38	18.75	37.5	34.38	0	25	37.5	37.5
9	2.94	8.82	67.65	20.59	12.12	12.12	39.39	36.36	0	25	37.5	37.5
10	9.68	16.13	61.29	12.9	6.25	18.75	50	25	0	12.5	50	37.5
11	6.67	26.67	56.67	10	6.25	15.63	59.38	18.75	0	12.5	62.5	25
12	6.06	21.21	51.52	21.21	6.25	18.75	43.75	31.25	0	14.29	42.86	42.86
Average, %	**5.7**	**23.06**	**57.07**	**14.18**	**8.37**	**13.76**	**50.29**	**27.57**	**3.41**	**16.07**	**42.53**	**37.99**
Standard deviation	**3.9**	**7.99**	**7.68**	**5.68**	**2.89**	**4.83**	**7.53**	**7.44**	**8.08**	**9.78**	**18.71**	**17.75**
Min	**0**	**8.82**	**42.42**	**3.03**	**3.03**	**3.23**	**37.5**	**15.63**	**0**	**0**	**12.5**	**12.5**
Max	**12.12**	**39.39**	**67.65**	**21.21**	**13.33**	**18.75**	**62.5**	**36.36**	**12.5**	**14.29**	**75**	**75**

Appendix F4.E Weekly Level of Compliance for Plastic Waste: Asokwa Sub-Metro

	ASOKWA				ATONSU				AHINSAN			
Week	**Excellent**	**Good**	**Fair**	**Poor**	**Excellent**	**Good**	**Fair**	**Poor**	**Excellent**	**Good**	**Fair**	**Poor**
1	18.18	0	30.3	51.52	14.81	0	33.33	51.85				
2	9.38	6.25	37.5	46.88	9.38	9.38	25	56.25	0	0	50	50
3	12.9	9.68	29.03	48.39	12.9	0	22.58	64.52	0	0	25	75
4	12.12	3.03	33.33	51.52	12.12	0	33.33	54.55	0	0	12.5	87.5
5	13.33	10	30	46.67	18.18	0	24.24	57.58	0	0	25	75
6	3.13	12.5	25	59.38	19.35	3.23	19.35	58.06	0	12.5	25	62.5
7	17.24	6.9	44.83	31.03	9.38	3.13	25	62.5	12.5	0	25	62.5
8	19.35	3.23	29.03	48.39	19.35	3.23	22.58	54.84	0	0	25	75
9	9.68	0	25.81	64.52	19.35	3.23	19.35	58.06	12.5	0	25	62.5
10	7.14	0	25	67.86	11.76	2.94	35.29	50	0	0	12.5	87.5
11	3.13	9.38	21.88	65.63	12.9	3.23	19.35	64.52	0	0	25	75
12	12.5	6.25	9.38	71.88	12.12	6.06	18.18	63.64	0	0	12.5	87.5
Average, %	**11.51**	**5.6**	**28.42**	**54.47**	**14.3**	**2.87**	**24.8**	**58.03**	**2.27**	**1.14**	**23.86**	**72.73**
Standard deviation	**5.33**	**4.34**	**8.62**	**11.64**	**3.82**	**2.8**	**6.02**	**4.9**	**5.06**	**3.77**	**10.39**	**12.27**
Min	**3.13**	**0**	**9.38**	**31.03**	**9.38**	**0**	**18.18**	**50**	**0**	**0**	**12.5**	**50**
Max	**19.35**	**12.5**	**44.83**	**7.88**	**19.35**	**9.38**	**35.29**	**64.52**	**12.5**	**12.5**	**50**	**87.5**

Appendix F4.F Weekly Level of Compliance for Other Waste: Asokwa Sub-Metro

	ASOKWA				ATONSU				AHINSAN			
Week	**Excellent**	**Good**	**Fair**	**Poor**	**Excellent**	**Good**	**Fair**	**Poor**	**Excellent**	**Good**	**Fair**	**Poor**
1	24.24	3.03	36.36	36.36	13.33	13.33	33.33	40				
2	21.88	9.38	37.5	31.25	16.13	16.13	41.94	25.81	12.5	12.5	62.5	12.5
3	21.88	21.88	18.75	37.5	20.59	5.88	44.12	29.41	25	12.5	50	12.5
4	17.65	5.88	35.29	41.18	21.88	12.5	40.63	25	12.5	0	75	12.5
5	18.75	12.5	40.63	28.13	22.58	25.81	35.48	16.13	25	12.5	62.5	0
6	17.65	11.76	38.24	32.35	25	9.38	40.63	25	12.5	25	50	12.5
7	15.15	15.15	36.36	33.33	18.18	15.15	39.39	27.27	12.5	12.5	62.5	12.5
8	9.38	15.63	46.88	28.13	30	16.67	26.67	26.67	12.5	12.5	62.5	12.5
9	24.24	12.12	33.33	30.3	12.9	16.13	29.03	41.94	0	25	37.5	37.5
10	20	13.33	33.33	33.33	29.03	6.45	35.48	29.03	12.5	25	37.5	25
11	16.67	10	33.33	40	34.38	9.38	31.25	25	0	0	57.14	42.86
12	12.5	3.13	46.88	37.5	25	6.25	34.38	34.38	0	0	87.5	12.5
Average, %	**18.33**	**11.15**	**36.41**	**34.11**	**22.42**	**12.76**	**36.03**	**28.8**	**11.36**	**12.5**	**58.6**	**17.53**
Standard deviation	**4.53**	**5.41**	**7.28**	**4.38**	**6.69**	**5.77**	**5.43**	**7.07**	**8.76**	**9.68**	**14.85**	**12.57**
Min	**9.38**	**3.03**	**18.75**	**28.13**	**12.9**	**5.88**	**26.67**	**16.13**	**0**	**0**	**37.5**	**0**
Max	**24.24**	**21.88**	**46.88**	**41.18**	**34.38**	**25.81**	**44.12**	**41.94**	**25**	**25**	**87.5**	**42.86**

Appendix F5: Separation Efficiency and Level of Contamination

Appendix F5.A Separation Efficiency and Level of Contamination: Organic Bin-Senior Staff Area (KNUST)

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	94.33	2.09	0.15	0.06	0.08	0.29	0.38	0.44	1.64	0.42	0.11
2	92.7	4.04		0.08	0.02	0.14	1.65	0.06	0.5	0.62	0.2
3	90.37	2.67	0.04	0.04	0.04	0.02	0.53	0.72	1.79	3.72	0.06
4	90.83	2.56		0.14	0.12	0.07	5.21	0.02	0.59	0.43	0.03
5	95.83	2.22	0.14		0.15	0.05	0.19		1.07	0.27	0.09
6	96.27	1.78	0.06		0.06	0.02	0.22	0.08	1.18	0.34	
7	97.21	1.52		0.02	0.07	0.07	0.28	0.07	0.55	0.21	
8	95.31	1.83	0.11	0.03	0.14	0.03	0.59	0.06	1.04	0.81	0.06
9	95.17	1.97	0.13	0.13	0.1	0.13	0.45		1.13	0.63	0.16
10	95.77	1.56		0.08	0.03	0.08	0.36	0.23	0.81	1.09	
11	95.43	2.02	0.03	0.03		0.17	0.77		1.08	0.36	0.11
12	92.97	2.72	0.1	0.05	0.33	0.03	0.76	0.31	1.25	1.09	0.38
13	93.74	2.58	0.13		0.27	0.07	0.44	0.07	1	1.04	0.67
14	93.21	2.96	0.21		0.16	0.24	0.42		1.4	1.4	
15	91.85	3.47	0.14	0.11	0.5	0.19	0.83	0.22	1.27	0.96	0.47
16	90.29	3.25	0.26	0.09	0.23	0.21	0.91	2.22	1.8	0.61	0.12
17	93.73	2.82	0.22			0.11	0.52	0.69	1.3	0.22	0.39
18	93	2.57	0.13	0.13	0.1	0.03	0.86	1.55	0.86	0.57	0.21
Average	**93.78**	**2.48**	**0.13**	**0.08**	**0.15**	**0.11**	**0.85**	**0.48**	**1.13**	**0.82**	**0.22**
Overall % Organic	**93.78**										
Overall % Contamination	**6.45**										

Appendix F5.B Separation Efficiency and Level of Contamination: Organic Bin-Junior Staff Area (KNUST)

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	92.05	1.91	0.22	0	0.19	0.19	1.01	0.07	0.3	3.97	0.07
2	92.21	2.74	0.07	0.07	0.1	0.3	0.67	0	1.07	2.54	0.23
3	93.85	1.21		0.08			0.85	0.45	0.73	2.71	0.11
4	93.54	1.77	0.03	0.06	0.14	0.14	0.87	0	1.26	2.05	0.14
5	95.79	1.64	0.03	0.03	0.08	0.05	0.79	0.11	0.66	0.82	0
6	93.13	2.14	0.06	0.19	0.36	0.02	1.24	0	1.63	0.92	0.3
7	93.94	1.67	0.05	0.13	0.16	0.05	0.82	0.26	0.87	1.88	0.16
8	93.64	1.5	0.13	0.03	0.16	0.13	1.12	0.22	0.73	2.2	0.13
9	88.26	1.53	4.83	0.03	0.24	0.09	1.19	0.43	0.98	2.38	0.03
10	93.03	1.64	0.03	0.06	0.23	0.14	1.16	0.17	0.76	2.71	0.08
11	92.2	2.25	0	0	0.1	0.07	0.82	0.13	1.5	2.87	0.07
12	90.33	2.86		0.05	0.3	0.14	0.82	0.22	1.7	3.38	0.19
13	92.4	3.07	0.03	0.03	0.21	0.1	1.22	0.07	1.05	1.5	0.31
14	94.77	2	0			0.06	0.58	0	0.89	1.32	0.37
15	93.58	2.44		0	0.07	0.04	1.06	0.53	1.06	0.71	0.53
16	90.9	1.87	0.03	0.07	0.23	0.1	1.38	0.16	1.44	3.18	0.65
17	93.35	1.84	0.14	0.04	0.25	0.07	1.34	0	0.72	2.24	
18	93.51	2.3	0	0.18	0.55	0.04	1.09	0	0.8	1.31	0.22
Average	**92.8**	**2.02**	**0.38**	**0.06**	**0.21**	**0.1**	**1**	**0.16**	**1.01**	**2.15**	**0.21**
Overall % Organic	**92.8**										
Overall % Contamination	**7.3**										

Appendix F5.C Separation Efficiency and Level of Contamination: Plastic Bin-Senior Staff Area (KNUST)

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	31.17	28.31	10.39	9.09	0.52	2.86	3.9	3.64	6.49	2.34	1.3
2	22.49	51.78	4.14	2.96	2.96	2.37	4.14	0.59	3.85	4.73	0
3	33.44	19.55	2.1	2.42	5.33	1.78	4.36	2.58	15.51	12.92	0
4	33.81	26.9	0.95	3.33	2.86	2.62	5.48	9.05	5.24	8.33	1.43
5	22.78	32.59	4.43	5.06	3.8	1.58	4.43	7.91	8.54	8.54	0.32
6	19.92	29.25	4.77	1.45	6.22	1.87	4.15	2.7	10.58	17.63	1.45
7	3.54	47.98	5.56	2.02	5.05	5.56	6.57	0	8.59	12.63	2.53
8	35.19	25.75	5.36	6.01	3.22	2.15	3	0	8.8	7.3	3.22
9	17.19	42.58	1.56	3.13	9.38	1.95	6.25	1.95	9.38	5.47	1.17
10	32.65	35.37	1.02	4.08	1.02	3.06	5.44	3.4	8.5	4.76	0.68
11	20.22	41.91	4.41	1.47	5.51	2.21	4.04	0.74	9.56	9.93	0
12	42.49	30.23	0.63	0.85	0.42	0.85	1.06	0.21	2.33	15.64	5.29
13	49.85	30.32	0.87	1.75	5.25	1.46	1.46	0.29	3.5	4.66	0.58
14	1.67	43.75	2.5	3.75	3.75	0.42	5	0.42	35.83	2.92	0
15	6.13	34.48	6.9	5.36	5.36	0.77	4.6	14.56	6.51	13.41	1.92
16	6.25	39.45	3.13	1.56	15.23	0.39	2.34	0	15.63	10.94	5.08
17	30.33	28.67	1.33	0.67	1	1.33	3.33	0	10	17.33	6
18	35.2	30.93	1.87	0.8	6.93	0	1.6	0	4.8	15.47	2.4
Average	**24.68**	**34.43**	**3.44**	**3.1**	**4.66**	**1.85**	**3.95**	**2.67**	**9.65**	**9.72**	**1.85**
Overall % Plastics	**45.63**										
Overall % Contamination	**54.37**										

Appendix F5.D Separation Efficiency and Level of Contamination: Plastic Bin-Junior Staff Area (KNUST)

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	29.26	28.6	1.97	0.66	1.31	3.06	7.86	0.66	8.52	17.25	0.87
2	3.5	59.18	1.46	1.46	2.92	4.96	7.29	0	12.24	6.71	0.29
3	8.09	43.86	2.87	2.61	1.04	3.66	7.05	0.26	10.44	19.06	1.04
4	15.36	41.67	2.08	2.6	1.56	6.25	5.73	2.6	9.9	11.72	0.52
5	15.29	44.47	1.65	2.35	4.24	2.59	4.47	2.82	11.76	8.71	1.65
6	9.94	48.93	4.43	0.15	0.46	8.26	4.28	4.13	9.79	8.72	0.92
7	8.06	49.53	1.42	1.66	2.37	3.79	2.13	1.18	9.48	19.19	1.18
8	17.5	44.55	0.45	2.73	1.82	1.36	2.5	0.68	7.95	18.86	1.59
9	11.28	46.59	2.67	6.82	1.19	2.08	2.67	0	9.5	15.73	1.48
10	6.95	56.95	2.32	2.32	2.32	1.99	3.31	2.98	11.92	8.28	0.66
11	13.3	49.51	1.97	2.46	4.93	5.17	4.68	3.94	6.65	5.67	1.72
12	7.58	49.27	0.58	3.21	13.12	2.04	3.21	4.66	3.5	11.66	1.17
13	18.42	42.58	1.44	1.2	6.46	1.44	1.44	0.96	8.85	15.79	1.44
14	7.96	46.14	3.28	3.98	4.45	2.34	2.81	3.51	7.96	14.99	2.58
15	10.19	53.5	0.96	1.91	7.01	0.64	4.46	0	7.64	11.78	1.91
16	16.95	39.75	4.39	1.67	4.39	1.88	3.35	0	9.62	12.97	5.02
17	13.96	41.6	2.56	1.14	4.56	2.28	2.28	0.85	8.55	17.38	4.84
18	10.83	53.56	1.99	1.14	1.14	2.28	2.56	0.57	13.68	12.25	0
Average	**12.47**	**46.68**	**2.14**	**2.23**	**3.63**	**3.12**	**4**	**1.66**	**9.33**	**13.15**	**1.6**
Overall % Plastics	**54.68**										
Overall % Contamination	**45.33**										

Appendix F5.ESeparation Efficiency and Level of Contamination: Others Bin-Senior Staff Area (KNUST)

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	39.26	6.51	0.44	1.25	1.44	1.44	8.83	5.07	9.33	25.17	1.25
2	44.08	7.82	0.21	0.84	0.67	1.97	13.17	4.18	9.24	11.84	5.98
3	47.5	6.44	0.42	0.91	0.6	1.37	5.1	7.04	8.34	20.48	1.79
4	46.69	5.91	0.46	1.79	0.71	1.04	6.71	2.42	6.16	22.7	5.41
5	49.44	5.7	0.78	0.48	0.56	1.3	6.44	2.41	7.88	17.21	7.81
6	27.3	6.63	0.4	0.93	1.16	1.51	7.65	3.87	17.21	21.34	12.01
7	53.31	7.22	0.86	0.94	1.1	1.1	5.59	4	8.16	14.9	2.82
8	49.46	7.15	0.8	0.46	1.14	1.77	7.83	2.8	8.46	11.89	8.23
9	38.52	5.46	0.3	2.3	1.26	1.3	6.72	3.42	17.24	18.24	5.24
10	50.45	6.46	0.42	1.06	0.79	1.22	6.25	4.98	10.69	14.35	3.34
11	46.37	6.54	0.66	1.61	2.16	1.66	7.98	4.32	12.24	14.35	2.11
12	35.88	6.34	0.73	1.01	2.3	1.06	5.51	3.22	13.6	24.76	5.6
13	21.63	6	0.88	1.57	1.66	0.88	5.9	7.38	13.05	34.41	6.64
14	28.08	5.13	0.55	1.34	2.63	0.43	8.3	4.03	16.97	28.02	4.52
15	25.13	5.6	0.58	2	3.2	1.11	5.06	6.88	18.38	25.4	6.66
16	38.45	7.12	0.84	0.69	1.74	2.11	6.86	7.07	12.76	17.62	4.75
17	48.76	4.25	0.98	0.31	1.3	1.14	7.05	2.28	7.1	19.69	7.15
18	34.09	7	0.95	0.99	0.99	0.77	4.02	5.46	19.95	18.51	7.27
Average	**40.24**	**6.29**	**0.63**	**1.14**	**1.41**	**1.29**	**6.94**	**4.49**	**12.04**	**20.05**	**5.48**
Overall % Others	**50.29**										
Overall % Contamination	**49.71**										

Appendix F5.F Separation Efficiency and Level of Contamination: Others Bin-Junior Staff Area (KNUST)

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	26.06	7.15	0.55	0.86	2.59	0.8	4.93	1.23	8.63	45.72	1.48
2	33.33	6.87	0.51	1.18	0.34	1.35	3.08	1.83	6.09	43.01	2.4
3	30.7	5.31	0.31	0.45	0.28	0.55	2.97	1.97	5.8	47.98	3.69
4	34.34	4.33	0.12	0.66	0.62	0.54	3.01	0.58	6.4	45.23	4.17
5	33.47	4.35	0.38	0.79	0.72	0.15	2.76	0.72	6.62	46.1	3.93
6	36.75	5.52	1.02	0.32	0.26	3.03	4.53	0.67	8.42	37.48	2.01
7	27.24	3.46	0.74	0.66	1.18	0.41	2.88	1.58	7.85	50.68	3.98
8	33.72	4.37	0.18	0.91	0.87	0.44	2.84	1.96	8.58	42.67	3.46
9	37.22	4.33	0.11	1.4	0.89	1	3.65	1.86	6.76	39.94	2.83
10	32.43	3.33	0.2	0.77	0.54	0.37	3.63	2.49	4.37	47.01	4.87
11	30.75	5.06	0.2	0.4	2.28	0.64	4.91	1.29	5.65	44.59	4.22
12	28.71	4.09	0.41	0.29	1.64	0.41	7.66	0.58	7.02	41.17	8.01
13	32.64	4.32	0.2	0.26	1.18	0.98	5.04	1.77	4.97	44.67	3.99
14	25.78	3.86	0.56	1.03	1.98	1.22	6.59	1.22	5.46	46.94	5.36
15	27.08	5.33	0.29	0.58	1.24	0.8	2.63	2.41	8.03	48.32	3.28
16	24.96	4.08	0.12	0.83	0.89	0.83	4.79	1.83	9.4	48.49	3.78
17	31.47	4.24	0.24	0.34	1.06	0.77	3.42	0.67	5.64	50.07	2.07
18	40.73	7.18	0.3	0.68	1.56	0.13	2.87	3.63	6.97	34.01	1.94
Average	**31.52**	**4.84**	**0.36**	**0.69**	**1.12**	**0.8**	**4.01**	**1.57**	**6.81**	**44.67**	**3.64**
Overall % Others	**61.5**										
Overall % Contamination	**38.53**										

Appendix F5.G Separation Efficiency and Level of Contamination: Organic Bin-Asokwa

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	85.81	2.08	0.03	0.22	0.11	0.18	0.61	0.17	1.93	7.82	1.05
2	81.75	2.42	0.09	0.14	0.12	0.09	0.55	0.33	1.68	12.25	0.35
3	76.99	2.38	0.14	0.29	0.19	0.1	0.68	0.38	2.1	16.56	0.21
4	68.7	2.78	0.19	0.02	0.18	0.07	0.68	0.83	1.53	24.28	0.72
5	64.76	3.39	0.02	0.06	0.09	0.08	0.81	0.12	1.73	26.96	1.98
6	74.25	2.82	0.09	0.06	0.12	0.08	0.45	0.39	1.8	19.58	0.36
7	73.23	3.96	0.12	0.43	0.08	0.11	0.77	0.04	1.72	18.7	0.85
8	72.49	2.85	0.14	0.16	0.12	0.1	0.48	0.21	2.24	20.44	0.76
9	69.78	3.52	0.16	0.19	0.1	0.07	0.64	1.43	2.21	20.28	1.62
10	76.3	2.94	0.17	0.14	0.15	0.05	0.62	0.55	1.08	16.99	1.01
11	75.4	3.23	0.16	0.06	0.06	0.06	0.4	0.39	1.36	18.6	0.28
12	71.96	4.14	0.07	0.24	0.02	0.09	1.02	0.24	0.91	19.46	1.87
Average	**74.29**	**3.04**	**0.12**	**0.17**	**0.11**	**0.09**	**0.64**	**0.42**	**1.69**	**18.49**	**0.92**
Standard deviation	**5.67**	**0.63**	**0.06**	**0.12**	**0.05**	**0.03**	**0.17**	**0.38**	**0.42**	**4.98**	**0.62**
Overall % Organic	**74.29**										
Overall % Contamination	**25.69**										

Appendix F5.H Separation Efficiency and Level of Contamination: Organic Bin-Atonsu

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	64.68	1.96	0.03	0.26	0.21	0.11	0.42	0.46	0.89	30.73	0.27
2	64.03	2.13	0.06	0.05	0.07	0.05	0.42	0.38	1.73	30.63	0.44
3	61.33	2.29	0.09	0.18	0.08	0.1	0.47	0.16	0.94	33.22	1.13
4	66.19	2.73	0.03	0.1	0.14	0.01	0.76	0.43	1.23	27.75	0.64
5	51.47	3.08	0.1	0.08	0.12	0.09	0.81	0.34	2.11	40.52	1.27
6	58.44	2.59	0.05	0.12	0.12	0.02	0.81	0.3	1.34	35.21	1
7	52.16	2.81	0.04	0.03	0.14	0.07	0.32	0.16	1.75	41.24	1.27
8	57.2	3.01	0.03	0.1	0.22	0.02	0.4	0.08	0.86	37.26	0.82
9	60.06	2.61	0.04	0.02	0.16	0.01	0.3	0.01	0.63	35.42	0.72
10	60.69	2.93	0.04	0.05	0.06	0.02	0.37	0.07	1.14	34.3	0.32
11	65.86	2.49	0.03	0.02	0.14	0	0.27	0.11	0.79	30	0.31
12	58.18	2.71	0.01	0.04	0.12	0.06	0.44	0.15	0.68	37.09	0.51
Average	**60.02**	**2.61**	**0.05**	**0.09**	**0.13**	**0.05**	**0.48**	**0.22**	**1.17**	**34.45**	**0.73**
Standard deviation	**4.87**	**0.35**	**0.03**	**0.07**	**0.05**	**0.04**	**0.2**	**0.15**	**0.47**	**4.2**	**0.37**
Overall % Organic	**60.02**										
Overall % Contamination	**39.98**										

Appendix F5.I Separation Efficiency and Level of Contamination: Organic Bin-Ahinsan

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
2	63.64	2.59	0	0.07	0.15	0.07	0.56	0.3	0.82	31.67	0.11
3	70.98	3.06	0.07	0.07	0.22	0.11	0.22	0	1.88	19.67	3.72
4	62.31	2.77	0.06	0.08	0.14	0	0.41	0.17	1.58	31.14	1.36
5	50.36	2.36	0	0.12	0.67	0	0.15	0.1	1.66	40.86	3.72
6	61.11	3.69	0.05	0.07	0.07	0.1	0.25	0.2	1.64	32	0.82
7	60.55	5.02	0	0.13	0.26	0	0.36	0.46	1.21	31.53	0.49
8	56.14	4.4	0	0.03	0.19	0.06	0.16	0.06	1	35.77	2.19
9	53.32	3.32	0	0	0.07	0	0.43	0.33	0.85	39.09	2.6
10	53.98	4.3	0	0.12	0.16	0	0.35	0.35	1.37	28.05	11.33
11	67.47	2.86	0	0.05	0.14	0.02	0.24	0.07	0.88	26.92	1.34
12	55.27	5.14	0	0.15	0.5	0.06	0.32	0	1.17	36.47	0.93
Average	**59.56**	**3.59**	**0.02**	**0.08**	**0.23**	**0.04**	**0.31**	**0.19**	**1.28**	**32.11**	**2.6**
Standard deviation	**6.37**	**0.98**	**0.03**	**0.05**	**0.19**	**0.04**	**0.12**	**0.16**	**0.37**	**5.98**	**3.14**
Overall % Organic	**59.56**										
Overall % Contamination	**40.45**										

Appendix F5.J Separation Efficiency and Level of Contamination: Plastic Bin-Asokwa

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	32.14	14.92	3.22	1.84	2.25	1.12	5.62	9.3	5.52	21.67	2.4
2	41.74	17.29	3.19	2.7	1.64	0.45	2.21	1.68	5.85	19.66	3.6
3	49.47	18.26	4.99	1.46	3.98	0.5	2.11	1.78	3.34	12.77	1.33
4	46.31	14.49	2.65	2.61	1.64	0.48	3.43	2.61	5.4	17.77	2.61
5	40.1	14.72	2.41	1.9	1.24	0.18	1.86	0.4	4.02	31.45	1.72
6	44.71	20.75	1.97	1.01	0.96	0.38	2.58	0.81	2.43	22.49	1.91
7	50	14.71	2.21	2.17	0.98	0.4	2.24	0.72	6.36	18.98	1.23
8	39.54	17.98	2.89	1.67	1.49	0.14	2.98	1.4	4.02	22.46	5.42
9	35.68	14.41	1.24	1.12	1.21	0.36	2.39	1.48	4.26	35.14	2.72
10	47.91	14.33	1.29	1.39	1.6	0.27	1.94	1.63	4.52	23.16	1.97
11	42.23	12.66	1.25	2.5	1.22	0.31	2.22	0.16	4.16	32.32	0.97
12	43.73	11.54	1.81	1.29	1.99	0.18	2.02	3.3	3.94	29.24	0.96
Average	**42.8**	**15.51**	**2.43**	**1.81**	**1.68**	**0.4**	**2.63**	**2.11**	**4.49**	**23.93**	**2.24**
Standard deviation	**5.42**	**2.58**	**1.08**	**0.58**	**0.82**	**0.26**	**1.04**	**2.43**	**1.12**	**6.71**	**1.28**
Overall % plastics	**21.43**										
Overall % Contamination	**78.6**										

Appendix F5.K Separation Efficiency and Level of Contamination: Plastic Bin-Atonsu

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	53.92	14.54	1.55	4.66	2.12	1.23	2.45	3.02	3.27	11.68	1.55
2	33.55	17.47	2.38	2.47	1.98	0.94	4.01	2.82	3.81	27.21	3.36
3	24.51	12.99	2.77	3.17	3.06	0.61	2.77	1.58	2.81	44.74	0.97
4	38.9	12.13	1.46	1.86	1.1	0.3	2.03	1.56	3.82	35.07	1.76
5	32.06	12.69	2	1.18	2.14	0.36	3.18	5.11	1.47	35.74	4.07
6	36.86	11.5	1.55	1.46	1.15	0.34	2.42	3.01	2.45	37.01	2.26
7	26.45	13.85	1.92	1.6	3.29	0.38	2.37	1.57	5.05	39.75	3.77
8	29.85	14.5	1.42	6.67	2.15	0.53	4.05	3.26	2.94	32.53	2.1
9	31.19	11.44	1.01	1.29	1.4	0.1	2.58	1.99	3.84	43.23	1.92
10	29.58	10.53	1.41	1.41	4.41	0.08	1.98	1.75	3.35	38.02	7.49
11	40.98	12.67	0.83	1.59	0.76	0.08	2.72	1.78	2.91	35	0.68
12	28.21	14.09	0.85	1.66	1.03	0.06	2.21	1.42	3.81	45.48	1.18
Average	**33.84**	**13.2**	**1.6**	**2.42**	**2.05**	**0.42**	**2.73**	**2.41**	**3.29**	**35.46**	**2.59**
Standard deviation	**8.01**	**1.85**	**0.59**	**1.67**	**1.09**	**0.36**	**0.69**	**1.09**	**0.89**	**9.13**	**1.88**
Overall % plastics	**19.27**										
Overall % Contamination	**80.74**										

Appendix F5.L Separation Efficiency and Level of Contamination: Plastic Bin-Ahinsan

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
2	24.57	34.25	1.16	3.32	2.46	0.72	1.16	1.45	4.34	20.52	6.07
3	17.62	19.54	2.92	0.2	2.72	0.4	1.21	0.5	3.63	41.59	9.67
4	12.55	16.03	1.48	0.74	1.16	0.32	1.27	7.59	3.48	39.24	16.14
5	26.03	24.22	3.42	0.7	2.71	0.3	1.11	0.9	3.62	34.87	2.11
6	19.78	27.67	3.28	2.18	2.55	0.36	1.82	3.52	5.1	31.31	2.43
7	24.51	21.82	1.71	0.57	1.06	0.08	0.9	0.33	7.08	39.9	2.04
8	9.63	17.85	0.71	1.42	1.7	0.14	2.69	0.42	4.53	44.62	16.29
9	28.04	20.03	2.45	1.03	0.26	0.13	0.9	1.03	4.13	27.39	14.6
10	45.09	23.45	3.64	0.91	1.09	0	0.91	0	3.27	19.09	2.55
11	28.22	23.21	0.72	0.72	1.29	0.14	1.43	0.57	2.29	38.54	2.87
12	30.97	16.99	0.5	0.08	0.17	0.08	1	0.33	1.42	46.13	2.33
Average	**24.27**	**22.28**	**2**	**1.08**	**1.56**	**0.24**	**1.31**	**1.51**	**3.9**	**34.84**	**7.01**
Standard deviation	**9.63**	**5.27**	**1.18**	**0.94**	**0.94**	**0.21**	**0.53**	**2.23**	**1.47**	**9.21**	**6.03**
Overall % plastics	**26.92**										
Overall % Contamination	**73.08**										

Appendix F5.M Separation Efficiency and Level of Contamination: Others Bin-Asokwa

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	56.63	3.38	0.14	0.52	1.1	0.77	6.25	2.64	6.77	20.89	0.91
2	48.51	3.35	0.4	0.3	0.72	0.75	7.82	6.84	6.64	20.87	3.8
3	39.13	5.46	0.51	0.51	0.37	0.59	6.95	3.96	4.76	36.88	0.88
4	39.26	5.26	0.75	0.8	1.82	0.4	8.04	3.47	7.35	30.3	2.54
5	43.19	5.22	0.28	0.43	0.26	0.62	6.58	3.32	9.14	30.19	0.77
6	48.45	4.41	0.43	0.66	0.25	0.73	5.55	3.6	6.88	27.38	1.66
7	34.51	6.81	0.15	1.06	0.38	0.56	6.34	3.24	13.12	31.71	2.12
8	35.33	4.84	0.63	0.3	0.96	0.33	8.01	2.1	7.18	36.09	4.21
9	41.48	5.1	0.54	0.35	0.3	0.52	3.97	1.48	9.59	34.71	1.97
10	33.56	7.51	0.91	1.41	0.5	0.44	5.79	3.97	6.6	36.96	2.36
11	46.29	5.19	0.45	0.54	0.42	0.34	5.39	3.22	4.82	32.41	0.93
12	37.34	4.31	0.41	0.49	1.2	0.23	5.38	6.13	5.72	35.67	3.13
Average	**41.97**	**5.07**	**0.47**	**0.61**	**0.69**	**0.52**	**6.34**	**3.66**	**7.38**	**31.17**	**2.11**
Standard deviation	**6.92**	**1.21**	**0.23**	**0.33**	**0.49**	**0.18**	**1.23**	**1.51**	**2.31**	**5.66**	**1.16**
Overall % others	**51.18**										
Overall % Contamination	**48.81**										

Appendix F5.N Separation Efficiency and Level of Contamination: Others Bin-Atonsu

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
1	46.59	5.55	0.41	0.77	0.68	0.63	6.37	5.78	5.06	26.55	1.63
2	33.84	3.74	0.11	0.46	0.59	0.37	3.72	1.46	4.04	47.9	3.76
3	22.08	6.04	0.4	0.8	0.73	0.55	3.47	0.93	6.21	55.11	3.67
4	31.19	6.64	0.48	1.02	0.74	0.36	4.56	4.1	5.96	44.04	0.92
5	19.18	5.46	0.21	0.16	0.44	0.28	3.11	2.54	4.22	59	5.41
6	35.44	5.26	0.27	0.69	0.24	0.27	2.76	1.94	4.31	41.64	7.17
7	31.81	5.88	0.2	0.33	0.53	0.18	2.41	5.38	7.41	42.94	2.91
8	31.9	6.25	0.2	0.05	0.38	0.08	3.33	2.79	3.84	48.16	3.02
9	36	6.34	0.19	0.29	1	0.15	4.52	1.23	4.83	41.75	3.68
10	38.61	4.5	0.08	0.23	0.47	0.13	2.57	0.66	3.98	45.5	3.28
11	39.02	4.37	0.16	0.13	0.57	0.02	2.29	0.27	5.54	44.72	2.91
12	38.97	5.58	0.18	0.34	0.41	0.08	3.07	1.24	5.14	39.59	5.4
Average	**33.72**	**5.47**	**0.24**	**0.44**	**0.57**	**0.26**	**3.52**	**2.36**	**5.05**	**44.74**	**3.65**
Standard deviation	**7.47**	**0.88**	**0.13**	**0.31**	**0.2**	**0.19**	**1.16**	**1.83**	**1.08**	**8.05**	**1.7**
Overall % others	**59.58**										
Overall % Contamination	**40.44**										

Appendix F5.O Separation Efficiency and Level of Contamination: Others Bin-Ahinsan

Week	Organic	Plastic Film	PET & PVC Rigid	PE &PP Rigid	Other Plastics	Other Pack. Mat.	Metals	Glass	Paper	Others	Textiles
2	39.78	2.25	0.48	0.73	0.22	0.04	1.51	0.56	2.72	47.3	4.41
3	32.91	4.7	0.2	0.27	0.67	0.27	1.88	0.2	3.69	53.39	1.81
4	16.49	7.46	0.08	0.17	0.99	0.08	11.76	0.83	8.12	42.09	11.93
5	21.09	8.32	0.25	0	0.25	0.99	2.97	1.32	5.85	49.09	9.88
6	17.02	8.15	0.21	0.21	0.07	0.07	1.65	1	3.72	64.02	3.86
7	27.29	11.79	0	0.23	0.53	0	2.49	0.98	4.01	45.35	7.33
8	19.16	10.95	1	0.47	0.87	0	1.07	0.87	2.27	62.68	0.67
9	30.42	10.54	0.15	0	0.15	0.15	1.96	5.87	5.27	39.91	5.57
10	37.77	8.04	0	0.67	0.34	0.08	2.68	1.68	4.86	33.08	10.8
11	32.37	13.12	0.22	0.87	0.43	0	0.79	0.58	3.1	44.84	3.68
12	36.73	5.87	0.04	0.13	0.31	0.13	1.24	2.16	1.68	48.7	3
Average	**28.28**	**8.29**	**0.24**	**0.34**	**0.44**	**0.16**	**2.73**	**1.46**	**4.12**	**48.22**	**5.72**
Standard deviation	**8.59**	**3.22**	**0.29**	**0.3**	**0.3**	**0.29**	**3.07**	**1.56**	**1.83**	**9.18**	**3.77**
Overall % others	**62.41**										
Overall % Contamination	**37.59**										

Appendix F6: Set-out Rate

Appendix F6.A: Set -out Rate - Senior Staff Area

WEEK	% 1 bin	% 2 bins	% 3 bins	% none
1	4	20	76	0
2	8	24	68	0
3	7.69	15.38	76.92	0
4	7.69	15.38	73.08	3.85
5	3.85	15.38	76.92	3.85
6	7.69	19.23	69.23	3.85
7	7.69	30.77	57.69	3.85
8	7.69	19.23	69.23	3.85
9	7.69	15.38	73.08	3.85
10	11.54	15.38	65.38	7.69
11	7.69	7.69	76.92	7.69
12	15.38	7.69	65.38	11.54
13	11.54	19.23	61.54	7.69
14	3.85	19.23	69.23	7.69
15	7.69	15.38	69.23	7.69
16	7.69	30.77	50	11.54
17	3.85	19.23	65.38	11.54
18	7.69	30.77	53.85	7.69
AVERAGE	7.72	18.9	67.61	5.77

Table F6.B: Set-out Rate - Junior Staff Area

WEEK	%HH 1 bin	%HH 2 bins	%HH 3 bins	%HH none
1	14.29	14.29	71.43	0
2	3.57	14.29	82.14	0
3	3.57	10.71	85.71	0
4	3.57	17.86	78.57	0
5	0	28.57	67.86	3.57
6	3.57	10.71	85.71	0
7	0	25	75	0
8	0	21.43	78.57	0
9	3.57	10.71	85.71	0
10	0	10.71	89.29	0
11	7.14	10.71	82.14	0
12	3.57	17.86	78.57	0
13	3.57	7.14	89.29	0
14	0	14.29	85.71	0
15	7.14	17.86	75	0
16	3.57	10.71	85.71	0
17	7.14	14.29	78.57	0
18	7.41	18.52	74.07	0
AVERAGE	**3.98**	**15.31**	**80.5**	**0.2**

Table F6.C: Set-out Rate - Asokwa

WEEK	%HH 1 bin	%HH 2 bins	%HH 3 bins	%HH none
1	0	0	100	0
2	0	6.06	93.94	0
3	3.03	3.03	93.94	0
4	2.94	5.88	91.18	0
5	6.06	3.03	90.91	0
6	5.88	2.94	91.18	0
7	8.82	5.88	85.29	0
8	5.88	5.88	88.24	0
9	0	8.82	91.18	0
10	11.76	11.76	76.47	0
11	5.88	17.65	76.47	0
12	0	14.71	85.29	0
Average	**4.19**	**7.14**	**88.67**	**0**

Table F6.D: Set-out Rate – Atonsu

WEEK	%HH 1 bin	%HH 2 bins	%HH 3 bins	%HH none
1	3.23	12.9	83.87	0
2	5.88	5.88	88.24	0
3	0	14.71	85.29	0
4	0	11.76	88.24	0
5	2.94	8.82	88.24	0
6	2.94	14.71	82.35	0
7	5.88	5.88	88.24	0
8	2.94	11.76	82.35	2.94
9	5.88	8.82	85.29	0
10	2.94	8.82	88.24	0
11	2.94	14.71	82.35	0
12	0	5.88	91.18	2.94
Average	**2.96**	**10.39**	**86.16**	**0.49**

Table F6.E Set-out Rate - Ahinsan

WEEK	%HH 1 bin	%HH 2 bins	%HH 3 bins	%HH none
1				
2	0	0	100	0
3	0	0	100	0
4	0	0	100	0
5	0	0	100	0
6	0	0	100	0
7	0	0	100	0
8	0	0	100	0
9	0	0	100	0
10	0	12.5	87.5	0
11	0	12.5	87.5	0
12	0	0	0	0
Average	**0**	**2.27**	**88.64**	**0**

APPENDIX G: DETAILS OF OPTIMIZATION INPUT PARAMETERS AND RESULTS

Appendix G1: Centralized Composting

1. Cost of Land

   Assumption: 810m^2 of land cost GH¢5000 on the average in Kumasi therefore land cost/m^2 = GH¢6.2/m^2

2. Salaries assumed for various workers are:

   Manager - GH¢700/month

   Technical officer - GH¢500/month

   Technicians - GH¢330/month

   Unskilled workers - GH¢5/day

   Driver - GH¢200/month

   Note: An additional 20% of the above salaries are added to account for incentives and social security

3. Supplies and Tools

   This includes costs for personal safety equipments like: overalls, nose masks, hand gloves, boots and other tools like: shovels, rakes, brooms. These were estimated based on current market prices.

4. Utilities

   Recent approved utility tariffs for Commercial users were used to estimate the cost of these utilities.

5. Marketing

   The assumed marketing cost for the compost is GH¢0.5/0.05t = GH¢10/t

6. Capital costs were annualized using the equation:

   $$A_l = \frac{I_l \times r}{1-(1+r)^{-n}}$$

   A_l – Annualized capital cost

   I_l - Capital cost

   n – Expected life of equipment/plant

   r – Discount rate

The total capital cost for centralized composting was annualized assuming a plant life of 20 years and discount rate of 20%.

Appendix G2: Decentralized (Community) Composting

The cost of land and salaries for unskilled workers are similar to that pertaining to centralized composting. The salary of the site supervisor is assumed to be GH¢10/day plus 20% of this amount as incentive. The total capital cost for community composting was also annualized assuming a plant life of 20 years and discount rate of 20%.

Appendix G3: Plastic Recycling

The cost estimates were compiled based on information received from, City Waste Management, Afiaman near Pokuase Accra, KASHAAF Company Ltd (Agbogbloshie, Accra) and HACKI PLAST (Agbogbloshie, Accra) and Lardinois and van de Klundert (1995)

Working hours: 286 days per year (5.5 days a week, 8 hours full day)

1. Equipment cost

Appendix G3.A Plastic Recycling Equipment Cost

Equipment type	Number	Expected life, yrs	Purchase cost	Annualized cost of equipment, r = 0.2	Annualized cost of equipment/t
Shredder (locally made)	1	15	$ 2000	427.76	1.15
Dryer (agglomerator)	2	10	$5000	1192.61	3.2
Pelletizer	1	10	$8500	2027.44	5.45
Total $/t					9.8
Total GH¢/t					13.72
US$1 = GH¢1.4					

2. Labour requirement

Appendix G3.B Plastic Recycling Labour Requirement

Personnel type	Number	Daily wage, GH¢	Total cost, GH¢
Sorting	6	5	30
Washing	14	5	70
Shredding	3	5	15
Drying	2	5	10
Pelletizing	3	5	15
Supervisor	1	10	10
Total, GH¢			150
Incoming waste of 1.3t/d			
Total cost GH¢/t			115.4

3. Equipment maintenance cost and power cost

Appendix G3.C Plastic Recycling Equipment Maintenance Cost

Equipment type	Maintenance cost	Maintenance cost/t	Power cost	Power cost/t
Shredder (locally made)	GH¢1/d	GH¢4/t	GH¢15/d	GH¢60/t
Dryer (agglomerator)	GH¢10/d	GH¢10/t	GH¢40/d	GH¢40/t
Pelletizer	GH¢10/d	GH¢10/t	GH¢20/d	GH¢20/t
Total		**GH¢24/t**		**GH¢120/t**

4. Collection using tricycles:

Cost estimation for tricycle was done in conjunction with staff of Zoomlion Ghana Ltd. Kumasi

Cost of tricycle/t = GH¢800

Life = 3years

Annualized cost of tricycle/t = GH¢1.02/t

Cost of collection bin/t = GH¢800

Life = 5years

Annualized cost/t of bin = GH¢5.03/t

Cost of maintenance of tricycle/t = GH¢0.61/t

Fuel cost/t for tricycle = GH¢1.11/t

Wages for 7 site attendants and 2 tricycle attendants/t = GH¢35.79/t

Incentives to households/t = GH¢200/t

Supplies (protective wear) = GH¢9.94/t

5. Cost of infrastructure

Structure: GH¢25,000

Life 20, discount rate = 20%

Annualized cost = GH¢5133.913

Annualized cost/t = GH¢13.8/t

6. Cost of water

Water = GH¢6.7/t

7. Detergent cost

Lime = GH¢20/t

Omo = GH¢20/t

8. Rent for land

Rent = GH¢50/month

Rent/month = GH¢1.75/t

Appendix G4: Landfilling and Collection

1. Construction cost – US$6.5 million
2. Estimated life – 15 years
3. Interest rate at year of construction (2003-2004) (i) = 21.5% (Dec 2003-Jan 2004 BOG prime rate)
4. Total estimated waste to be disposed off in landfill (designed capacity) - 4140000t

   A_l = US$1477071

   Capital cost of landfill per tonne of waste = US$5.35/t = GH¢7.49/t
5. Land costs per tonne of waste handled at the landfill (Ll)

   100 acres - GH¢20,000

   Annualized cost of land /tonne = GH¢0.016/t
6. Operational and maintenance cost - GH¢7.2/t
7. Cost borne by KMA per tonne of material collected by contractor**:**

   Communal collection - GH¢ 10/t

   Door to door collection - GH¢ 33.6/t

Note: With the House to house collection system households provide their own bins hence this cost is not added to the collection cost.

8. Cost of communal containers:

   $15m^3$ - GH¢ 4800, $23m^3$ - GH¢7500

   Assuming the bulk density of waste to be $350kg/m^3$ (KMA-WMD) then the amount of waste collected in communal containers = $350kg/m^3$ x $15m^3$ = 5.25 tonnes

   $350kg/m^3$ x $23m^3$ = 8.05 tonnes

   Estimated life of containers – 5 years

   Discount rate = 20%

   Annualized cost of containers

   A_c = $15m^3$ containers

   Site maintenance - GH¢ 50/month (wages for site attendant)

   Co*ll* = GH¢1.16/t ($15m^3$ container), GH¢1.06/t ($23m^3$ container): average collection cost = GH¢1.11/t

Appendix G5: Details of Other Model Input Parameters

1. Waste Composition and Total Generation

The waste composition is estimated based on study in the Asokwa Sub-metro. The total waste available was based on projected waste generation for Kumasi for the year 2010 and the assumption that 85% of waste generated is collected.

Appendix G5.A Estimated Household Waste Composition for Kumasi (2010)

Material	Quantity, t/yr	t/d	Composition, %
Organic	172726	473	57
Recyclable plastic	18182	50	6
Other Plastics	3030	8	1
Metals	6061	17	2
Others	103029	282	34
Total	**303028**	**830**	

- The fraction of organic waste sent to the centralized composting plant, bio_c is assumed to be the fraction of organic waste and paper in the mixed waste stream. Likewise the fraction of non-biodegradable materials, plastics and metals (fnb_c, Pr_c & M_c) recovered at the centralized composting plant.

- The fraction of organic waste sent to the community composting plant, bio_{cc} is assumed to be the fraction of organic waste and paper in the organic bin from the source separation study. Likewise the fraction of non biodegradable materials, plastics and metals (fnb_{cc}, Pr_{cc} & M_{cc}) recovered at this plant
- The fraction of recyclable plastics, non plastic materials and non-recyclable plastics (P_{pr}, $f$np & $f$op) were assumed based on expected performance of community collection of plastic waste and information from plastic recycling companies.
- Recyclable plastic is assumed to be the fraction of plastic film and rigid PE & PP plastics found in the waste stream.

2. Waste Reduction Factors

η - 0.5 (Mcdougall et al. 2001)

γ – 0.93 (estimate from plastic recycling companies)

3. Sources of Selling Prices of Recovered Materials

pCcc, pCc – (estimate from survey undertaken by Zoomlion Ghana Limited)

pPrc , pMc, pPrcc & pMcc – (estimate from purchasing companies)

pPl – (estimate from plastic recycling companies)

Appendix G6: Details of Some Model Results

Appendix G6.A Changes in waste flows with % increases in capital cost for centralized composting plant

	0	**50**	**100**	**150**	**200**	**250**	**300**
$\mathbf{W}_{im}$	148016	148016	148016	199496	199496	199496	199496
$\mathbf{W}_{ij}$	51480	51480	51480	0	0	0	0
$\mathbf{W}_{jm}$	18018	18018	18018	0	0	0	0
$\mathbf{W}_{ik}$	858	858	858	858	858	858	858
$\mathbf{W}_{km}$	257.4	257.4	257.4	257.4	257.4	257.4	257.4
$\mathbf{W}_{in}$	371.8	371.8	371.8	371.8	371.8	371.8	371.8
$\mathbf{W}_{nm}$	92.95	92.95	92.95	92.95	92.95	92.95	92.95

Appendix G6.B Changes in waste flows with % increases in capital cost for community composting plants

	0	**100**	**300**	**400**	**500**	**550**	**600**	**700**
$\mathbf{W}_{im}$	148016	148016	148016	148016	148016	244112	244112	244112
$\mathbf{W}_{ij}$	51480	51480	51480	51480	51480	51480	51480	51480
$\mathbf{W}_{jm}$	18018	18018	18018	18018	18018	18018	18018	18018
$\mathbf{W}_{ik}$	858	858	858	858	858	0	0	0
$\mathbf{W}_{km}$	257.4	257.4	257.4	257.4	257.4	0	0	0
$\mathbf{W}_{in}$	371.8	371.8	371.8	371.8	371.8	371.8	371.8	371.8
$\mathbf{W}_{nm}$	92.95	92.95	92.95	92.95	92.95	92.95	92.95	92.95

Appendix G6.C Changes in waste flows with % increases in capital cost for community plastic recycling plants

	0	100	300	400	500	550	600	650
$\mathbf{W}_{im}$	148016	148016	148016	148016	155452	155452	155452	155452
$\mathbf{W}_{ij}$	51480	51480	51480	51480	51480	51480	51480	51480
$\mathbf{W}_{jm}$	18018	18018	18018	18018	18018	18018	18018	18018
$\mathbf{W}_{ik}$	858	858	858	858	858	858	858	858
$\mathbf{W}_{km}$	257.4	257.4	257.4	257.4	257.4	257.4	257.4	257.4
$\mathbf{W}_{in}$	371.8	371.8	371.8	371.8	0	0	0	0
$\mathbf{W}_{nm}$	92.95	92.95	92.95	92.95	0	0	0	0

APPENDIX H: PUBLICATIONS RELATED TO RESEARCH

Appendix H1: List of Publications

My contribution to the publications: I wrote the papers, while receiving guidance, supervision and some relevant information from the co-authors.

1. Mizpah Asase, Ernest K. Yanful, Moses Mensah, Jay Stanford, Samuel Amponsah, (2009). Comparison of Municipal Solid Waste Management Systems in Canada and Ghana: A Case Study of the Cities of London, Ontario, and Kumasi, Ghana. Waste Management 29 (2009) 2779–2786

2. Mizpah A.D. Asase, Moses Y. Mensah, Samuel K. Amponsah (2008). Organised Source Separation of Household Waste – Pilot Study of University Staff Residences in Ghana. In Conference proceedings: 6^{th} International conference **ORBIT** (Organic Recovery and Biological Treatment) **2008** - 13 - 15th of Oct. 2008, Wageningen, The Netherlands (Paper was presented at the conference by Dr. Moses Mensah)

3. Mizpah A.D. Asase, Moses Y. Mensah, Samuel K. Amponsah, (2008). Development of Data-Based Decision-Support System for Management of Source Separated Municipal Waste in Kumasi, Ghana. Poster presented at the 21st International CODATA Conference Ukraine, Kyiv, 5 - 8 October, 2008 (Paper was posted at the conference by Dr. Moses Mensah)

Appendix H2: Copy of Paper published in Waste Management Journal

Waste Management 29 (2009) 2779–2786

Contents lists available at ScienceDirect

Waste Management

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

Comparison of municipal solid waste management systems in Canada and Ghana: A case study of the cities of London, Ontario, and Kumasi, Ghana

Mizpah Asase [a], Ernest K. Yanful [b,*], Moses Mensah [a], Jay Stanford [c], Samuel Amponsah [d]

[a] Department of Chemical Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[b] Department of Civil and Environmental Engineering, The University of Western Ontario London, Ontario, Canada N6A 5B9
[c] City of London, 300 Dufferin Ave. P.O. Box 5035, Ontario, Canada N6A 4L9
[d] Mathematics Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

A R T I C L E I N F O

Article history:
Accepted 12 June 2009
Available online 16 July 2009

A B S T R A C T

Integrated waste management has been accepted as a sustainable approach to solid waste management in any region. It can be applied in both developed and developing countries. The difference is the approach taken to develop the integrated waste management system. This review looks at the integrated waste management system operating in the city of London, Ontario-Canada and how lessons can be drawn from the system's development and operation that will help implement a sustainable waste management system in the city of Kumasi, Ghana. The waste management system in London is designed such that all waste generated in the city is handled and disposed of appropriately. The responsibility of each sector handling waste is clearly defined and monitored. All major services are provided and delivered by a combination of public and private sector forces.

The sustainability of the waste management in the city of London is attributed to the continuous improvement strategy framework adopted by the city based on the principles of integrated waste management. It is perceived that adopting a strategic framework based on the principles of integrated waste management with a strong political and social will, can transform the current waste management in Kumasi and other cities in developing countries in the bid for finding lasting solutions to the problems that have plagued the waste management system in these cities.

Contents

* Corresponding author. Tel.: +1 519 661 4069; fax: +1 519 661 3942.
E-mail address: eyanful@eng.uwo.ca (E.K. Yanful).

0956-053X/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.wasman.2009.06.019

1. Introduction

Municipal solid waste management (MSWM) over the years has been undertaken with many drivers world wide. The objectives of MSWM have evolved from the primary concerns of environmental health protection to considering human safety, resource conservation and the reduction of, as much as possible, the environmental burdens of waste management (energy consumption, pollution of air, land and water and loss of amenity) (McDougall and Hruska, 2000). Increasing waste generation rates due to population growth, changing lifestyles of people, development and consumption of products with materials that are less biodegradable have led to the diverse challenges for MSWM in various cities of the world. Distinct differences have been identified in literature between MSWM in developed and developing countries. In most developed countries, public health is no more a major driver of waste management; the current focus is on optimization of waste management practices with a broader goal of resource conservation (Wilson, 2007; McDougall et al., 2001). MSWM in most developing countries is often characterized by inadequate service coverage, operational inefficiencies of services, limited utilization of recycling activities, inadequate management of non-industrial hazardous waste and inadequate landfill disposal (Zurbrügg and Schertenleib, 1998). Although distinct differences exist between waste management in developed and the developing countries, as developing countries achieve economic growth coupled with population growth the environmental and economic burdens of solid waste management will increase. According to UNEP (2005) the rate of waste generation generally increases in direct proportion to that of a nation's advance in development and failure to provide a management system could result in greater environmental degradation with increase health risk to the urban population. There is the need for developing countries to be guided in taking the appropriate steps in developing sustainable waste management systems. This is important owing to the fact that the more the environment is degraded in a particular region, the greater the effort that will be required to restore its quality (UNEP, 2005). Lessons can be drawn from experiences in developed countries to guide developing countries as they seek to improve on existing MSWM systems, since waste management systems have evolved through many steps over the years in developed countries (Wilson, 2007). It is becoming widely recognized that an integrated approach to waste management leads to the sustainability of the waste management system. The concept of integrated waste management (IWM) according to McDougall et al. (2001) takes an overall approach and manages waste in an environmentally effective, economically affordable and socially acceptable way. It involves the use of a range of different treatment options at a local level and considers the entire solid waste stream. An IWM approach is broadly evident in the waste management system in most developed countries (McDougall et al., 2001). Some initiatives towards IWM in developing countries have been reported which were mostly organized by non-governmental organizations for sections of some cities. In order to support the adoption of the IWM approach on a city wide basis in developing countries, it would be useful to present a specific case study or an example of the development and implementation of an integrated waste management system for a city in a developed country. The experiences and lessons learned could be utilized as a basis to develop a framework for implementing successful IWM system in developing countries. This paper seeks to add to the discussion of the adoption of the IWM approach on a city wide basis in developing countries, using an example from a municipality in a developed country for comparison. By learning lessons from the experiences in a developed country, waste management experts and regulators in developing countries can also avoid past mistakes made by developed countries, in the evolution of waste management practices.

The aim of this paper is to provide an overview of the different elements of municipal solid waste management in London, ON (referred to as London in the rest of the paper), Canada and Kumasi, Ghana with the discussion of possible lessons that can be adopted from the MSWM system in London to help develop an IWM system in Kumasi. Background information on the two cities is presented to enhance an understanding of their characteristics. To enable the comparisons between waste management in the two cities, the existing waste management systems are described in terms of waste generation, waste composition, waste collection methods, service coverage and transportation, waste treatment and disposal, municipal solid waste management strategic plan and government laws and regulations. The description of the waste management systems in the two cities was carried out with information from reports, documents obtained from the official websites of the city authorities and personal communication with the authorities responsible for waste management in the cities.

The MSWM systems in London and Kumasi are then discussed in terms of the key features of IWM and common system drivers identified in case studies of IWM studies presented in McDougall et al. (2001). Some concluding thoughts are then put forward as to how the city of Kumasi can develop an IWMS based on the success features adopted by the city of London.

2. Description of the city of London, Ontario (ON) and Kumasi

2.1. Background Information on the city of London, ON

The city of London is located in the heart of southwestern Ontario, Canada. The city covers a land size of 420.57 km^2 with an elevation of 251 m. London has a humid continental climate. Because of its location in the continent and proximity to the Great Lakes, London experiences very contrasting seasons. The summers are usually warm to hot and humid while the winters are normally quite cold but with frequent thaws. For its southerly location within Canada, it does receive quite a bit of snow, averaging slightly over 200 cm (80 in.) per year. The city of London is the 15th largest city in Canada and 6th largest in the province of Ontario with a population of 352,395 people as of the year 2006 (Steblin and Stanford, 2008; City of London, 2009).

2.2. Background information on the city Kumasi

Kumasi is the 2nd largest city in Ghana after the national capital city, Accra. Kumasi is located in the transitional forest zone and is about 270 km north of the national capital. It is between latitude 6.35–6.40° and longitude 1.30–1.35°, an elevation which ranges between 250 and 300 m above sea level with an area of about 254 km^2. The average minimum temperature is about 21.5 °C and a maximum average temperature of 30.7 °C. The average humidity is about 84.16% at 0900 GMT and 60% at 1500 GMT. The city has a double maxima rainfall of 214.3 mm in June and 165.2 mm in September. The Kumasi Metropolitan Area has been estimated to have a daytime population of about 2 million. It has been projected to have a population 1,610,867 in 2006 and 1,889,934 by 2009 based on a growth rate of 5.47% per annum. The growth of industries and the large volume of commercial activity in and around Kumasi as well as the high migrant number may account partly for the relatively high urban population. The Metropolis falls within the wet sub-equatorial type (Ghanadistricts, 2008).

3. Municipal solid waste management system overview in London, ON and Kumasi

3.1. Waste generation

On the average, 1.2 kg per capita of household solid waste is generated in the city of London per day. The estimated daily municipal waste generation rate in Kumasi is 0.6 kg per capita. In the year 2006, a total of 267,000 tonnes of both residential (58%) and non-residential (42%) waste was managed in the city of London as against 365,000 tonnes generated in Kumasi. It is estimated that households generate the highest amount of waste in Kumasi, followed by Markets, then industries with the least from institutions although the exact proportions could not be provided. The waste generation rate in the municipality is expected to increase by 15% by the year 2010 (WMD-KMA, 2008). Although the per capita waste generation in Kumasi is lower than that of the city of London the large population in Kumasi makes the overall waste generated in Kumasi higher than that of London.

3.2. Waste composition

The composition of household waste in the city of London and Kumasi is shown in Table 1. The available waste composition data for London was for household waste only; other non-residential waste handled by the city authority is not included. The composition of waste available for Kumasi is for the total municipal waste. Although the waste composition for London is not for the entire waste streams, comparing it with waste composition from Kumasi shows the characteristic difference in waste composition from developed and developing countries. The composition of waste in Kumasi is predominantly made of biodegradable materials and a high percentage of inert materials as well. The inert material is mostly made of wood ash, sand and charcoal. Paper and organic waste dominate household waste in London and are present in almost equal proportions. London also has a higher percentage of recyclables. These differences in waste composition may be attributed to the differences in the living standard and lifestyle of the inhabitants of the two cites. The abundance and type of the natural resources found in the countries of the two cities may also reflect in differences in the waste composition (UNEP, 2005).

Table 1
Available waste composition data in London, ON and Kumasi.

Waste component	London, ON[a] (%)	Kumasi[b] (%)
Biodegradable/organic	30	64
Paper	32	3
Plastic	10	4
Metals	3	1
Glass	6	–
Others	19	–
Inert	–	22
Wood	–	3
Textiles		3

[a] Household waste average (garbage and recycling combined from waste audits) for 2005 and 2007 for the city of London (City of London, 2007).
[b] Waste (total municipal) composition in Kumasi (WMD-KMA, 2008).

3.3. Waste collection methods, service coverage and transportation

The city of London provides waste management services to all residents of the city. To ensure the collection of all waste generated in the city, guidelines have been provided to residents of the city on how to handle the various types of waste that are generated. Eighty percentage of the population is served by curbside garbage (garbage is defined here as the residual waste after blue box recyclables have been separated from household waste) collection, whilst 20% are served by multi-residential & public space garbage pickup. The curbside garbage pick up is carried out by 17 rear loading packers (trucks) and 2 side loading packers. Multi-residential and public space pick up is carried out by two front loaders and two rear loading packers. There also exists the blue box recycling program for the collection of recyclables in the city. The blue box recycling materials are collected on the same days that garbage is collected. Materials collected in the blue box program include: boxes (cereal, detergent, cracker, etc.), paper, cardboard, aluminum containers and foil, glass, steel, plastic (number 1, 2, 4 or 5), milk and juice cartons. Special days are provided for curbside collection of yard waste (plant trimmings, grass clippings, leaves and branches) in the year. There are five depots located throughout the city for residents to dispose of various waste streams. Provision has been made for the disposal of household special waste (any material that is corrosive, flammable, ignitable or reactive) at the city's landfill. The city also offers garbage collection to about 1500 small businesses.

Two types of methods are employed for the collection of municipal waste in Kumasi. These are the house-to-house (curbside) solid waste collection utilizing compactor trucksand communal solid waste collection. The Communal Collection System involves the location of metal containers (skips) at designated sites known as transfer stations, which are shared by a number of houses within that community. When the skips are full, they are transported and emptied at final disposal site by skip loading trucks. Collection of waste from institutional and industrial premises also relies on container services. Eighty-five percentage of the waste generated is collected in the municipality. The waste collection service in the city is carried out by the private sector under various agreements with the metropolitan assembly.

3.4. Waste treatment and disposal

Waste collected in the city of London as garbage is disposed off in the city's landfill.

In the year 2006, 205,000 tonnes of wastes was disposed of in the city of London's "W12A" landfill, from residential (45%), city

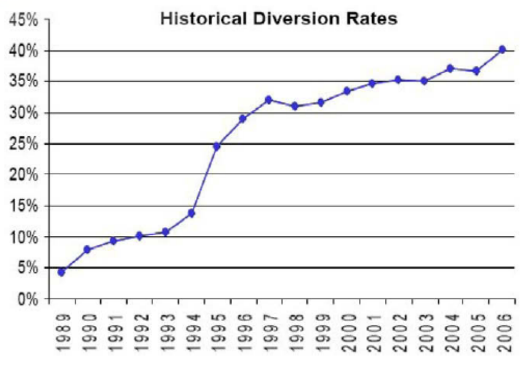

Fig. 1. The city of London's Historical Waste Diversion rates (City of London, 2007).

Table 2
Initiatives introduced in London, ON to achieve 40% diversion (Steblin and Stanford, 2008).

Year	Initiative
1987	Household special waste depot
1990	Curbside blue box pickup
1994	Appliances banned from garbage collection
1995	Added new items to blue box
	Grass clippings banned from garbage collection
1996	Curbside pickup of yard materials
2000	Multi-residential building recycling
	Pumpkin depots
2002	Electronics recycling depot
2003	Public space recycling
2005	Renovation material recycling accepted at enviro-depots
2006	Four container limit for garbage

Table 3
City of London programs – facility ownership (Steblin and Stanford, 2008).

Waste management facility	Facility ownership	
	Public sector (%)	Private sector (%)
Multi-material drop-off depots	100	0
Material recovery facility (MRF)	0	100
Yard materials composting facility	0	100
Household special waste depot	100	0
Landfill site	100	0
Closed landfills	50	50

Table 4
City of London programs – service providers (Steblin and Stanford, 2008).

Service	Service provider	
	Public sector (%)	Private sector (%)
Administration, awareness and education	100	0
Recycling collection	0	100
Recycling processing	0	100
Yard materials collection	98	2
Yard materials composting	0	100
Household special waste depot	70	30
Closed landfill management	65	35
Garbage collection	98	2
Landfill management and administration	100	0
Landfill site operations	30	70

Table 5
Waste diversion costs – 2006 (Steblin and Stanford, 2008).

Diversion program	Tonnes managed	% Diversion	Net program cost ($)
Recycling – curbside	24,850	16	1,300,000
Recycling – multi-residential	2800	2	500,000
Leaf and yard waste composting	16,100	10	1,400,000
Other diversion programs	18,250	12	400,000
Total	62,000	40	3,600,000

Note: Does not include indirect costs.

operations (25%), brownfield (3%) and businesses (27%). The recyclables collected by the blue box program are transported to a materials recovery facility (MRF) in the city where they are sorted, baled, placed on transport trucks and shipped to end markets to be turned into new products. Ninety-eight percentage of recyclables set out are shipped to end markets and only 2% of it ends up in the landfill.

The city of London's waste management system, as of the year 2006, diverted 40% of waste from the landfill. The city of London's Historical Waste Diversion rates is shown in Fig. 1. A number of initiatives introduced to achieve this diversion rate from 4% in 1989 are shown in Table 2. Recycling contributed 18%, curbside depots and self management of yard waste 17%, and other programs, as enumerated in Table 2, 5% to the 40% diversion rate achieved by the year 2006 in the city of London. The city of London utilizes both public and private sector facilities to manage the waste generated in the city. Table 3 presents the facilities available for waste management in the city and who owns them. The provision of waste management services in the city is also undertaken by both the public and private sectors. Table 4 gives the picture of how these services are divided between the two sectors. The city of London is considered to be one of the cities with the lowest waste management costs in the province of Ontario. The waste diversion costs and the waste management system cost for the city of London in the year 2006 is indicated in Tables 5 and 6 respectively.

The waste collected in Kumasi is disposed of at two sites with a capacity of 4,587,456 m^3; a sanitary landfill site and an open dump. The sanitary landfill is constructed on a 100 acre land and treats both solid waste and sewage. The sanitary landfill is managed by a private contractor on behalf of the city authority. Waste diversion through recycling and reuse is carried out on an informal basis which is not widely recognized as contributing to waste management in the city. The estimated cost of operating the landfill is US$ 250,000/month excluding the cost of land use and facility closure. The government bears 95% of the landfill management cost. The average waste collection costs US$ 350,000/month with waste generators bearing 15% and the municipal authority 85% (WMD-KMA, 2008). The total annual waste management cost is approximately US$7.2 million.

3.5. Municipal solid waste management (MSWM) strategic plan

The waste management system in the city of London is based on continuous improvement strategy (management philosophy) and sustainable waste management.

The London municipal council approved this long-term waste strategy in December 1997. According to Stanford (2000), the continuous improvement strategy is a dynamic framework that recognizes integrated waste management as an important environmental service in the community which contributes to the protection of human health and the environment. The implementation of the strategy involves the annual establishment of community needs and priorities, monitoring of the existing and other waste management systems, implementation and assess-

Table 6
Waste management costs – 2006 (Steblin and Stanford, 2008).

Component	Tonnes managed		Gross cost ($)	Fees and revenues ($)	Net program cost ($)
	Residential	Non-residential			
Waste Diversion	62,000	0	7,700,000	4,100,000	3,600,000
Collection	92,600	0	8,400,000	400,000	8,000,000
Landfill Disposal Operations	92,600	112,400	3,300,000	1,800,000	1,500,000
Miscellaneous (closed landfills, reserve fund, etc.)	92,600	0	2,800,000	0	2,800,000
Total			22,200,000	6,300,000	15,900,000

ment of approved initiatives, and utilization of various methods of communicating results. Two major elements of continuous improvement are the establishment of annual and short-term goals and systematic framework for evaluating system performance (environmental and economic). Annual and short-term system goals include: minimizing the production of garbage, minimizing the environmental burden of the overall system, minimizing costs to taxpayers and maximizing opportunities for new business. The systematic framework is designed to annually monitor the existing system for several environmental parameters and costs, monitor other comparable jurisdictions, obtain input and feedback from the system users, evaluate potential new waste management components and implement approved waste management components. The performance of the waste management system is measured in the diversion rate, life cycle analysis of environmental benefits, cost per tonne landfilled or cost per tonne diverted, customer satisfaction, capture rate, etc.

The Kumasi Metropolitan Assembly produced a strategic sanitation plan for Kumasi for the period 1990–2000 which was later reviewed and extended for the period 1996–2005. The component of solid waste management within the plan seeks to develop a landfill for the city and to engage the private sector in waste management services. These have, so far, been achieved in the city. No specific plan exists solely for waste management in the city with targets to meet and indicators to measure its progress.

3.6. Government laws and regulations

In the province of Ontario, the provincial government provides regulations and policies for waste management. Key provincial legislations pertaining to waste management are 3Rs Regulations (under the Environmental Protection Act) and Waste Diversion Act. Ontario's 3Rs Regulations were passed in 1994 and outline specific minimum waste management requirements for municipalities, industry and institutions. In 2002, under the Waste Diversion Act, Waste Diversion Ontario was formed to support the development, implementation and operation of waste diversion programs for materials including blue box materials, used tires, used oil, household special waste and electronic and electrical equipment. In 2004, the provincial government set a goal for all Ontario municipalities and businesses to divert 60% of the Province's waste. The local government (municipal government) passes bye-laws, delivers or contracts for services and uses taxes and fees to pay for services to meet provincial regulations. The bye-laws that govern waste management in the city of London are the municipal waste and resource material collection bye-law (provides regulation for the collection of municipal waste and resource materials in the city) and the waste management system fees and charges bye-law (provides for imposing fees and charges for services, activities and use of the city's waste management system).

No distinct law has been identified in Ghana for the management of solid waste; however, some key policy documents exist. Available key national policy documents pertinent to solid waste management are the National Environmental Sanitation Policy (prepared by the Ministry of Local Government and Rural Development in 1999 to develop and maintain a clean, safe and pleasant environment for human settlements), Guidelines for Landfills/Safe and Sound Management of the Bio-Medical Wastes in Ghana (drawn up by the environmental protection agency to establish standards for design, construction and management of waste disposal systems to protect public health and the environment) and Manual for the Preparation of District Waste Management Plans in Ghana. The Kumasi Metropolitan Assembly has bye-laws related to the handling of wastes, which are deemed to be outdated particularly in terms of penalties. The enforcement of these bye-laws has also been weak.

3.7. Challenges for MSWM in Kumasi as enumerated by city authorities

Current challenges to waste management in Kumasi that city authorities face are:

- Inadequate funding for capital investment for effective delivery of waste management services.
- Inadequate equipment holding culminating in limited coverage of service delivery
- Inadequate bye-laws and lack of enforcement of available ones.
- Inadequate revenue mobilization to finance Waste Management Service costs.
- Bad attitude of residents such as indiscriminate disposal of household waste and littering due to lack of effective environmental health education and service promotion strategy.
- Poor infrastructure, particularly road networks and waste collection points, mostly in new settlements, which impacts negatively on service delivery.

4. Comparison of the two MSWM systems

The waste management systems in the cities of London and Kumasi typically describe the situation of waste management in developed and developing countries. The trends evident globally in waste management are described in Wilson (2007) as developed countries exhibit a high degree of sound environmental considerations in their waste management utilizing sanitary landfills, waste treatment and processing, energy and material recovery options whereas waste disposal is uncontrolled and waste treatment, processing, energy and material recovery are rare in developing countries.

The MSWM systems in London and Kumasi are discussed in terms of the key features of IWM and common system drivers identified in case studies of IWM presented in McDougall et al. (2001). These key features of IWM include the utilization of an overall approach, the use of a range of collection and treatment methods and handling of all materials in the waste stream in an environmentally effective, economically affordable and socially acceptable manner. The system drivers identified by waste managers include: good system management, vision, stability, critical mass, landfill space, funding, legislation, control of all solid wastes and public opinion and communication. The key IWM features and system drivers are combined for the discussion of the two waste management systems as follows.

4.1. Good system management

It is asserted in UNEP (2005) that, in many instances in developing countries, the largest impediments to efficient and environmentally sound handling of MSWM are managerial, rather than technical. Improving the operational and management capabilities of individuals and institutions involved in MSWM at the local level is therefore extremely important. A good system management is discussed here as a system that takes an overall approach and has vision and stability. The city of London exhibits good system management by adopting the continuous improvement strategy for waste management in the city. It has well defined long and short-term goals and has put in place a strategic framework for achieving these goals. The system collects essential data that is utilized in monitoring progress and finding ways for improvement. The political framework of the city provides stability and avoids unnecessary interference in the waste management system. All city staff including senior staff are paid employees and are not elected or appointed by government (Steblin and Stanford, 2008), hence are not affected by the political process making them independent and providing stability for the waste management system.

In order to achieve long-term stability, the city of London owns the landfill which is a key facility in the waste management system. In Kumasi, the strategy for solid waste management is not well defined. Possible actions to improve waste management are broadly mentioned in the strategic sanitation plan of the city without specific immediate goals and a framework to achieve the goals. Data on waste management is scanty. The highly politicized administration of the city can sometimes interfere with long-term waste management projects in the city. A lesson that can be drawn from the city of London to provide a clear pathway and stability for the establishment of a sustainable waste management system in Kumasi is the drawing up of a waste management plan for the city. This could be done after careful assessment of all waste produced in the city and available infrastructure. A system must be put in place to collect regular data on the performance of the waste management services which could then be used to annually assess the performance of the waste management system and to identify possible points of intervention. Instituting a good management system will require training of staff that will be highly motivated and determined to provide practical solutions to the challenges in the waste management of the city.

4.2. Control and handling of all wastes generated

The city of London, with a per capita household waste generation of 1.2 kg/day and a population density of 837.9 persons per km^2 in the year 2006, handled a total of 267,000 tonnes of waste, as compared with the 365,000 tonnes generated in Kumasi with a per capita waste generation of 0.6 kg/day and a population density of 6342 persons per km^2. This comparison shows that, although Kumasi has a lower per capita waste generation rate due to the higher population, the total amount of waste to be managed is greater than that of the city of London. This clearly indicates the amount of waste handled in an urban area of a developing country is no less than that handled in a developed country; hence there is an urgent need for instituting integrated waste management systems in both urban settings. The use of a range of collection and treatment methods in the city of London ensures that the entire waste generated in the city is accounted for, while over 15% of waste generated in Kumasi is not collected or accounted for. The two systems of waste collection in Kumasi could be carefully evaluated and optimized for the different sections of the city to ensure that all the waste generated in the city is accounted for. The bye-law for waste and resource material collection for the city of London holds the municipal authority and the citizens accountable for the handling of all wastes generated in the city. This ensures control of all the waste in the city. The waste handling bye-law for Kumasi needs to be revised, as noted by the city authority. In revising the bye-law, the responsibilities of both citizens and the local authority should be clearly defined with stringent and appropriate penalties that will facilitate compliance as is seen in the city of London's waste management bye-laws.

4.3. Consideration of critical mass for system design

Scarcity of land for landfills and stringent environmental regulations drove many cities in developed countries to develop integrated waste management systems with the goal of reducing the amount of waste going to landfills (McDougall et al., 2001). The reduction of waste generation has been a major driver of the waste management approach in the city of London. In view of the bottlenecks involved in the development of new landfills, the city authorities targeted the reduction of amount of waste that is landfilled in order to extend the life of the existing landfill. This led to the rigorous waste diversion program that is being implemented in the city. The evolution of the waste diversion program in London shows the ability to develop appropriate infrastructure in relation to the types and quantities of materials available for waste diversion. It is ensured that the method of collection of particular waste materials corresponds to the quantities of these materials in the waste stream and the availability of end markets for these materials. Kumasi is one of the only municipalities in Ghana that can boast of having an engineered sanitary landfill. Although at present the issue of disposal space has been resolved, there is still the need to divert materials from the landfill in order to prolong the life of the landfill due to the increasing amounts of waste and increasing non-biodegradable materials in the waste stream. As the private sector is involved in the collection of waste in Kumasi, waste diversion programs could be explored in collaboration with the existing informal sector involved in waste recycling in the city. A rigorous analysis of various locally developed waste collection and resource recovery strategies with community involvement could probably reduce the amount of waste that is unaccounted for, collected and transported to the landfill. Strategies for the collection of materials must be based on the availability of these materials in the waste stream in quantities that will make the cost of collection worthwhile. Private sector involvement in the development of waste diversion in Kumasi could be more effective if the environment created is competitive and there is a way to monitor performance and provide accountability.

4.4. Environmentally effective system

A unique feature of the city of London's waste management system is the use of a computer model to measure the environmental performance of the total municipal waste management system. The computer model "Integrated Waste Management (IWM) Model" was developed by Corporations Supporting Recycling (CSR) and the Environment and Plastic Industry Council (EPIC) with their technical consultants, Proctor & Redfern and Environsphere, in cooperation with the city of London and Environment Canada. The progress made in the city of London in reducing the environmental impacts of the waste management system are clearly shown from the model results produced for the city for the years 1995–2006 (City of London, 2007). As part of the continuous improvement strategy adopted the city of London is committed to ensuring the reduction of the environmental impacts of its waste management system. Although the waste management system in Kumasi seeks to protect the environment, there is no system in place to evaluate the impacts of the waste management system on the environment. An assessment of the environmental performance of the waste management system will be a good indicator of the progress made in waste management in the city if it is considered by the city authorities.

4.5. Economically affordable system

The waste management system in London is funded in a number of ways. General property taxes are the largest contributor to the funding of residential waste management. In 2006, 72% of the gross cost of residential waste management was covered by property taxes, 25% by recycling revenues and recycling payment from industry and 2% from fees from some services like 4-yard garbage bin rentals and extra service payment for multi-residential garbage pickup. As future waste diversion is planned for the city, high percentage of property taxes is not viewed as a sustainable option of funding by the city administration. The city administration is considering various sources of revenue including increasing property taxes, introducing flat rate or user fees, increasing landfill tipping fees and/or seeking additional funding from government and industrial sources. Funding for waste management in Kumasi has been mostly provided by government subsidies and city revenue, only 15% of service costs is paid by households whose waste is collected under the door-to-door scheme. This has been indicated as one major problem that undermines the waste management system. There is the need to evaluate various funding schemes in order to improve service delivery. The involvement of the private sector to provide waste recovery services could help generate revenue to fund some aspects of the waste management system. A good system analysis and strategies in place for waste management in Kumasi could provide efficiency in the utilization of the available resources to cover most of the system costs while attracting grants and subsidies from the international donor community.

4.6. Socially acceptable strategies

Waste management system in the city of London is developed based on the support of the citizens. Proposed strategies for waste management are subject to public opinion. It can be seen in the document 'road map to maximize waste diversion in London' (City of London, 2007) that the citizen's views are sought and utilized in implementing waste management plans for the city. The citizen is at the centre of waste management in the city and it ensures that citizens and city authorities hold themselves accountable to waste management strategy adopted, which makes the system sustainable. Citizens of Kumasi should be made aware that they are accountable for the impact of their choices on how much waste they produce and how it will be managed. The communities should be involved in making decisions concerning waste management strategies. There should be a method of communicating waste management system performance and proposed strategies with the community in order to get feedback and support from the community. The communication system that best suits the public should be utilized.

4.7. Enactment and enforcement of legislation

Adequate legislation in place for the handling, treatment and disposal of all waste generated in the city of London has contributed positively to the development of the current integrated waste management system. The national, provincial and municipal legislation in place provides support for the waste management system in the city. The flexibility of the legislation, especially in the case of the city bye-laws, makes it possible for the legislation to be in consonance with the strategy accepted for waste management in the city in consultation with the citizenry. The sanctions for flouting the waste management bye-laws is clearly spelt out and implemented. This ensures compliance with the city's regulations concerning waste management. This is a good lesson that can be adopted in the city of Kumasi. As the bye-laws for waste handling the city are being reviewed, the structure can be made flexible with provision for periodic reviews to agree with the strategy for waste management in the city. The bye-laws must be made easily accessible or visible to all citizens to ensure that there are no excuses for non-compliance.

5. Conclusions

The significant strides made in achieving the current level of success in the city of London's waste management system is broadly due to the city's belief that a sustainable waste management system is based on sound guiding principles, strong service delivery values with as many locally based solutions as possible and moving at a fiscally responsive pace. This mindset is needed to move waste management in Kumasi and largely in developing countries towards achieving higher levels of sustainability. Any substantial change in the MSW management in Kumasi will require close cooperation between government, private sector and citizens. Although the city of London continues to draw up and implement strategies to meets its targets for achieving a high level of sustainability in its MSWM system, it serves as a good example to many cities as they aspire to see improvement in MSWM.

The resources and characteristics available for MSWM in London and Kumasi are obviously different as elaborated in the MSWM overview. The lessons that can be drawn from the MSWM features of the city of London to improve MSWM in Kumasi include:

I. Preparing a strategic, integrated solid waste management plan for the city. The plan should be drawn taking into account the waste generation sources, quantity, characteristics and the socio-economic and cultural structure of the city. In developing the plan, all possible stakeholders in the waste management system must be identified and brought together. Performance indicators should be agreed upon by all stakeholders and properly communicated to all parties to ensure that stakeholders feel part of the waste management system and are committed to its success. The plan should also consider financing schemes that will adequately pay for the cost of waste management and adoption of modes of payment that will be most effective considering all income groups in the city. This will require research and collaboration from all stakeholders. Intensive education of the inhabitants of the city is required to ensure they fully understand the health hazards posed by inadequate MSWM which will motivate them to pay for MSWM services.

II. Enacting strong and adequate legislation both from the national and city level to guide waste management decisions and strategies. To this end, there is the need for the enactment of a comprehensive national waste management law, backed by the requisite regulatory framework in terms of the bye-laws by the Kumasi Metropolitan Authority. These bye-laws should be made accessible (communicated sufficiently) to the inhabitants of the city to ensure no excuses for non-compliance.

III. Evaluating the real impacts of the waste management system. It will be good to measure the extent of pollution or environmental impacts associated with the existing waste management system to better appreciate the need for instituting adequate measures to prevent its occurrence.

IV. Taking steps to extend the lifespan of the cities landfill through waste diversion. Although Kumasi has a sanitary landfill, there is the need to divert waste from the landfill to increase its lifespan due to increasing waste generation and the increasing public opposition to siting MSWM facilities near their neighborhoods as citizens become more aware of the risks associated with MSWM facilities. As is seen from the situation in London, even though the landfill still has a possible life span of 20 years all efforts is being put in place to increase it through waste diversion. Attention could be paid to the activities of the informal sector involved in recycling activities in the cities and avenues sought to utilize their services and recognize their contribution to waste diversion and resource conservation.

V. Utilizing locally based solutions for MSWM service delivery. Locally based solutions should be sought for waste management equipment to ensure that they are serviced frequently and are in good condition at all times. This could reduce the investment needed for effective service delivery.

There is no single approach to waste management that makes it sustainable however the principles of integrated waste management could be followed to guide the development of site specific

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MSW system that will be sustainable as demonstrated in the city of London. The good news is that Kumasi does not need to reinvent the wheel. All the requirements for sustainable waste management are documented in many other jurisdictions and can be easily transferred to Kumasi.

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