KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KUMASI, GHANA

DEVELOPING AN OPTION FOR SUSTAINABLE PLASTIC WASTE MANAGEMENT IN GHANA: A CASE STUDY OF SUNYANI MUNICIPALITY, GHANA

BY

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DECLARATION

I hereby declare that, except for specific references which have being duly acknowledged, this thesis is my own work and that, to the best of my knowledge, it has not been submitted either in part or whole for any other degree elsewhere.

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ABSTRACT

Urbanization and continuous economic growth of Sunyani municipality have resulted in rapid increase in volume and types of solid waste. This thesis provided a consolidated data on municipal solid waste (MSW) generation, as well as data on plastic waste component of the MSW which is quite problematic. The total amount of waste collected during the study period of one month was 6857.1 kg and an average of 685.68 kg per day. The study results shows that the total amount of 2,516,823.3 kg of solid waste is generated in the municipality for the period of one month which translate to an average of 83,894.11 kg of MSW generated daily. The solid waste generation rate was 0.57 kg per person per day. The average amount of plastic waste generated daily was found to be23851.7 kg and this represents 22.93% of the MSW. The plastic waste generation rate was 0.14 kg per person per day. The percentage of various sorted types of plastic in the MSW were as follows: PET (12.94%), HDPE (4.95%), PVC (0.01%), LDPE (17.26%),PP (14.59%), PS (11.24%), Others (5.14%) and HDPE/LDPE composite (sachet water plastic) (34.61%). The sachet water plastic, which is without resin code, was analysed and identified by Fourier Transform Infrared (FTIR) machine. The sachet water plastic, which is also the most abundant plastic component in the MSW was pelletized into recyclate (pellets) which is stored and can be sold to other recycling companies.

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To the Almighty God be glory and praise for His grace that kept me through.

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DEDICATION

This work is dedicated to my father Mr George W. Boateng, my mother Ms Augustina Oforiwaa, my wife Ms Martha Oduro and my lovely children Lovebridge, Clive and Lloyd.

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LIST OF ABBREVIATIONS

MSW	Municipal Solid Waste
SWM	Solid Waste Management
RL&T	Rubber, Leather and Textiles
MMDAs	Metropolitan, Municipal and District Assemblies
AMA	Accra Metropolitan Area
SMA	Sunyani Municipal assembly
C&D	Construction And Demolition Waste
PE	Polyethylene
PS	Polystyrene
PVC	Polyvinyl Chloride
EP	Epoxide
PF	Phenol-formaldehyde
PUR	Polyurethane
PTFE	Polytetrafluoroethylene
UP	Unsaturated polyester resins
LDPE	Low-Density Polyethylene
HDPE	High-Density Polyethylene
PPVC	Plasticized Polyvinyl Chloride
PET	Polyethylene terephthalate
BOD	Biological Oxygen Demand
FTIR	Fourier Transform Infrared
DESSAP	District Environmental Sanitation Strategy and Action Plan
EPA	Environmental Protection Agency

CHAPTER ONE

INTRODUCTION

1.1 Background

Urbanization, industrialization and continuous economic growth have resulted in rapid increase in volume and types of solid and hazardous waste. The amount of municipal solid waste (MSW), one of the most important by-products of an urban lifestyle, is growing even faster than the rate of urbanization. In 2003, there were 2.9 billion urban residents who generated about 0.64 kg of MSW per person per day (0.68 billion tonnes per year) worldwide. Ten years on, these amounts have increased to about 3 billion residents generating 1.2 kg per person per day (1.3 billion tonnes per year). It is estimated that by 2025, this will increase to 4.3 billion urban residents generating about 1.42 kg/capita/day of municipal solid waste (2.2 billion tonnes per year) (World Bank, 2013)

The World Bank Group, in 2013, provided a consolidated data on MSW generation, collection, composition, and disposal by country and by region. Despite the importance of this report, reliable global MSW information is not typically available. Even where it is available, data is often inconsistent, incomparable and incomplete. The report however made projections on MSW generation and composition for 2025 in order for decision makers to prepare plans and budgets for solid waste management in the coming years (Global Waste Management Market Report 2007).

Solid Waste Management (SWM) in most nations is being handled by national and local governments. Although considerable efforts are being made by many Governments and other entities in tackling waste-related problems, there are still more room for improvement. In developing countries where open dumping with open burning is the norm, it is common for municipalities to spend 20-50 percent of their available budget on solid waste management even though 30-60 percent of all the urban solid wastes remain uncollected and less than 50 percent of the population is served. In low-income countries, collection alone drains up 80-90 percent of municipal solid waste management budget. In mid-income countries, collection costs 50-80 percent of total budget. In high-income countries, collection only accounts for less than 10 percent of the budget, which allows large funds to be allocated to waste treatment facilities. (World Bank, 2013).

In advanced countries, upfront community participation reduces the collection cost and facilitates waste recycling and recovery. Hence, developing countries face uphill challenges to properly manage their waste with most efforts being made to reduce the final volumes and to generate sufficient funds for waste management. If most of the waste could be diverted for material and resource recovery, then a substantial reduction in final volumes of waste could be achieved and the recovered material and resources could be utilized to generate revenue to fund waste management through a system based on the 3Rs (reduce, reuse and recycle). It has been shown that with appropriate segregation and recycling system significant quantity of waste can be diverted from landfills and converted into resource (UNEP, 2009).

Accra, the capital city of Ghana, is said to be generating over 2,200 metric tons of waste daily (Daily Graphic, February 6, 2014: page 40). This has put pressure on city authorities responsible for managing waste and ensuring that the capital city is clean at all times. At all the places demarcated as landfill site or dumpsite, residents have met them with fierce resistance due to the environmental and health implications associated with the sites. Such sites are noted for unbearable stench, flies and rodents as well as heavy smoke which engulfs the nearby communities. Examples abound in Accra of residents picking up arms against the siting of landfill sites or dumps near their communities. Mallam, Oblogo, Achimota and most recently Pantang, near Abokobi, are typical examples of residents picking up arms against the siting of these landfill sites. At all these locations, authorities were forced to close down the landfill sites as they succumbed to the pressure from their constituents. These pressure and threats from residents near the landfill site have resulted in the Environmental Protection Agency (EPA) giving the assembly an ultimatum to close down some of these dumpsite because of the environmental and health hazards the site was posing to residents (Daily Graphic, February 6, 2014: page 40).

Currently, most Metropolitan, Municipal and District Assemblies (MMDAs) have engaged the services of Zoomlion Ghana Limited, a waste management company, to collect their waste and manage their landfill site by constantly using its machines to compact the waste and ensure that trucks bringing in waste dispose it properly. Zoomlion also from time to time spray some of the landfill sites and their surroundings to reduce the infestation of flies and rodents. As part of steps to mitigate the excessive smoke that engulfed the nearby communities, some of the MMDAs also engaged the scavengers at the sites to find solutions to the burning of the refuse.

Although the organic solid waste take a bulk of the MSW, the problem of organic solid wastes management is not a big issue as compared to plastic wastes. This is because the organic solid waste is biodegradable. However, the non-biodegradable nature of plastic waste poses a big problem since the plastic waste can stay in the environment for quiet a period of time causing all sorts of problems.

The management of these Plastic Waste through combustion (incineration) is not environmentally friendly and sustainable since this may release carbon dioxide, a major contributor to global warming (greenhouse effect). Landfilling with Plastic Waste is not also desirable since plastic is non-degradable and no economic value would have been derived from the waste in that case. According to a study conducted in Accra, Ghana by GOPA Consultants in 1983, Plastic Waste accounts for 1-5% (of net weight) of the total amount of waste generated (Lardinois and Van de Klundert, 1995). Since then, there has been a tremendous increase in plastic waste particularly sachet water bags due to increase urbanization and consumption pattern.

The best option for Sustainable Plastic Waste Management is through recycling. This is because the benefits of recycling of Plastic Waste are numerous and also environmentally friendly compared to the other methods of waste disposal. Through recycling of Plastic Waste, we can have material and energy recovery and therefore value will be derived from the waste instead of regarding it as garbage or trash.

This topic was deemed necessary after series of media reportage on plastic waste menace in the Accra Metropolitan Area (AMA). Upon viewing and listening to various discussions, a quick survey was done to assess the situation in Sunyani Municipal assembly (SMA). The observation confirmed that the situation though not as huge as the one in AMA; was emerging since Sunyani is a growing municipality. This thesis work will also serve as a working document for policy makers and serve as a way of turning garbage into wealth as well as providing jobs to the urban poor. It is hoped that this document shall be useful to other countries where plastic waste is engulfing all the major cities and causing all sorts of environmental problems.

1.2 Problem Statement

Waste management is one of the major challenges confronting most Metropolitan, Municipal and District Assemblies (MMDAs) in Ghana. Very limited research work have been done on waste generation and disposal in some urban areas in Ghana. It is envisaged that for proper integrated solid waste management to be put in place, the characteristics of the solid waste generated must be known (Sakai *et al.* 1996).Sunyani is one of the vibrant and commercial municipalities in Ghana due to Urbanization and continuous economic growth. In 2000 the population of Sunyani municipality was 101,145. Currently, with a growth rate of 3.8 percent, the estimated population is 147,301. The growth rate of Sunyani compared with the national growth rate of 2.7 percent indicates a high growth rate (GSS, 2010).The accompanying increase in economic activities in the municipality coupled with historic and cultural heritage of the people make sanitation an important issue to consider in keeping the municipality clean.

Effective and adequate solid waste management in the municipality is therefore necessary to ensure clean environment in order to promote public health and sustainable development. The problem of domestic waste disposal especially iced water sachets and other plastics has been of a major concern in the municipality (Sunyani Municipal Assembly annual report, 2011). These solid wastes are scattered all over the municipality especially some days after market day. The worry is the fact that our gutters get choked with plastic waste leading to flooding in most parts of the city after the rains. Some other concerns have been that our streets have been engulfed with sachet water plastic waste destroying their aesthetic beauty thereby driving away tourists (Wienaah, 2007). Our livestock may also feed on plastic waste and get choked and die. Choked gutters with plastic waste also become fertile breeding grounds for mosquitoes infesting the general populace with malaria (Wienaah, 2007).

As a result of the widespread replacement of the existing cultural packaging methods of food, beverage, water and other products using leaf wrappers, brown paper and metal cup with plastics, there has been an increase in plastic waste in the municipal solid waste streams in large cities in Ghana. The use of plastics in food and water packaging industry is favoured due to its versatility, inertness and flexibility. After the usage of the product, these plastic packaging materials, are most often dumped indiscriminately. This has made solid waste management one of the major challenges of Sunyani Municipal assembly over the years.

The Organic component of Municipal Solid Waste may not be too much of a problem since that is biodegradable. However, the Plastic Waste component of the Municipal Solid Waste is quite problematic because this can stay in the environment for a considerable length of time causing all sorts of problems. The two existing waste management practices in the municipality namely: combustion and land filling are not commercially and environmentally friendly since the former may release carbon dioxide, a major contribution to global warming and the latter is not desirable since plastics takes a longer time to biodegrade. There is therefore the need for a better and sustainable option for waste management through recycling.

1.3 Main Objective of the Research

The main objective of the research is to develop an integrated waste management option for plastic waste in Sunyani municipality.

1.4 Specific Objectives of the Research

The specific objective of this research is to:

- Quantify the MSW in Sunyani Municipality
- Sort, identify and quantify the amount of plastics in the MSW
- Determine per capita solid waste and plastic waste generation in the municipality.
- Produce pellets from plastic waste which can be used to manufacture other plastic products

1.5 Justification

Quantification and characterization of solid waste generation assumes great significance which will enable accurate assessment of waste load and encourage proper planning of solid waste management system. Although extensive work has been conducted on solid waste generation and disposal in Ghana, there is no such work conducted in the Sunyani municipality. Even where it has been done, less attention is given to the plastic component in the waste stream. Quantification and characterization of solid waste as well as the MSW generated would help in achieving proper solid waste management and utilization of reusable resources in the municipality. Plastic waste which is the most problematic component in the municipal solid waste stream needs a better and sustainable option for waste management through recycling.

Recycling of plastic waste are environmentally friendly compared to the existing methods of waste disposal in the municipality. Also, through recycling of Plastic Waste, material and energy recovery can be obtained and therefore value will be derived from the waste instead of regarding it as garbage or trash. In Ghana, and Sunyani municipality in particular, people have developed strong taste for drinking water which comes in plastic bags (sachet water) and PET bottles due to its portability. After drinking the water, these bags are discarded indiscriminately thereby littering the whole environment. These bags now constitute a major proportion of the plastic waste generated throughout the country. Also over the years, plastics have replaced leaves, glass and metals as a cheaper and more efficient means of packaging (IRIN, 2006). Soon after usage, these are randomly discarded. They then collect around the city, choking gutters, threatening small animals, damaging the soil and decreasing the beauty of the city.

CHAPTER TWO

LITERATURE REVIEW

2.1 Waste in the Environment

During manufacturing process, products are produced from raw materials and delivered to the consumers. Thus, converting raw materials into a form that can be used to fabricate a finished product. The process generate three main categories of waste in each stage of product's life cycle: atmospheric emissions, waterborne waste and solid wastes.

Solid waste is material, which is not in liquid form, and has no value to the person who is responsible for it. Synonyms to solid waste are terms such as "garbage", "trash", "refuse" and "rubbish (Zurbrugg, 2003).

2.2 Types Of Solid Waste

The type of solid waste of a country may be categorised in several ways. With respect to its impact on solid waste management, the type of solid waste is categorised on the basis of the sources of the solid waste. There are two basic sources and for that matter, two types of solid wastes. These are: non-municipal and municipal as discussed below (UCCP & California University, 2009).

2.2.1 Sources And Categories Of Non-Municipal Solid Waste

Non-municipal solid waste is the discarded solid material from industry, agriculture, mining, and oil and gas production. These include: construction materials such as roofing sheets, electrical fixtures, bricks; wastewater sludge; incinerator residues; ash; scrubber sludge; oil/gas/mining waste; railroad ties, and pesticide containers (UCCP & California University, 2009).

2.2.1.1 Industrial Waste

Industrial waste is a type of waste produced by industrial activity, such as that of factories, mills and mines. It has existed since the outset of the industrial revolution (USEPA, 2010). The typical waste generators are light and heavy manufacturing, fabrication, construction sites, power and chemical plants and the type of wastes generated are packaging waste, food wastes, construction and demolition materials, hazardous wastes, ashes and special wastes (Hoornweg & Thomas, 1999).

Industrial waste also needs further local refinement. Many industrial processes have specific wastes and by-products. In most cities this material, with its relatively easier flow and quality control, is the first material to be recycled. Some industrial process waste requires specific treatment. For most MSW management plans industrial by-products are not included in waste composition analyses, however household and general waste should be included since it is usually disposed at the municipal landfill site.

2.2.1.2 Construction and Demolition Waste

An important component of solid waste that needs to be considered is ‘construction and demolition waste’ (C&D). These include building rubble, concrete, Masonry materials, soil, rock, wood (including painted, treated and coated wood and wood products), land clearing debris, wall coverings, plaster, dry wall, plumbing fixtures, non-asbestos insulation, roofing shingles and other roof coverings, asphaltic pavement, glass, plastics that are not sealed in a manner that conceals other wastes, empty containers which are ten gallons or less in size and having no more than one inch of residue remaining on the bottom, electrical wiring and components containing no hazardous liquids (NYS Dept. of Environmental Conservation, 2010).In some cities this can represent as much as 40% of the total waste stream (World Bank, 2012)

2.2.1.3 Agricultural Waste

These waste are resulted from the cultivation of crops, tending of orchards, vineyards, dairies, feedlots and the running of farms in general contributes to the solid waste stream in the form of spoiled food wastes, agricultural wastes such as dung, animal carcass, husks of corn etc., hazardous wastes (e.g., pesticides) (Hoornweg & Thomas, 1999).

2.2.2 Sources and Categories of Municipal Solid Waste

Municipal solid waste is made up of durable and nondurable goods, containers and packaging materials, food waste and yard trimmings, miscellaneous organic waste arising from residential, commercial, institutional and industrial sources.

2.2.2.1 Residential (Household) Wastes

Usually residential waste consist of food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (e.g., bulky items, consumer electronics, white goods, batteries, oil, tires), and household hazardous wastes) and these are generated by single and multifamily dwellings (Hoornweg & Thomas, 1999).

2.2.2.2Commercial Wastes

Commercial wastes consist of paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes generated by Stores, hotels, restaurants, markets, office buildings, print shops, service stations, etc (Hoornweg & Thomas, 1999).

2.2.2.3 Institutional Waste

These wastes consist of paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes. The waste generators in this category are Schools, hospitals, prisons and government centres (Hoornweg & Thomas, 1999).

2.2.2.4 Municipal Service Waste

Services such as street cleaning, landscaping, parks and beaches maintenance, upkeep of other recreational areas and water and wastewater treatment plants generate wastes such as street sweepings; landscape and tree trimmings; general wastes from parks, beaches, and other recreational areas and sludge (Hoornweg & Thomas, 1999).

2.3 Composition of Municipal Solid Waste

In the municipal solid waste stream, waste is broadly classified into organic and inorganic. In general, the organic waste can be classified into three broad categories: putrescible, fermentable and non-fermentable. *Putrescible waste* are waste that tend to decompose rapidly such that if not carefully controlled produce unpleasant smell. The major sources of putrescible waste are food preparation and consumption, flowers, and yard waste. *Fermentable waste* tend to decompose rapidly but without unpleasant odour. Major sources are crop and market debris. *Non-fermentable waste* tend to resist decomposition and breakdown slowly (World Bank, 2012).

MSW composition is categorized as organic, paper, plastic, glass, metals, and 'other.' These categories can be further refined, however, these six categories are usually sufficient for general solid waste planning purposes. Other types of solid waste not included in MSW are industrial waste generated from manufacturing and processing, construction and demolishing waste, agricultural waste, oil and gas, and mining waste produced from extraction and processing of minerals. These wastes are not generally considered as MSW but they need to be taken into account when dealing with MSW because it often end up in MSW stream. Waste composition is influenced by many factors, such as level of economic development, cultural norms, geographical location, energy sources, and climate (World Bank, 2012).

2.3.1 Waste Composition by Income and Economic Development

As a country urbanizes and populations become wealthier, consumption of inorganic materials (such as plastics, paper, and aluminium) increases, while the relative organic fraction decreases. Generally, low and middle-income countries have a high percentage of organic matter in the urban waste stream, ranging from 40 to 85% of the total (World Bank, 2012). Paper, plastic, glass, and metal fractions increase in the waste stream of middle- and high-income countries. This is so because, in high-income countries, an integrated approach for organic waste is particularly important, as organic waste may be diverted to water-borne sewers, which is usually a more expensive option (World Bank, 2012).

2.3.2 Waste Composition by Region

The composition of the municipal wastes can vary from region to region and from season to season. Solid waste generated in industrialized countries is characterized by high organic content as compare to waste generated in developing countries.

2.4 Solid waste generation Quantities

Current global MSW generation levels are approximately 1.3 billion tonnes per year, and are expected to increase to approximately 2.2 billion tonnes per year by 2025 (World Bank, 2012). This represents a significant increase in per capita waste generation rates, from 1.2 to 1.42 kg per person per day in the next fifteen years (World Bank, 2012). However, global averages are broad estimates only as rates vary considerably by region, country, city, and even within cities. Waste generation in sub-Saharan Africa is approximately 62 million tonnes per year. Per capita waste generation is generally low in this region, but spans a wide range, from 0.09 to 3.0 kg per person per day, with an average of 0.65 kg/capita/day (World Bank, 2012). The countries with the highest per capita rates are islands, likely due to waste generated by the tourism industry, and a more complete accounting of all wastes generated.

Six hundred out of the 2,200 tonnes of solid waste generated in Accra are left uncollected daily resulting in the current sanitation challenges in some suburbs of the city. It is estimated that Ghana has an average daily waste generated per capita of 0.45 kg, equating to 3.0 million tons of solid waste annually (Mensa and Larbi, 2005). Accra and Kumasi, with a combined population of about 4 million and a floating population of about 2.5 million generate over 3,000 tons of solid waste daily. It is estimated that only 10% of solid waste generated are properly disposed off mainly through landfill sites but options are rapidly depleting. The result is standard and unsafe facilities which poses public health risks and aesthetic burdens.

Determining the total amount of waste generated is very important information when selecting the right kind of logistics in waste collection and transport. This will guide the selection of specific equipment for collecting the waste, designing waste collection routes, material recovery facilities and disposal facilities (Tchobanogblous*et al*, 1993).

2.5 Global Solid Waste Composition

In the municipal solid waste stream, waste composition is broadly categorized as organic, paper, plastic, glass, metals, and 'other.' These categories can be further refined, however, these six categories are usually sufficient for general solid waste planning purposes. Table 2.1 describes the different types of waste and their sources.

Table 2.1: Types of Waste and Their Source

Waste	Source
Organic	Food scraps, yard (leaves, grass, brush) waste, wood, process residues
Paper	Paper scraps, cardboard, newspapers, magazines, bags, boxes, wrapping paper, telephone books, shredded paper, paper beverage cups. Strictly speaking paper is organic but unless it is contaminated by food residue, paper is not classified as organic.
Plastic	Plastic Bottles, packaging, containers, bags, lids, cups
Glass	Glass Bottles, broken glassware, light bulbs, coloured glass
Metal	Metal Cans, foil, tins, non-hazardous aerosol cans, appliances (white goods), railings, bicycles
Other	Other Textiles, leather, rubber, multi-laminates, e-waste, appliances, ash, other inert materials

Statistics show that most of the wastes are found in urban areas around the world. Below are charts showing composition solid waste generated in some part of the world.

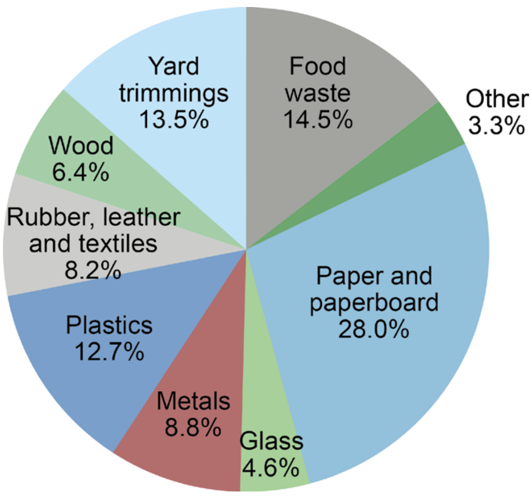


Figure 2.1: U.S. MSW Composition, 2011

2.6: Composition of Waste in Ghana

The amount of solid waste generated in Ghana has been increasing with the rapid increase in population. It was estimated; base on the population of 22 million, that Ghana generates 3.0million tonnes of solid annually and average per capita daily generation of 0.45kg (Mensah and Larbi, 2005). This is expected to increase as the population increases.

Table 2.2: Composition of Solid Waste in Accra

Description Of Waste	Waste Separation In Various Part Of Accra				
%Composition	Zoomlion-AKTP Associates, 2010 Dumpsite Waste Separation	MCI 2010	Zoomlion-R&D, 2009 Household Waste separation	Fobil, et al, 2002	Kramer, et al, 1994
Organic	40.3	67	69	60	73.1
Plastic	19.7	20	17	8	3.3
Metal	2.2	3	2	3	2.1
Glass	1.2	2	2	2	1.5
Textile	6.9	2	3	2	2.2
Paper	7.0	4	5	8	6.6
Others	22.6	2	2	13	11.2

Source: Miezah Kodwo, 2013

2.7 The Waste Management Hierarchy

The **waste management hierarchy** is a series of options for dealing with waste. It is a complex and expansion version of the 3Rs ideology (reduce - reuse – recycle) that indicates a preference for certain types of waste management(Rationalwiki,2014). It is an arrowed triangle logo which ranks as how favourable each option is from an environmental perspective. However, it tends not to say anything about cost or practicality. The standard outline of the hierarchy ranks 6 approaches to waste management. In order (most preferable to least preferable) these are: prevention, minimisation, reuse, recycle, energy recovery and disposal (Rationalwiki, 2014).

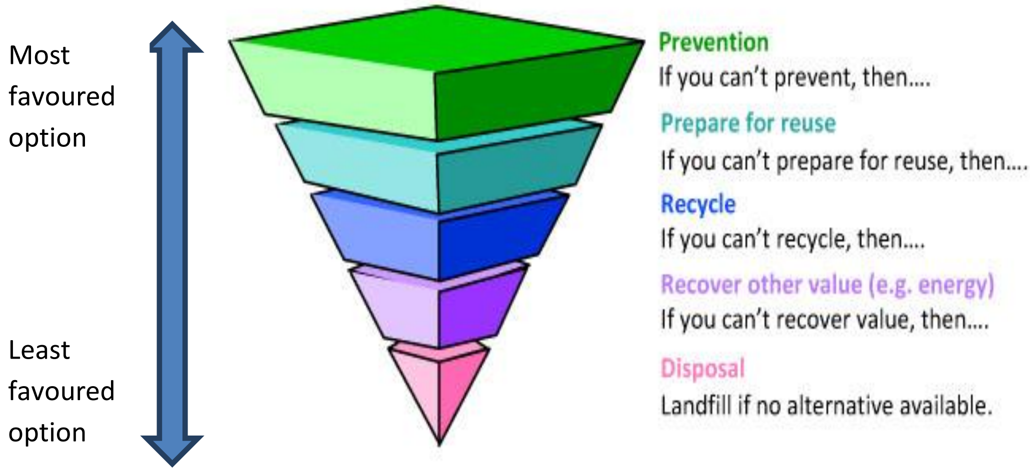


Figure 2.3: Proposed Waste Management Hierarchy

2.7.1: Landfill

Landfill is the oldest form of waste treatment and the least desirable option because of the many potential adverse impacts it can have. The most serious of these is the production and release into the air of methane, a powerful greenhouse gas 25 times more potent than carbon dioxide. Methane can build up in the landfill mass and cause explosions.

In addition to methane, the breakdown of biodegradable waste in landfill sites may release chemicals such as heavy metals resulting in run-off called leachate (European Commission, 2010). This liquid can contaminate local groundwater and surface water and soil, which could pose a risk to public health and the environment. Awareness of these risks resulted in calls for legislation at European level. Under EU legislation, environmental authorities are responsible for issuing permits, conducting inspections and ensuring standards are met (European Commission,2010). The Landfill Directive obliges Member States to reduce the amount of biodegradable waste they landfill to 35% of 1995 levels by 2016, which will significantly reduce the problem of methane production (European Commission, 2010).

In addition, methane gas must be collected in landfill sites and, if possible, used to produce energy. EU legislation on landfilling is making a big difference. Thousands of sub-standard landfill sites have been closed across Europe and the amount of municipal waste put into landfills in the EU has fallen by more than 25% since 1995. However, while a handful of Member States landfill only a small part of their waste, this still remains the most common form of municipal waste disposal in the majority of Member States. (European Commission, 2010)

2.7.2 Energy recovery

Modern waste incineration plants can be used to produce electricity, steam and heating for buildings. Waste can also be used as fuel in certain industrial processes. Poor or incomplete burning of waste materials can result in environmental and health damage through the release of hazardous chemicals, including dioxins and acid gases. To ensure hazardous substances are completely destroyed, incineration plants need to burn waste under controlled conditions and at sufficiently high temperatures. Where the emissions of hazardous substances cannot be prevented, additional measures must be taken to reduce the releases into the environment (European Commission, 2010).

For these reasons, the European Union has set environmental standards for incineration and co-incineration plants. This legislation helps ensure that the environmental costs of waste incineration are minimised while the benefits are maximised (European Commission, 2010). The legislation sets limit values for emissions from plants and requires these to be monitored. It also requires the recovery of any heat generated, as far as possible, and sets thresholds for the energy efficiency of municipal waste incinerators (European Commission, 2010).

Energy recovery through incineration is often not the most efficient way of managing used materials, particularly those that are difficult to burn or which release chemicals at high temperatures (European Commission, 2010). Member States are encouraged to use life-cycle thinking to weigh up the possible environmental benefits and drawbacks when deciding whether to incinerate waste. Primary energy production from municipal waste incineration has more than doubled since 1995. (European Commission, 2010)

2.7.3 Recycling

Much of the waste we throw away can be recycled. Recycling reduces the amount of waste that ends up in landfill sites, while cutting down on the amount of material needed from the natural environment. This is important because Europe is dependent on imports of scarce raw materials, and recycling provides EU industries with essential supplies recovered from waste such as paper, glass, plastic and metals, as well as precious metals from used electronic appliances. EU waste policy aims to ensure that waste is used wherever possible as raw material to make new products (European Commission, 2010).

Recycling also saves energy: recycling an aluminium can, for example, saves around 95% of the energy needed to make a new one from raw material (European Commission, 2010).

The EU has set recycling targets for many types of waste, including old vehicles, electronic equipment, batteries and packaging, municipal waste and waste from construction and demolition activities. Member States are working hard to put systems in place to ensure these targets are met. These systems include Extended Producer Responsibility, which makes producers responsible for the entire life cycle of the products and packaging they produce, including the last stage of the product life cycle, when it becomes waste. Individuals have a very important role to play (European Commission, 2010). In many Member States, householders are asked to separate their waste into different material types (paper, glass, plastics, metal, garden waste and so on). This approach helps to ensure that the highest possible quality material is produced at the end of the recycling process. This maximises the value of the materials and increases the number of products that can be made from them. (European Commission, 2010)

2.7.4 Re-use

Re-use involves the repeated use of products and components for the same purpose for which they were conceived. Refrigerators, ink cartridges and computer printers, for example, can all be refurbished for re-use. The re-use of products or materials such as clothes and furniture that would otherwise become waste has social, economic and environmental benefits, creating jobs and making products available to consumers who could not necessarily afford to buy them new (European Commission, 2010).

Many Member States are introducing policies which encourage re-use and markets in re-used goods. (European Commission, 2010)

2.7.5 Prevention

Good waste management begins with preventing waste being produced in the first place – after all, what is not produced does not have to be disposed of. Waste prevention is becoming more and more important as the global population increases and we eat away at our finite supply of natural resources. However, this is a very challenging concept as it is difficult to measure something which, by definition, never existed. One of the key tools being used to encourage waste prevention is eco-design, which focuses on environmental aspects during the conception and design phase of a product (European Commission, 2010). Eco-friendly products should be made using recycled secondary raw materials and should avoid the use of hazardous substances. These products should consume less energy during the use phase and should be able to be recycled once they have been discarded (European Commission, 2010). Waste prevention is closely linked to improving manufacturing methods and influencing consumers so that they demand greener products and less packaging. Many Member States are running awareness-raising campaigns to educate the public and encourage consumers to demand goods that produce less waste and drive the creation of a more resource-efficient market. (European Commission, 2010)

2.8: Plastic - The problematic Component of MSW

Plastic Waste component of the Municipal Solid Waste is quite problematic because it stays in the environment for a considerable length of time causing all sorts of problems. The common management of Plastic Waste by most countries through burning is not environmentally friendly and sustainable since this may release carbon dioxide, a major contributor to global warming (greenhouse effect) (Wienaah, 2007). Landfilling with Plastic Waste is not also desirable since plastic is non-degradable and no economic value would have been derived from the waste in that case.

2.8.1 What are Plastics

Plastics are man-made organic materials that are produced from oil and natural gas as raw materials. Plastics consist of large molecules (macromolecules), the building blocks of all materials (Hans-Georg, 2003). The molecular weights of plastics may vary from about 20, 000 to 100,000 mg/L (Wienaah, 2007). Plastics can be regarded as long chains of beads in which the so-called monomers such as ethylene, propylene, styrene and vinyl chloride are linked together to form a chain called a polymer. Polymers such as polyethylene (PE), polystyrene (PS) and polyvinyl chloride (PVC) are the end products of the process of polymerization, in which the monomers are joined together (Hans-Georg, 2003). In many cases only one type of monomer is used to make the material, sometimes two or more. A wide range of products can be made by melting the basic plastic material in the form of pellets or powder (Warmer Bulletin, 1992).

Plastics can be either thermoplastics or thermosets. Thermoplastics are plastics that repeatedly soften on heating and harden on cooling. They can be melted down and made into new plastic end products (Hans-Georg, 2003). They are dense and hard at room temperature, become soft and mouldable when heated, dense and hard again and retain new shapes when cooled (see Figure 2.4a for a schematic overview of the structure of thermoplastics) (Wienaah, 2007). This process can be repeated numerous times and the chemical characteristics of the material do not change. In Europe, over 80% of the plastics produced are thermoplastics (Warmer Bulletin, 1992).

Thermosets, on the other hand are not suitable for repeated heat treatments because of their complex molecular structures (see Figure 2.5b) (Wienaah, 2007). The structure of thermosetting materials resembles a kind of thinly meshed network that is formed during the initial production phase. Such materials cannot be reprocessed into new products unlike thermoplastics (Wienaah, 2007). Thermosets are widely used in electronics and automotive products.

Examples of Thermosets include Epoxide (EP), Phenol-formaldehyde (PF), Polyurethane (PUR), Polytetrafluoroethylene (PTFE), Unsaturated polyester resins (UP). Molecular structures of both thermoplastic and thermoset are shown in Figure 2.4

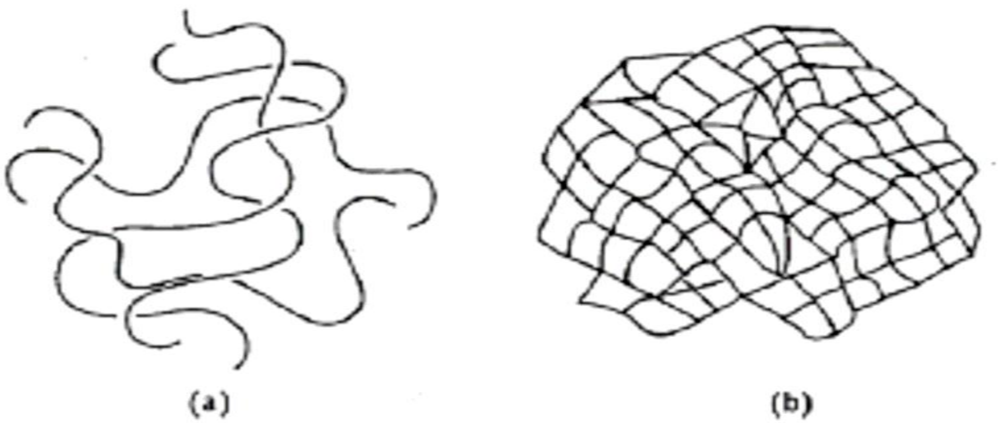


Figure 2.4: The Structure of (A) Thermoplastic and (B) Thermosets

2.8.2 The History of Plastics

The development of plastics can be regarded as one of the most important historical technical achievements of the twentieth century. In just five decades, plastics have virtually dominated every aspect of daily life, paving the way for new inventions, and has been considered as the cheapest materials used in place of other materials such as metal, wood and glass. The success of these materials has been based on their properties of resilience, resistance to moisture and chemicals, resistance to tensile stress and biodegradation, their stability, and the fact that they can be moulded into any desired form (Lardinois and Van de Klundert, 1995).

Alexander Parkesine in the late 1850s invented the first synthetic plastics material, cellulose nitrate, by the modification of cellulose fibres with nitric acid. Early 1930s saw the massive development of the most common plastics used today by manufacturing industries. This period witnessed the introduction of thermoplastics made from the basic materials such as styrene, vinyl chlorine and ethylene, etc onto the market. But the main growth of the plastics industry saw a peak in 1973, when production reached over 40 million tonnes per year (Saechtling, 1987). Following a temporary drop in production during the oil crises and the economic recession in the beginning of the 1980s, the world production of plastics continued to increase to approximately 77 million tonnes in 1986 (Saechtling, 1987), and 86 million tonnes in 1990 (Schouten and Van der Vegt, 1991). The development of plastics did not ceased at that time but rather led to continuous research into plastics till date.

2.8.3 Types of Plastics and their Chemistry

2.8.3.1 Polyethylene (PE)

Figure 2.5:Piled Polyethylene Carrier Bags

Polyethylene is perhaps the simplest plastic, composing of chains of repeating units. It is produced by the addition polymerization of ethylene ($CH_2 = CH_2$). There are two main types of polyethylene. These are low-density polyethylene (LDPE) and high-density polyethylene (HDPE) (Osei-Bonsu, 2013). The properties of PE depend on the manner in which ethylene is polymerized. When ethylene is polymerized at high pressure (1000 to 2000 atm), elevated temperature and catalysed by peroxides, the product is LDPE (Osei-Bonsu, 2013). This form of PE has molar mass of 20,000 to 40,000 g/mol. LDPE is soft, flexible and easy to cut, with the feel of candle wax. When very thin it is transparent, when thick it is milky white, unless a pigment is added (Wienaah, 2007).

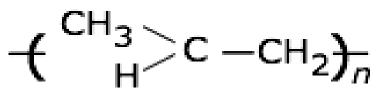
LDPE is used in the manufacture of film bags, sacks and sheeting, blow-moulded bottles, food boxes, flexible piping and hosepipes, household articles such as buckets and bowls, toys, telephone cable sheaths, etc. When PE is catalysed by organometallic compound at moderate pressure (15 to 30 atm), the product is HDPE. Under these conditions, the polymer chains grow to very great length, and molar mass averages hundreds of thousand. HDPE is tougher and stiffer than LDPE, and is always milky white in colour, even when very thin

(Wienaah, 2007). It used for bags and industrial wrappings, soft drinks bottles, detergents and cosmetics containers, toys, jerry cans, crates, dustbins, and other household articles.

2.8.3.2 Polypropylene (PP)

Figure 2.6:(a) Polypropylene Cup

Polypropylene is formed by addition polymerization propylene ($CH_3CH{=}CH_2$). It is generally represented as



Polypropylene is more rigid than PE, and can be bent sharply without breaking. PP exhibit excellent track, arc resistance, dielectric strength, low permeability to water vapour and gases, resistance to chemicals and solvent including aqueous salt, acid and alkaline solutions that are destructive to metals (Hans-Georg, 2003). Typical applications based on these properties include car battery casings, medicine bottles, ketchup bottles, yogurt container and pancake syrup bottles. It is attacked, however, by aromatic and chlorinated hydrocarbon, halogens and active oxidizing agents at high temperature. PP is found in everything from flexible packaging to fibres for fabrics and stools and chairs, high-quality home ware, domestic appliances, suitcases, wine barrels, crates, pipes, fittings, rope, woven sacking, carpet backing netting surgical instruments, nursing bottles, food containers, etc. (Wienaah, 2007)

2.8.3.3 Polystyrene (PS)

Figure 2.7: Piled Polystyrene Foam

Polystyrene (PS) is a thermoplastic material that is obtained by polymerisation of monomer styrene extracted as liquid from petroleum. In its unprocessed form, polystyrene is a brittle, transparent material and it is solid at room temperature and soften to liquid at temperature above 100^0C (Abota, 2012). It is often blended (copolymerized) with other materials to obtain the desired properties. High-impact polystyrene (HIPS) is made by adding rubber. Polystyrene foam is often produced by incorporating a blowing agent during the polymerization process. PS is used for cheap, transparent kitchen ware, light fittings, bottles, toys, food containers, etc. (Wienaah, 2007).

2.8.3.4 Polyvinyl chloride (PVC).

Figure 2.8: Polyvinyl Chloride(PVC)Pipes

Polymerization of vinyl chloride (CH_2=CHCl) produces a polymer similar to PE, but having chlorine atoms alternating carbon atoms on the chain. Polyvinyl chloride is a hard, rigid material, unless plasticizers are added (Wienaah, 2007). Common applications for PVC include bottles, thin sheeting, transparent packaging materials, water and irrigation pipes, gutters, window frames, building panels, etc. If plasticizers are added, the product is known as plasticized polyvinyl chloride (PPVC), which is soft, flexible and rather weak, and is used to make inflatable articles such as footballs, as well as hosepipes and cable coverings, shoes, flooring, raincoats, shower curtains, furniture coverings, automobile linings, bottles, etc. (Wienaah, 2007).

2.8.3.5Polyethylene terephthalate (PET)

Figure 2.9 Water Bottle Made Of Polyethylene Terephthalate (PET)

PET is condensation polymer formed from the monomers a diol, ethylene glycol (a colourless liquid obtained from ethylene) and terephthatalic acid (a crystalline solid obtained from xylene). The hydroxyl and the carbonyl group in the presence of catalyst and heat react to form ester (COOR) group which link PET units together into a long chain polymer (Hans-Georg, 2003). The presence of the aromatic ring in the PET repeating unit gives the polymer its characteristic stiffness and strength, especially when the polymer chain is aligned with one another in an orderly arrangement by stretching. PET exists as an amorphous (transparent) and as a semi-crystalline (opaque and white) thermoplastic material (Hans-Georg, 2003). Generally, it has good resistance to mineral oils, solvents and acids but not to bases. The semi-crystalline PET has good strength, ductility, stiffness and hardness while the amorphous type has better ductility but less stiffness and hardness. PET has good barrier properties against oxygen and carbon dioxide. Therefore, it is utilized in bottles for mineral water. Other applications include food trays for oven use, roasting bags, audio/video tapes as well as mechanical components and synthetic fibers (UNEP, 2009).

Other types of plastics include polycarbonate (PC), polyurethane (PU) and nylon or polyamide (PA).

2.8.4: Identification of Plastics

Many different types of plastics may look identical, or one type of plastic may appear to have several physical and chemical characteristics depending on the type of additive that has been used. It is important to correctly identify plastic material before recycling. Failure to do so can create severe problems during reprocessing, leading to products with poor appearance and impaired mechanical properties. It is usually difficult to tell exactly which type of plastic is present solely from the type of product. Many different types of plastics may look identical, or one type of plastic may appear to have several physical and chemical characteristics depending on the type of additive that has been used (Wienaah, 2007). The following tests may be needed to make a definite identification of a plastic:

2.8.4.1 Flotation test

This test can be used to disentangle larger quantities of mixed or shredded polymers, as well as to separate them from non-plastics. The test is also useful for making the complicated distinction between PP and HDPE, and between HDPE and LDPE. When placed in a tube of water and alcohol in certain proportions (this can be tested using a "hydrometer", with a range of 0.9-1.0) the materials will separate according to their density; one material will sink and the other will float (Wienaah, 2007). For example, in a mixture with an exact density of

0.925, the PP will sink and HDPE will float; in one with a density of 0.93, LDPE will float and HDPE will sink.

Note, however, that the flotation test is not exact enough to distinguish between PP and LDPE, since their densities can overlap. In this case the fingernail test and the visual appearance of the material may be more conclusive indicators (Wienaah, 2007).

Another flotation test using pure water and salt can be used to distinguish between PS and PVC, both of which sink in pure water. When a specific amount of salt is added to the water, the PS will float to the surface, while the PVC and dirt will remain on the bottom of the container. The amount of salt need not be measured, but may be determined by experience (Wienaah, 2007).

2.8.4.2 Burning test

This test is carried out as follows (Vogler, 1984). Cut a 5 cm long sliver of the plastic material, 1 cm wide at one end, and tapering to a point at the other. Hold the sample over a sink or stone, and light the tapered end. The colour and smell of the flame can be used to tell the type of polymer. PVC can be confirmed by touching the sample with a red hot copper wire and returning the wire to the flame; it should burn with a green flame. Burn of all residues before repeating the test with the same wire (Wienaah, 2007).

Caution: When conducting this test, be sure to hold the sample at a safe distance from the body and clothing, since the melted material may drip and burn if it falls directly from the flame. Do not breathe in the smoke, since it may contain dangerous substances. Figure 5 shows a demonstration of the burning test. In economically less developed countries, particularly in the informal sector, polymers are usually identified by manual/visual inspection, whereas in industrialized countries, mechanical separation techniques are used (Wienaah, 2007).

2.8.4.3 Infrared Spectroscopy Analysis

The recovery of household plastics is burdened with several problems, including the high costs of separation and the general low level of purity of the waste materials. The packaging industry may use more than 60 different kinds of plastics which are often mixtures or combinations of plastics and other materials. These preclude the melting option, as uncontrolled mixing of different kinds of plastics leads to inferior properties of the resulting material. The plastics may also be contaminated with residues of the packaged product, particularly food, or other packaging material (paper, aluminium) (Wienaah, 2007).

2.8.4.4 Using Plastic Resin Codes

This is a model coding system (using numbers combined with the abbreviations PE, PP, etc.), developed by the Society of Plastics Industry (SPI), in the United States to facilitate the identification of the six most common plastics used on a regular basis. This system, which certainly makes identification easier, are now gaining general acceptance and changes in the packaging of some products, for example using less material or only one type of material, are slowly becoming apparent (Halbekath, 1989). This coding system (see Figure 2.10) is especially suitable for moulded products where the coding can be engraved onto the moulds. In this way, households will be able to identify and separate the various types of plastics before disposal.

Name of Plastic	Identification code	Name of Plastic	Identification code
Polyethylene Terephthalate	01 PET	Polypropylene	05 PP
Polypropylene High Density Polyethylene	02 PE-HD	Polystyrene	06 PS
Polyvinyl chloride	03 PVC	Other plastic (example polycarbonate, PC)	07 O
Low Density Poly-ethylene	04 PE-LD		

Figure 2.10: Plastic Resin Codes

2.8.5 Quantification of Plastic Waste

It is important to put into contest the waste plastic generation in relation with the overall MSW, prior to the identification of plastic waste. Extensive study on plastic waste quantification, including measurement and sample analysis could be costly, time consuming and complicated (UNEP, 2009). One or more of the following methods could be used to quantify plastic waste depending on local conditions:

2.8.5.1 Survey at the Point of Generation

This method of quantifying waste involves visiting or contacting waste generators (e.g. businesses, apartment buildings, etc.) and determining through measurement or observation of the amount of waste disposed during a given time period. Since waste generation is highly variable from place to place, or from one time to another, it is advisable to collect many data points in order to develop a reliable estimate of the *average* amount of waste disposed by that class of waste generator. Typically, estimates of generation are correlated with another variable that describes the generator, such as, number of employees, number of acres, etc. This correlation permits estimates of waste quantities to be "scaled up" to a level larger than the individual generator – e.g., to the countywide or state-wide level (UNEP, 2009).

2.8.5.2 Examination of Records at the Point of Generation

Some businesses and institutions maintain records that reflect the amount of waste disposed over time. This information often can be found in invoices from the waste hauler or from the log sheet. Typically, the amount of waste is expressed in terms of *volume* rather than weight, so a volume-to-weight conversion factor may be necessary in order to quantify the weight of waste (UNEP, 2009).

2.8.5.3Vehicle Survey at the Disposal Facility

This method quantifies the waste that arrives at a disposal facility according to waste sector. Since disposal facilities often do not classify disposed waste according to the same waste sectors that are used in municipal solid waste planning or waste characterization studies, it is sometimes necessary to use statistically valid surveying techniques to determine the portion of a facility's disposed tonnage that corresponds to each sector. The portions that are revealed through the vehicle survey are then applied to a known total amount of waste that is disposed at the facility during a given time period (UNEP, 2009).

2.8.5.4 Examination of Records at the Disposal Facility

Most disposal facilities keep transaction records that reflect the tonnage brought for disposal. In cases where the facility classifies waste according to the same sectors that are considered in the waste characterization study, facility records can provide thorough and reliable data to show the portion of a facility's disposed tonnage that corresponds to each sector. The portions that are revealed in the records are then applied to a known total amount of waste that is disposed at the facility during a given time period (UNEP, 2009).

2.8.6 Sources of waste plastics

Due to its characteristic properties such as light in weight, flexibility and durability, plastics has become one of the most commonly used material for many purposes. Thus, waste plastics are generated from a wide variety of sources. The main sources of plastic waste in Ghana can be classified as follows: industrial, commercial and municipal waste (MLGRD, 1999).

2.8.6.1 Industrial waste

These are wastes generated by the plastic processing, manufacturing, packaging and assembling industries. This is an excellent material for reprocessing, because this material has relatively good physical characteristics, since it is sufficiently clean and not mixed with other materials. It is relatively thick, free from impurities and in ample supply (MLGRD, 1999).

Major sources of these plastic waste include fan blades, seat coverings, plastics used as packaging or wrapping of parts, battery containers from automobile industries, PVC pipes and fittings from Construction and demolition companies etc. Although this type of plastic waste is not common in Ghana, considerable amounts of waste plastics generated by many industries remain uncollected or end up at the municipal dumpsite (MLGRD, 1999).

2.8.6.2 Commercial waste

Shops, supermarkets, hotels, restaurants, institutions during their operations generate waste. These wastes include some amount of plastic wastes which end up into our environment. A great deal of such waste is likely to be in the form of packaging material made of PE and PS either clean or contaminated. These plastics waste are often gathered and burnt as a means of their disposal and this pollute the environment (MLGRD, 1999).

2.8.6.3 Municipal waste

These are plastic waste collected from residential areas, streets, parks, collection depots and waste dumps (MLGRD, 1999). In Ghana, the management of this waste is the responsibility of the ministry of Local Government and Rural Development (MLGRD). This ministry is decentralized into Metropolitan, Municipal and District assemblies (MMDAs). The MMDAs work alongside their private partners such as Zoomlion. They collect the wastes including plastic from residential areas, streets, parks, waste dump site. The amount of plastic wastes from this source keeps on increasing due to the increase of population and life style of the people. In Ghana, the most common type of plastic waste within the municipal waste stream is the “sachet” water film bags that are discarded indiscriminately soon after consuming its contents. Once the content of the plastic sachets or bottles are emptied, they find their way into streets, gutters which then block the flow of water and result in flooding in some parts of Ghana whenever it rains. Such waste plastics are likely to be dirty and contaminated.

2.8.7 Hazardous Effects of plastic waste

The sight and smell of improperly managed wastes constitute a major discomfort to residents and visitors. Pollution of water resources increases the technical difficulty and cost of providing water supplies and the environmental health situation also has serious health impact, with attendant social and economic costs. Flooding with its associated damage to public infrastructure and private property increases with improper solid waste management. The plastic wastes affect the environment in various ways

2.8.7.1 Polluting the Environment

The waste plastic water sachets are discarded randomly after usage. These then scatter around the city, choking drains, threatening small animals, damaging the soil and polluting beaches. The environmental effects of plastics differ according to the type and quantity of additives that have been used. Some flame retardants may pollute the environment (e.g. bromine emissions) (Wienaah, 2007)..Pigments or colorants may contain heavy metals that are highly toxic to humans, such as chromium (Cr), copper (Cu), cobalt (Co), selenium (Se), lead (Pb) and cadmium (Cd) are often used to produce brightly coloured plastics. Cadmium is used in red, yellow and orange pigments. In most industrialized countries these pigments have been banned by law. The additives used as heat stabilizers (i.e. chemical compounds that raise the temperature at which decomposition occurs), frequently contain heavy metals such as barium (Ba), tin (Sn), lead and cadmium, sometimes in combination (Wienaah, 2007).

2.8.7.2 Water pollution and flooding

Plastic wastes find their way into the water bodies thus polluting the water. The plastics then float on the surface of the water bodies, thus preventing direct sunlight for the water organisms. Water animals are killed by plastic waste that finds their way in water bodies as they mistakenly eat plastics as food. Since plastics are indigestive material and stay inside them, then cause pains and this leads to death. After the decay of the animal, the ingested plastic is freed back to the environment again to continue causing problems (Abota, 2012).

Plastic waste in the environment constitute high potential for the spread of infections through run offs during rains and contamination of underground water. Serious leachate generations occur at dump site especially after rainfall and sometimes the leachate can be seen gushing out into areas at the foot of the waste dump where houses are built and the leachate floods enter the residents' compounds. These leachates which obviously contain pathogens are a direct risk to human health and a source of contamination to groundwater and surface waters.

The presence of chemicals as well as some microorganisms has increased the Biological Oxygen Demand (BOD) of the water bodies within the city. "*Ascaris*eggs, which require a lot of oxygen for their development have been identified in various water bodies in Accra (EPA, 2002). This parasite is found where human waste disposal and sanitation practices are poor as in the case of the Korle lagoon. Heavy metals have been identified in this lagoon (Fobil, 2000). The levels of heavy metals notably cadmium, lead and copper in the Korle Lagoon in Accra were found to exceed the World Health Organization's recommended levels (EPA, 2002).

2.8.7.3 Air pollution

The most important environmental problem caused by plastic waste is air pollution. Plastic wastes takes a longer time to biodegrade and made of toxic chemicals that pollute the air. During the production of plastics several substances such as additives and plasticizers may be added. It is very common to see plastic waste being burnt in Ghana (Wienaah, 2007). However, unless the combustion is complete, burning plastics release considerable quantities of polluting substances which causes respiratory problems and cancer as they are inhaled. The incomplete combustion of PE, PP, PS and PVC can cause further problems, as CO and smoke may be produced. As a result of incomplete combustion of PVC also dioxins and other hazardous substances may be formed. The burning of plastics releases CO_2 which is a major contributor to the global warming and affect the environment in general (Wienaah, 2007).

2.8.7.4 Land Pollution and Impact on aesthetic of the environment

Plastic wastes litter the land and find their way in blocking the gutters and drains. The blocking of the gutters and drains by plastic wastes cause flooding whenever it rains, because the rain water cannot get access to flow and the stagnation of the rain water created by plastic wastes provide breeding place for mosquitoes, which later cause malaria to the people (Abota, 2012). The plastic wastes do not affect only the people but also animals such as sheep, goats, cows, fowls etc and these animals die through the taking in of plastic waste along as they graze the field. Again, when plastic waste litter the farm lands, they entangle the crops preventing them to grow. The plastic waste also cover the soil and prevent air penetration into the soil , thereby killing the soil organisms that help to tilt the farmlands (Abota, 2012).

As a result of no cover at most of the dump sites, and the uncollected waste, adverse aesthetic impacts on the environment occur from windblown litter. The waste, which contains a high amount of plastic bags are blown about by the wind. This windblown litter makes the area unsafe and creates unsightly conditions in the environment. The litter and plastics make parts of the city very untidy and unhygienic. Also the dumps themselves have very unaesthetic appearance. The locations of the dumps raise the problem of decreasing value of land and landed property.

2.8.7.5 Human health and social effects

The outbreak of diseases such as cholera, diarrhoea and malaria, in some parts of Ghana especially, Accra has been as a result of improper waste management in and around these areas. "Common infectious diseases like malaria, intestinal worms, and upper respiratory infections are among the most common health problems reported at the out-patient facilities in Accra, and majority of these cases are residents in and around the slums" where sanitation is poor. Choked drains and gutters have created stagnant waters that act as breeding grounds for mosquitoes, which transmit, among other diseases, malaria (EPA, 2002). The nearness of the Oblogo waste dump site to the Densu River at Weija which is a source of drinking water and where treatment of the drinking water takes place is of great concern. The usually high temperatures associated with the dump sites undoubtedly facilitate high decomposition rates and degradation of organic components of the waste to produce landfill gases. Unhealthy odours almost often emanate from these sites spreading to the surrounding residences (Fobil, 2000).

2.9 Plastics Waste Recycling And Recovery Processes

Plastic recycling process is referred to as the process by which plastic waste material that would otherwise become solid waste are collected, separated, processed and returned to use (Lardinois and Van de Klundert, 1995). In recycling of plastic wastes to serve their intended purpose, retrieving the plastics from the waste stream and getting them back into the manufacturing process needs certain stages or steps such as collection, sorting, chipping, washing or cleaning and pelleting to achieve efficient and cost-effective process. For homogeneous plastic waste streams, recycling by mechanical (or physical) methods is the economically preferred recovery option. Heterogeneous plastic waste streams however are more efficiently treated or handled by chemical and thermal processes, for recovery of basic chemicals and /or energy (Gaiker-IVL and KTH, 2005).

2.9.1 Types of Plastics Waste Recycling

2.9.1.1 Mechanical Recycling

Mechanical recycling is the recycling of conventional waste plastics by physical means into plastics products. The mechanical recycling involves sorting plastics, washing, crushing and processed into flakes of consistent quality acceptable to manufacturers (Abota, 2012). The flakes are then fed into the extruder machine, which is incorporated with rotating single or double screw in heating barrel, through the hopper. The dry plastic flakes are melted down and then extruding into thin strands that are cooled and chopped into small, uniform pieces called pellets. The pellets are then bagged for sale or shipment (Abota, 2012).

Mechanical recycling is regarded as the best technology for recycling homogeneous and relatively clean plastics waste streams, provided end markets exist for the resultant pellets. It is the second largest recovery technique after energy recovery in Europe representing 13.6% and 14.8% in 2002 and 2003 respectively of total plastic waste recovered (APME, 2002-2003). This technique is also well suited for developing countries since it is less cost-intensive compared to the others. It is mechanical recycling that is currently being employed in Accra, Ghana to recycle about 50% of the plastic waste that is generated in the city daily.

2.9.1.2 Feedstock or Chemical Recycling

Chemical recycling or feedstock recycling involves breaking down the plastic waste materials into smaller chemical form by chemical process and reuse to produce raw material for manufacturing plastic products or different kinds of products. This may include breaking down polymeric product into its individual monomeric components or hydrocarbon feedstock and these components could then be fed back as raw material to reproduce the original plastic product. Feedstock recycling include chemical depolymerisation (glycolysis, methanolysis, hydrolysis, ammonolysis etc), gasification and partial oxidation, thermal degradation (thermal cracking, pyrolisis, steam cracking, etc), catalytic cracking and reforming, and hydrogenation. Besides conventional treatments (pyrolisis, gasification), new technological approaches for the degradation of plastics, such as conversion under supercritical conditions and co processing with coal are being tested (Aguado and Serrano, 1999). In feedstock recycling, only specific plastic waste materials are used in this process such as PET, nylon etc.

This technique of recycling is however not suitable for developing countries since it requires a lot of expertise, capital intensive and is quite cumbersome. Even in the developed countries, it is still under development and is being practiced by only a few companies. It has limitation of not recycling mixed plastic waste material but only separate plastic waste. Few companies have successfully developed and demonstrated technologies many of which can process mixed plastics streams. There has been some renewed interest in other areas of feedstock recycling, such as the depolymerisation of PET or treatment of PVC to make chemicals which can then be used in the production of new plastics (APME, 2002-2003). There are several separation methods that is need to be carried out in order to completely recycle the plastic waste materials by feedstock recycling.

2.9.1.3: Energy Recovery

Energy is recovered from plastic waste through incineration. Plastic wastes which is a waste with a high calorific value is mostly obtained from crude oil and since crude oil contains hydrocarbons which have high combustion rate resulting in production of energy for work output. Incineration is the burning organic wastes under controlled conditions. So combustion of plastic wastes produces heat energy used to generate power for other works. It is important to note that though it produce energy but it has environment effect if not properly controlled since it produces smoke and ashes which are harmful to living organisms.

In 2003, 4,750,000 tonnes of post-user plastics waste collected in Western Europe was reclaimed through energy recovery (APME, 2002-2003). This represented 22.5% of total collectable waste plastics and means energy recovery remains the most common recovery route for post-user plastics waste in Western Europe. Capacity expansions and new incineration plants have led to an increase in energy recovery capabilities in countries across Western Europe (APME, 2002-2003). This technique of recycling if not developed to the highest level can result in emissions which will pollute the atmosphere and also contribute to the current global warming issue. There is an exemplary incineration plant in Austria that is worthy of emulation. It has been developed with such high technology that emission levels are very low and conforms to EU directives on climate change. Numerous other examples also abound in Sweden. Ghana as a developing country may not be able to adapt it now for lack of capital and technological know-how.

2.9.2 Processes Involved In Plastics Waste Recycling

2.9.2.1 Collection of plastics

Effective collection of plastic waste can be done by identifying the sources of plastics wastes, the contributors of the plastic wastes. Plastic waste can be collected from two main source: Waste plastics from municipal sources (i.e. refuse containers and waste dumps) (Abota,2012). These are collected by hand and are roughly pre-selected by waste pickers or primary traders. This form of collection is labour-intensive and requires little capital investment. There are several points within a municipal solid waste stream where waste can be retrieved for recovery: at source, i.e. directly from private homes; from waste bins; from refuse collection vehicles; post-industrial plastic wastes, which are collected from the industry as a results of defects in the plastic products and process wastes; and at municipal waste dumps (Cointreau, 1984). In general, the nearer to the source, the less mixed and dirty will be the materials. (Selinger, Ben, 1986**)**

2.9.2.2: Sorting

After collection of the plastic wastes from the various collections points and sent to the recycling site, the next process is sorting. The plastic wastes are separated from other wastes such as metals, wood that accompanied the plastic during collection. The plastic wastes are then sorted into different types of plastic for recycling. Though plastics waste can be recycled in mixed form to make various useful plastic products, separated plastics have higher values and are preferred by most reclaimers. The degree of sorting of plastics waste varies considerably, depending on the demand and the special wishes of the manufacturers to whom it will be sold. The waste plastics may be sorted at any stage in the recycling process, according to colour, type of plastic, etc. The sorting stage is therefore crucial in plastic recycling and for that reason available sorting techniques are described below.

1 Manual sorting

Manual sorting of waste plastics is the identification of different materials by people with a "trained eye" while the materials pass by them on a moving conveyor (Scheirs, 1998). The materials are identified by the plastic identification codes and by the different characteristics of the plastics such as texture and appearance that distinguishes it for visual identification.

Manual sorting techniques can be used where the plastic components are large enough to justify the time and effort involved, since the method is very labour intensive, has bad working environment and is economically unviable. The possibility of human errors should not be neglected. The materials are used for low value applications (Scheirs, 1998).

2 Density-based sorting methods

Sorting by density technique can be done by blowing air across the falling plastics to separate wastes plastics into different components depending on their weight, or is carried out in a float-sink tank or hydrocyclone. This method however is poor for separating polyolefins as these have very similar densities. It is also impossible to separate PVC and PET, since their specific gravities overlap. The density can be altered by different fillers in the materials, which makes it difficult to have a complete separation (Tall, 2002).

In the float-sink separation, the plastics are placed in a fluid that has a density in-between the materials making it possible for less dense materials to float and the heavier to sink. Common fluids used are: water for the separation of polyolefins from other plastics. Water/methanol mixtures for separation of plastics with lower specific gravities, NaCl solutions and $ZnCl_2$ solutions for plastics with higher specific gravities (Scheirs,1998). Float baths can be arranged in a series, with each bath set at a desired specific gravity to sort the materials. Pumps provide circulation and direct the flow. The problems with this method are that the separation can be slow, difficult to control and give low-purity products. To achieve good separation, long retention times are required to allow the flakes to settle. Since the method uses gravity for separation, it is essential that the sizes of the material flakes are equal throughout the mix. One of the advantages of this separation is that before the plastic mixture is introduced to the separation fluid, the collected materials are exposed to wet grinding, where the paper labels and dirt particles are removed (Scheirs, 1998). The hydrocyclone uses the principle of centrifugal acceleration to separate plastic mixtures. The mixed plastics waste is separated first from polyolefins, then polystyrene and finally PVC and other materials. Plastics that are hard to separate with float-sink method, such as PE from PP or PS from a mixture of PVC and nylon, can be sorted by using an appropriate medium in the centrifuge. Dirt and paper labels are pulled off in the process (Wienaah, 2007).

The technique can selectively separate, wash and dewater plastic flakes from a mixture of plastics waste materials. The apparatus used is a double-cone, solid bowl screw centrifuge. This achieves efficiency of over 99.5% purity. The separation is fast and has a high selectivity, achieved by high speed rotation, because the equipment can produce a centrifugal field of 1000-1500 times higher than the acceleration accomplished due to gravity (Wienaah, 2007).

3 Washing and Drying

It is important that the waste plastics are washed, because clean waste materials improve the quality of the end product. The plastics can be washed at various stages of recycling process. Films and rigid materials are usually cleaned before the size reduction stage. Foreign materials such as glued paper labels are also removed. Rigid plastics are often washed a second time after they are shredded (Wienaah, 2007).

The washing of the plastic wastes can be done either manually or mechanically operated mechanism in a well-constructed washing tank , where by the dirty water can be drain out easily. Since the plastic wastes are already contaminated with a lot of dirty such as grease, oil, dust etc, it is important to use the required surfactants (detergents) and water (cold or hot) to loosen and remove the contaminates from the plastic materials (Lardinois and Van de Klundert, 1995). In the mechanical washing installation, a water-filled basin is equipped with a motor that drives a set of paddles at low speed. The plastic materials are left to soak for several hours, while they are stirred continuously by the paddles. Dirt (mainly sand) settles out during the process, and the clean plastic material is removed with a drainer. After washing, plastics waste can be dried either manually or mechanically. With the manual method the plastics are spread out in the sun to dry, and turned regularly. Plastic films can be hung on lines. The drying process can also be carried out mechanically using water drier, which in principle is a thermal drying machine at a certain temperature which is used to dry the washed plastic waste. Washing and drying waste plastics are not separate activities and tend to be carried out within the same unit (Wienaah, 2007).

2.9.2.3 Shredding

The sorted clean plastic waste is then sent to the shredder to be cut into small plastic flakes. In the case of big plastic bottles, it is important to cut the bottles into small sizes before feeding them into the shredder. This process is known as the size reduction. During the shredding process, the clean pieces of plastic selected according to product form, plastic type and colour are fed into the hopper on top of the shredder as shown in Figure 2.11 below. The rotating cutting blades of the shredder then shred the plastic sachets into pieces of a required size. When the pieces are small enough, they fall through a grid into a tray.

The rotary blade of the shredder is connected to the electric motor or the mechanical engine by pulley belt with the pulleys of both rotary blade and electric motor or engine. Through the transmission of power between the two, the blade of the shredder then rotates to initiate the cutting process. The cutting continues until the pieces are small enough to fall through the grid (Abota, 2012).

Figure 2.11: PlasticShredder

Source: Arcada Plastic laboratory, photo taken by Abota

The small pieces of plastic that comes out during the process are collected as seen in figure 2.12 below. The end products of shredding material is collected into bags from the tray to be stored, or is fed directly into an extruder or be sold to reprocessing industries and workshops.

Figure 2.12: Plastic Flakes

Source: Arcada Plastic laboratory, photo taken by Abota

The materials have been sorted according to colour, in this case white. If the waste plastics have not already been washed, the shredded pieces may then be washed at this stage to remove any dirt or dust. Depending on the quality and type of raw material, and the desired quality of the end product, different types of plastic waste may be mixed to a certain extent.

2.9.2.4: Pelletizing

This is done by connecting a pelletiser to an extruder. The plastic shredded plastic flakes are feed into an extruder through the hopper. The plastic flakes in the hopper of the extruder travels by the gravity into the feed rod and drops onto the rotating screw. The rotation of the screw conveys the plastic forward through the heating barrel. As the plastic is convey forward along the screw the channel depth decreases forcing the plastic to a smaller area. The plastic is melted by heat generated from the friction by the combination of compression and screw rotation and the heat from the barrel system. The plastic is well mixed when the melted plastic reaches the end of the screw. At this point the screw acts as pump to force the melted plastic out of the screw through the die and the melted plastic comes out as strands. The hot plastic strands pass through a water tank to cool and solidify the strands. As the plastic strands are cooled and solidifies, strands are conveyed towards a pelletiser which then cut the plastic strands into short, uniform, cylindrical pellets that are ready for use in manufacturing processes (Chang, 2013). The plastic waste generated by this process can be extruded again. The production capacity of the pelletizing process depends on the size of the extruder that is used. Figure 2.13 shows a pelletizing machine.

Figure 2.13: Plastic Pelletizer Machine

2.9.2.5: Plastic Extrusion

Figure 2.14 and 2.15 show typical extrution line and schematic single screw extruder respectively. Plastic extrusion is a steady-state process for converting a thermoplastic raw material to a finished or near-finished annular product. The raw material is usually in the form of plastic pellets or powder. The conversion takes place by forming a homogeneous molten mass in the extruder and forcing it under pressure through an extrusion die orifice that defines the shape of the product's cross section. The formed material, or extrudate, is cooled and drawn away from the die exit at a controlled rate. The extrudate can then be wound on a spool, cut to a specified length, or directed into another in-line process.

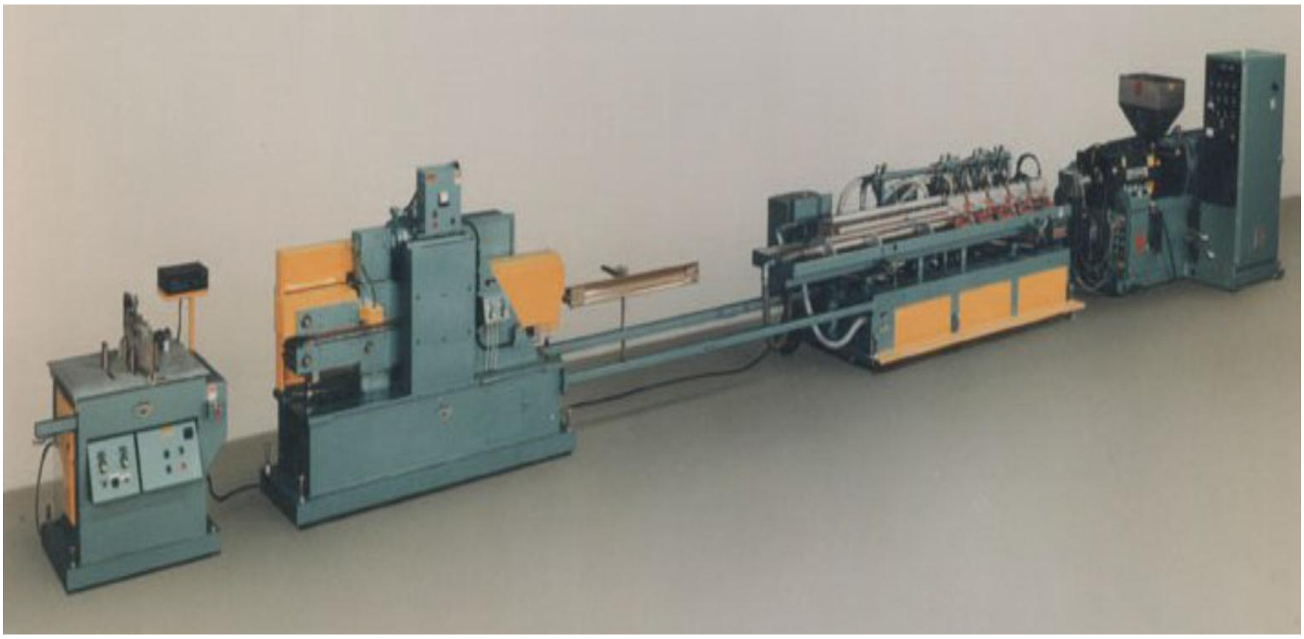


Figure 2.14: Representative Pipe Extrusion Line, Including The Extruder, Vacuum Tank, Belt Puller, And Cut-off Saw.

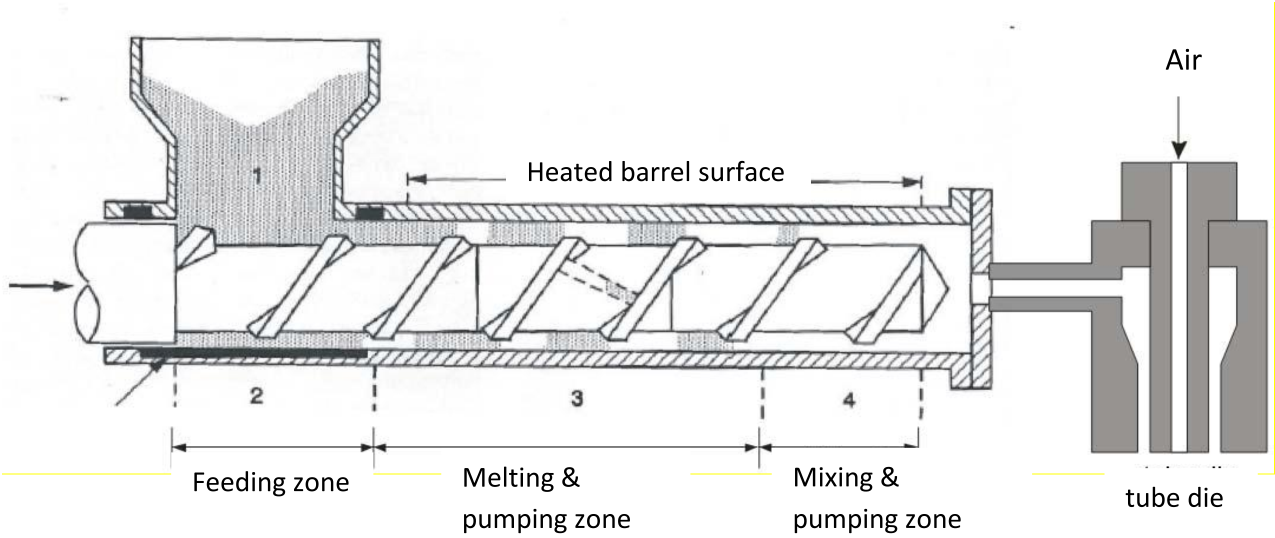


Figure 2.15 Schematics of Single Screw Extruder

2.9.2.6: In-line Processes Of Extrution

2.9.2.6.1: Injection Moulding

By contrast with extrusion which is a steady-state process, injection moulding is a cyclic processes. This cyclic characteristic produces some unique benefits and challenges as a manufacturing process. Injection-moulded products are discrete items with varying cross sections in each axis. Extruded products are very long and continuous, and have a cross section that is usually constant with respect to the axis or direction of production.

Injection moulding machine is the equipment used in injection moulding and it is comprises of several units that aid in the whole operations. The units of the injection moulding machine comprises of the injection unit, clamping unit, control system, tempering devices for the mould and mould cavity which is usually made from steel or aluminium (Potschand Walter, 2008).

The operation of the injection moulding machine involves the plastic granules (raw materials) been put into the machine through the hopper. Depending on the type of injection moulding machine concern, it normally consists of a cylinder barrel equipped with external heaters to the granules, the screw (single or double). The screw is driven by motor that rotates the screw. The molten granules travel along the length of the screw to the end or tip of the screw inside the barrel by the rotation of the screw which results in tearing or shearing action on the plastic granules to melt. As the screw continues to rotate, thus the volume of molten granules increases at the tip of the screw causes high pressure build up. This high pressure aids the screw to push forward to force or inject the molten plastics into mould cavity through injection nozzle as the screw moves back (reciprocating screw). The molten plastics takes the shape of the cavity as the pressure is maintained for the product to cool and solidifies (Briston, 1994). The product is ejected from the mould and the cycle is repeated.

With injection moulding process, both thermoplastics and thermosets materials are used in manufacturing various products, but mostly thermoplastic materials such as polystyrene, polypropylene, polyethylene are used. The process is simple, fast and does not need any further post moulding process. Products made from this manufacturing process include; Litter bins Bottles caps/lids Washing bowls Phone cases Drinking cups Electrical appliances case DVDs/ CDs Plastic chairs Plastic buckets etc.

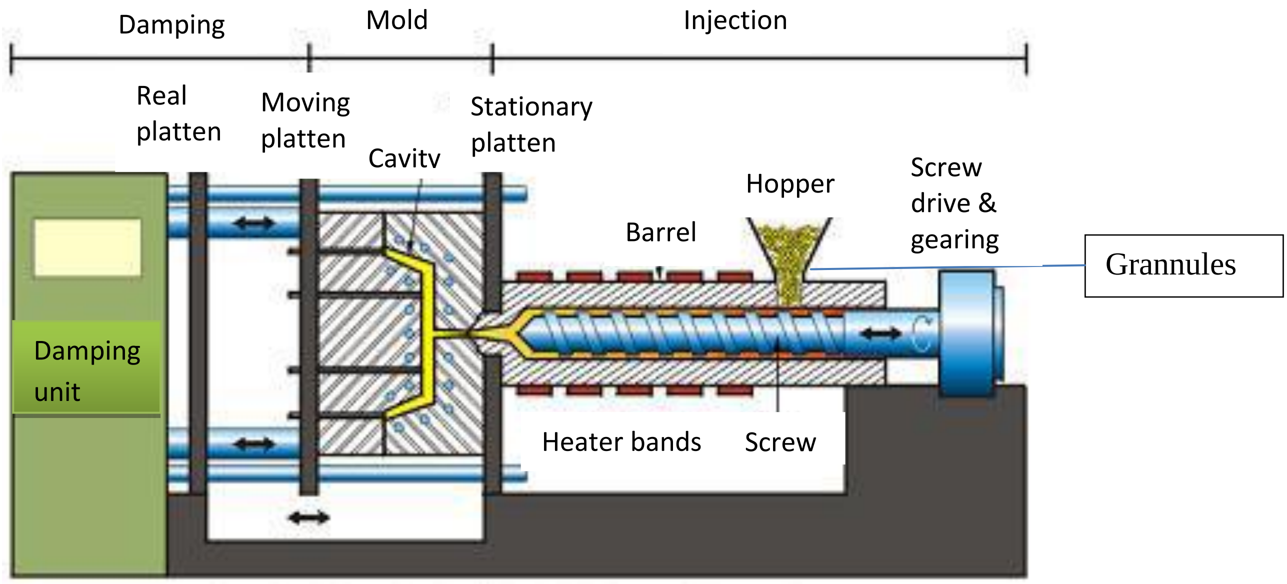


Figure 2.16: Schematic of Single Screw Injection Moulding Machine

2.9.2.6.2: Extrusion Moulding

The molten plastic is drawn or forced in a heated barrel through one or more dies by the turning screw aided with pressure to produce the required shape. The extruded product is cooled with the help of either air or water in a drum to solidify into the required shape. The extruded end product could be solid or hollow form such as pipes, plastic profiles, plastic films and sheets (Briston, 1994). A single screw extruder is shown in figure 2.17. It comprises of one or more screws, barrel or cylinder. Extrusion process is the best plastic manufacturing process used in turning recycled plastic flakes into pellet for making other plastic products.

Figure 2.17: A Single Screw Extruder Machine

2.9.2.6.3: Blow Moulding

Blow moulding is a process of producing hollow articles such as bottles. The principle of the process is shown in figure 2.18.

A piece of molten plastic (parison) is extruded through a die into an open mould or a split mould with the shape of the final product. The mould is then closed around the parison. As the parison is securely placed inside the mould, Compressed air is blown into the open end to expand the parison to take the shape of the cavity of the mould. The shape formed in the mould is then allowed to solidify and the mould opens into two halves to eject the final product out of the mould and the cycle is repeated. In blow moulding process, parison can be formed by injection moulding process and extrusion moulding process (EQI, 1991).

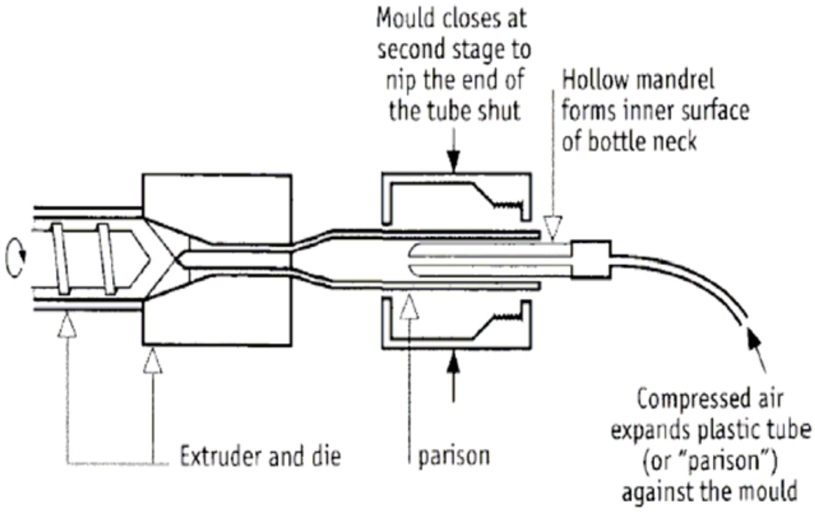


Figure 2.18: The Principle of Blow Moulding.

Compressed air is blown into the open end to expand the parison to the shape of the mould. The formed shape is allowed to cool until the finished object solidifies, which is then ejected from the mould and the cycle is repeated. The production capacities of the blow moulding machines used in Cairo, for example, vary between 100 and 200 kg of final products per day, depending on the power of the motor, which can range from 10 to 15 HP (EQI, 1991).

2.9.2.6.5: Film Blowing

Film blowing is technically the most complicated of the product manufacturing processes. Various techniques are used. The process of making garbage bags for example shown in Figure 2.19 is as follows.

Figure 2.19: The Production of Garbage Bags.

Source: WASTE Consultants cited by Michael Mensah Wienaah

After extrusion from a tubular die, the product, in this case a thin tube, moves upward to a film tower that contains a collapsing frame, guide rolls and motor-driven pull rolls. Compressed air is passed through the centre of the die and inflates the tube. The outside surface is cooled by air from an air ring mounted above the die. When the tube has passed through the pull rolls, it is sealed and cut to form the bag. For this process only high-quality pellets can be used as the raw material (Wienaah, 2007).

2.9.2.7: Benefits of Plastic Recycling

Benefits of recycling plastics to the country can be categorized into social, economic and environmental benefits. These are discussed below.

2.9.2.7.1: Social benefits

Plastic wastes litter the streets and choke gutters. This causes breeding grounds for mosquitoes and flies, which then causes diseases such as malaria and cholera to the people. Recycling of plastic wastes will contribute to reducing littering the streets with plastic waste. This leads to preventing the diseases associated with filth and littering of plastic wastes and this will save foreign exchange in the importation of drugs to treat such diseases. Recycling will also create a healthy environment for tourists attraction.

Recycling creates job for the people. Through recycling, many people will get employment particularly at the collection stage and hence be able to earn their living. This will help raise social standards and to eliminate social vices such as armed robbery drug trading and so on.

2.9.2.7.2: Economic benefits

The use of recycled pellets for product manufacture will save recycling companies from folding up as a result of high cost of importing virgin pellets. The cost of recycled plastic pellets is far cheaper than the virgin plastic, and therefore using the recycled plastic pellets will help reduced the cost purchasing the raw materials. Blowplast Ltd, a plastic manufacturing company in Ghana has established recycling plant and therefore buys plastic wastes from the people and recycle them for reuse. This create employment for the people to earn an income. As the people earn a living, the funds that accrue as a result can be channelled into other areas that could lead to higher profits (Wienaah, 2007).

The University of Nottingham in the UK recently conducted ‘life-cycle’ analyses of materials consumption, energy use and emissions for both virgin and recycled low-density polyethylene (LDPE), a type of plastic. From this study it can be concluded that the use of reprocessed pellets in the production of plastic bags saves around 70% in energy use and 90% in water use, compared to the use of pellets made of virgin material (Lardinois and Van de Klundert, 1995). The low energy and water consumption will save recycling companies from paying huge bills that could otherwise have adverse effect on their operations as the energy used in recycling of plastic waste for reuse is less as compare to that of the energy in the production virgin plastics (Wienaah, 2007).

2.9.2.7.3: Environmental benefits

Plastic is manufactured from crude oil and as the demand for plastic increases, considerable amount of energy resources is put on drilling and refining the crude oil. Recycling of plastic waste conserves natural resources, particularly raw materials such as oil and energy. The more that is recycled, the longer will natural resources be available for future generations. It means that there is less environmental impact due to mining, quarrying, oil and gas drilling, deforestation and so on. If there are fewer of these operations, the environment will be safe from continuous destruction and degradation. Furthermore, in an attempt of getting virgin plastics from the crude oil, gases such as carbon dioxide (CO_2), sulphur dioxide (SO_2) are emitted into the atmosphere thus causing global warming. Research have shown that the emissions of CO_2, SO_2, NO_X (NO and NO_2) are much less for recycled plastics compared to that for virgin materials (Lardinois and Van de Klundert, 1995). The environment will therefore be better safe from air pollution and global warming if recycling is adopted on large scales (Wienaah, 2007).

Recycling of plastic wastes will also safe both ground and surface waters from pollution. This is because recycling plastic waste will reduce the amount of the plastics that litter the gutters and streets or get to the landfill. Plastic waste if discarded randomly, choke gutters and even find their way into water bodies that serve as sources of drinking water for communities and towns. They also help to breed leachate that can seep into the ground thereby contaminating groundwater bodies as well.

2.9.2.8: Challenges of Recycling Plastic Wastes

Recycling of plastic wastes seems to be the way forward for sustainable management of plastic wastes as well as providing raw materials for the manufacturing companies.

Nevertheless, much more effort need be done in order to reach the waste management requirements the society needs in order to ensuring sustainable development.

2.9.2.8.1: Technological Challenges

The complex nature of the plastic waste streams in terms of plastic composition and the presence of impurities raises a very big question as to the development of automatic and effective separation methods for mixed plastic waste. An extensive cleaning, separation and pre-treatments prior to reprocessing is required to add value to waste plastics as raw materials for new products (Wienaah, 2007).

There is also still no known technology for the recycling of mixed plastic wastes. The plastic waste may contain a large number of hazardous compounds that makes difficult the recycling processes, such as degradation products of additives, brominated flame retardants, etc. It is therefore necessary to develop techniques to identify, quantify and extract these products from plastic prior to recycling them. Some efforts have been done in this direction (Gaiker-IVL and KTH, 2005). The optimal solution to the plastic waste management problems will be provided by the conjunction of the different treatment alternatives available (i.e. mechanical recycling, feedstock recycling and energy recovery). Therefore, it is necessary to achieve a good integration between all the aspects of the recycling activity (collection and separation of the waste streams, characterization methods for recycled plastics, identification of the optimal treatment technique, etc)

2.9.2.8.2: Market Acceptance

There may be a challenge as to whether consumers are willing to accept recycled products based on where the recyclates is obtained from (i.e from streets and even from gutters and damping sites), or on health and safety requirements. There is a mismatch between the availability of potential plastic waste material and demand of recycled plastic products due to a probable mistrust of the consumers for the properties of the recyclates. Quality assessment is a matter of significant importance in order to guarantee a suitable usage of recycled plastic materials in further applications, since the properties of the recyclates must be specified and guaranteed within narrow tolerances by the manufacturers according to the needs of their customers. Some researchers have cited three key properties in order to guarantee the quality of the recycled materials. These are degree of mixing (composition), degree of degradation and the presence of low-molecular weight compounds (degradation products, contaminants, etc). There are no standardized methods for measuring the critical properties of recycled plastic materials. This goes a long way to affect the quality of recycled plastic products and hence their marketability. This inconvenience is related to the above mentioned requirements of methods for quality assessment and standardization of the properties of the recycled materials and to the lack of information and appropriate marketing for the use of post-consumer products (Wienaah, 2007).

2.9.2.8.3: Health and Safety Concerns

Recycled plastics are obtained from waste that may be contaminated with other toxic waste in the waste stream. For instance recycled PET cannot be used in food packaging again since recycled plastics are gotten from waste that has been contaminated and if not properly sorted and washed well, there would be still some traces of contaminates in the final recyclate

CHAPTER THREE

METHODOLOGY

3.1 Materials and Equipment

Potassium Bromide

About 500 mg of KBr to be pressed with the sample to obtain the pellet for the IR analysis.

Pair of Gloves

Six pairs plastic or rubber gloves for sample collectors and sorters.

Plastic Sack

Ten sacks with up to 1 m^3 capacity for sample collection.

Measuring Box

One measuring box (0.5 metre high × 0.5 metre long × 0.5 metre wide) with a flat bottom. Weight should be minimized by using thin resin−bonded plywood for construction. A strong batten is bolted along each side.

Sorting Table

One sorting table (about 1.5 metres wide × about 3 metres long) made from a stout softwood frame with corners halved and bolted, and entirely covered by wire mesh of 50 mm, wrapped around every side and securely fastened. The table can be supported on trestles or fitted with legs.

Calibrated Buckets

Ten calibrated buckets of about 60 litres to contain sorted materials and also determine their volume.

Weighing Balance

One weighing balance with capacity up to 500 kg for weighing of sample.

Fourier Transform Infrared (FTIR) Spectrometer

One FTIR spectrometer (Spectronic Camspec Ltd, UK, Model-Interspec 200-X)for identification and characterization of waste plastics without resin code. This was obtained from the Chemistry Department of KNUST.

Grater and Sieve

One 0.2 mm grater for shredding of plastics and 3.2 μm sieve to get powdered sample for the FTIR analysis.

Extruder and Pelletizer

For creation of pellet.

3.3 Sampling Area

3.3.1 Municipal Profile

3.3.1.1 Location and Size

Sunyani Municipality is one of the twenty-two Administrative Districts in the Brong Ahafo Region of Ghana. It lies between Latitudes 7^0 20'N and 7^0 05'N and Longitudes 2^0 30'W and $2^0$10'W. It shares boundaries with Sunyani West District to the North, Dormaa District to the West, Asutifi District to the South and Tano North District to the East. Total land area - 829.3 Km^2 (320.1 m^2).

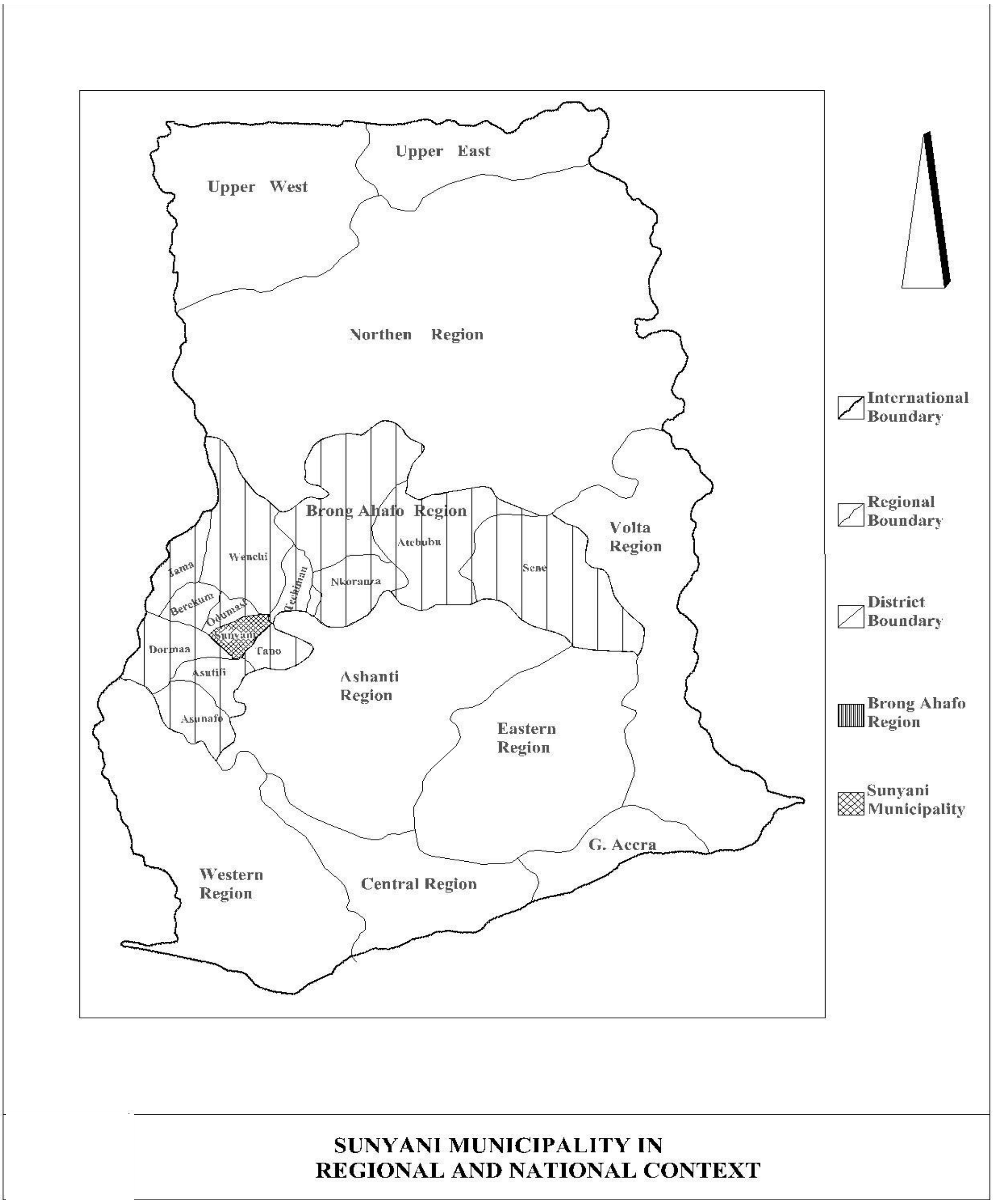


Figure 3.1: Sunyani Municipal in Regional and National Context

3.3.1.2. Demographic Characteristics

3.3.1.2.1. Population Size and Growth Rate

In 2000 the population of Sunyani municipality was 101,145. Currently, with a growth rate of 3.8 percent, the estimated population is 147,301. The growth rate of Sunyani compared with the national growth rate of 2.7 percent indicates a high growth rate.

This has contributed to pressure on the available facilities. It is therefore required that development authorities intervene to reduce this pressure.

Table 3.1 Populations for Sunyani Municipal and Sunyani West District

Name of Locality	1984	Growth rate	2000	Growth rate	2010
Sunyani Municipal	**-**	**-**	**101,145**	**3.8**	**147,301**
Sunyani West	-	-	78,020	3.8	147,301
Sunyani (Combined)	98,183	3.5	179,165	3.8	260,924

Source: Ghana Statistical Service computation, Sunyani, 2010

Table 2.1 above, indicates an increase from 3.5 percent to 3.8 percent of growth rate. Comparing with the national rate of 2.7 percent brings to fore issues of population management to be dealt with. This trend presents serious development challenges to the municipality, as the population growth does not match with the provision of social services and development infrastructure.

3.3.1.2.2. Population Density

The population density of the municipality is 122 persons per square kilometre (MPCU Computation, 2010). In comparing this to the population density of the nation 76/sq.km, the municipality is densely populated resulting in high demand for land.

From the survey conducted, the densely populated areas in the municipality include Zongo, New Dormaa and Area 2 in that order. On the average these areas have 18 persons per house. Nkwabeng, Abesim and Nkrankrom constitute the medium densely populated areas with an average of 13 persons per house. The low density areas are Estate, South Ridge, Airport Area, Atronie and Baakoniaba with an average of 8 persons per house. The densely populated areas are mostly in the low income group whereas the less dense areas are mostly in the high and medium income groups.

3.3.1.2.3 Rural Urban Split

The population in the municipality is generally concentrated in the three largest localities (Sunyani, Abesim and New Dormaa) which hold about 74.3 percent of the population, with only 25.7 percent distributed among the other settlements. Sunyani, the municipal capital, accommodates about 60% of the total population. The current concentration of 74.3 percent in the urban areas has accounted for the high urban growth and its associated problems of congestion and erection of slum

3.3.1.2.4 Age and Sex Composition

Table 3.2 Age And Sex Distribution Of The Municipality, 2010

Age Cohort	% Male	% Female
0-4	6.7	6.6
5-9	6.4	6.5
10-14	6.3	6.2
15-19	6.0	6.1
20-24	5.1	5.3
25-29	4.7	4.8
30-34	3.7	4.1
35-39	3.1	2.8
40-44	2.3	2.4
45-49	1.7	1.6
50-54	1.4	1.5
55-59	1.0	1.1
60-64	0.7	0.8
65+	0.5	0.6
Total	**49.6**	**50.4**

Source: 2000 PHC, GSS, MPCU computation, 2010

The male female ratio as indicated in table 1.2 shows a ratio of 50.4 females to 49.6 males, thus the sex ratio of the municipality is 1 Male: 1.01 Females. The situation in the municipality does not deviate so much from what the national figure depicts.

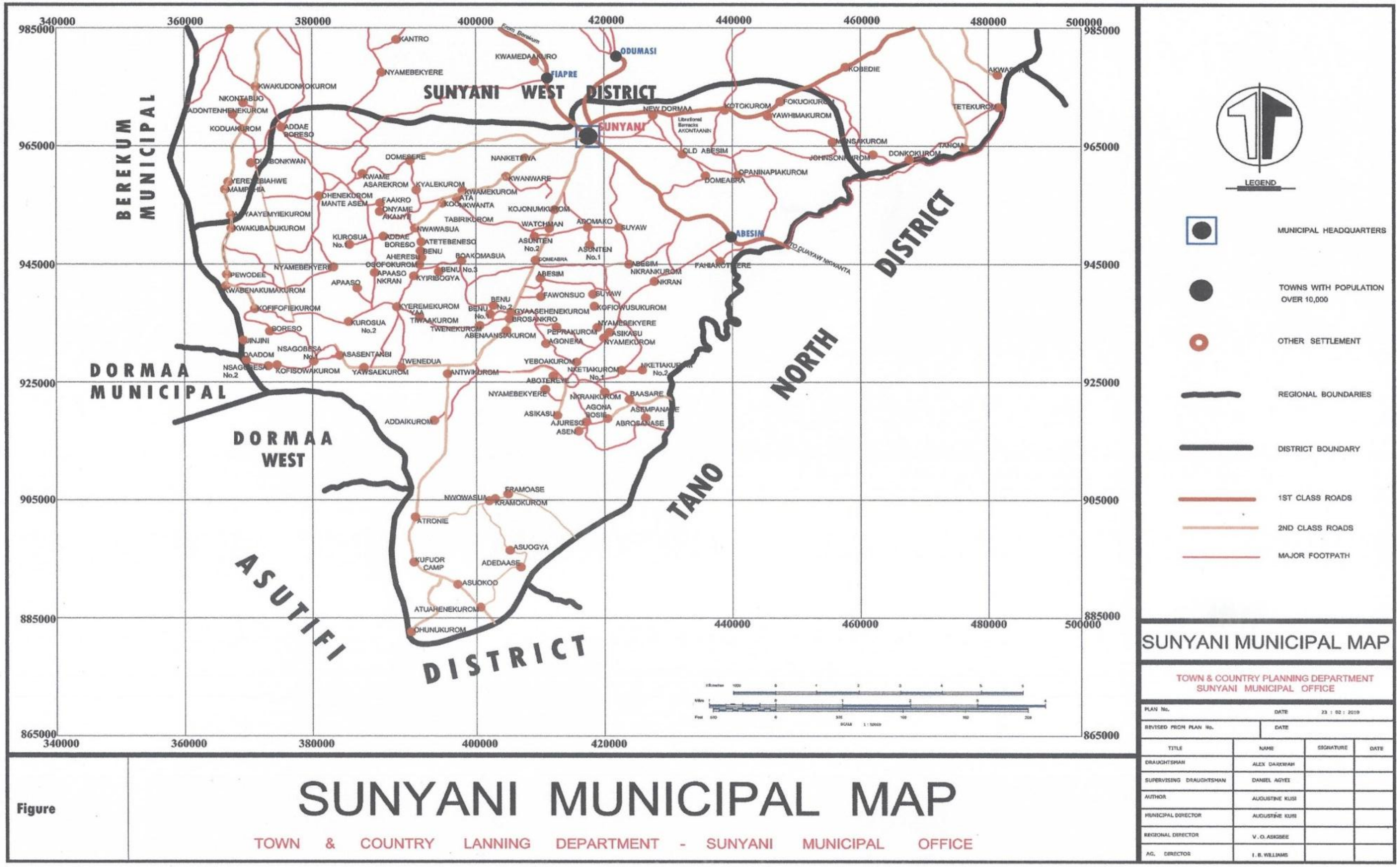


Figure 3.2: Map of Sunyani Municipality Showing Settlement

3.3.1.3 Education

Education delivery in the Municipality is by public and private. Out of the 264 basic schools, the private sector contributes 49.2 whereas public schools constitute 50.8 percent. The situation is different in relations to senior high schools where private and public constitute 62.5 and 37.5 percent respectively. Also private Vocational/Technical schools represent 75 percent whilst public shows 25 percent. There is one public polytechnic, one public university and nursing training school.

3.3.1.4 Health Care

Out of the total 23 health facilities in the Municipality, there are 4 health centres, 3 maternity homes, 5 school clinics, 7 private clinics, 3 private hospitals and one Municipal hospital.

3.3.1.5 Water and Sanitation

3.3.1.5.1 Water

The Municipality has about 28 streams, 1 river, 1 spring source, 65 hang dug wells, and 106 boreholes(MWS). Most of the streams and rivers have been contaminated or dried up eg, Sunyani stream, the Akokorakwadwo stream, Suyaw, and Bisi streams.

Rural and Urban water coverage stands at 33.5 and 47 percent respectively. In the case of urban supply the estimated demand is 15,000metric tones /day. Currently, the urban populace enjoys only 7000metric tonnes/day.

Areas such as Nkwabeng, Airport, and Liberation Barracks are described as the low pressure zones.

3.3.1.5.2 Sanitation

Largely, sewage waste is disposed off indiscriminately due to inadequate planned sewage system. Of all the Sullage disposed off in homes only 17 percent ends in soak away pits, 18 percent ends in gutters, 19 percent ends up in ditches and the largest representing 46 percent ends up on vacant plots, open spaces and bushes (EHU, SMA, 2010).

Table 3.3: Liquid Waste Disposal in the Municipality 2010

Public	**No.**	**Private**	**No.**	**Total**
WC	11	WC	1896	1907
VIP	4	VIP	476	480
STL	16	STL	-	
PAN	-	PAN	87	87
Pit Latrine	33	Pit Latrine	525	558
Pour Flash	2	Pour Flash	-	2
KVIP	3	KVIP	2	5
Total	**69**		**2986**	**3,055**

Source: SMA, Environmental Health Unit, 2010

3.3.2 Solid Waste Generation Sectors

The Sunyani municipality was categorized into the following waste generation zones:

- Residential (household waste, communal containers)
- Commercial (market places, lorry parks, hotels, restaurants, slaughter house, shops)
- Institutional (schools, police/prison/army barracks, main prison, offices)

The categorization of the waste generation zones from the municipality is based on the guidelines for the preparation of District Environmental Sanitation Strategy and Action Plan

(DESSAP) issued by the Ministry of Local Government and Rural Development (MLGRD). The residential zone was further zoned into three based on the economic status and population density. This became necessary since these areas had different rate of waste generation. These are:

- Zone 1: High income low density waste zones comprising of Estate, South Ridge, Airport Area, Berlin Top, Residential Area and Baakoniaba.
- Zone 2: Middle income middle density waste zones comprising of Nkwabeng, Abesim and Penkwase.
- Zone 3: Low income high density waste zones comprising of Zongo, New Dormaa and Area 1, area 2, Area 3, Area 4 and New Town.

3.3.3 Selection Of Waste To Be Analysed

Prior to sample collection, the main waste management contractor on the municipality, Zoomlion (Gh) Limited, was consulted for their input into the type of waste collected and disposed off at the landfill site. This was done through personal conversation with the head of environmental and sanitation Division of Zoomlion Ghana Limited, Sunyani. Below were the list of categories of waste selected for this study:

- Organics - food waste, garden waste (i.e yard trimmings and leaves)
- Paper and Cardboard (P&C) - newsprint, office paper, cupboard and packaging boxes.
- Plastics – PE, PP, PET bottles, PVC materials, Styrofoam packaging and LDPE/HDPE composites (sachet water packaging).
- Metals – ferrous scrap (i.e household appliances, cans and iron/steel products), non-ferrous scrap including aluminum, copper, lead and precious metals.
- Glass - clear glass, coloured glass, louver blades and others .

- Rubber, Leather and Textiles (RL&T) – jute sacks, clothing, upholstery, embroidery and carpets.
- Wood – sticks, pieces of wood, chippings, saw dust etc.
- Other - ash , soil and stones

3.3.4 Sample Target

Sample collection targeted a minimum coverage of 30% of the total households, 50% of the total commercial establishments and 50% of the total institutions within the municipality for waste sampling. All the towns or communities in the municipality was divided into several zones using the latest available demographic map from the municipal assembly. The percentage of the total waste generation in the survey zone was calculated by determining the approximate population density through satellite maps and then accordingly assigning a percentage of the total waste generation in each of the zone. Having decided the target sample size, the sample size of each zone was calculated based on percentage of the total waste generation of the zone.

3.4 Processing

3.4.1 Sample Collection

Samples were collected every Monday and Thursday within a sampling period. These days were chosen through balloting. 10 samples were collected in a day and a total of 80 samples were collected over the sampling period. The total volume of trash in each sample was 0.5 m^3. The samples were randomly taken and represented commercial wastes, institutional waste as well as residential(domestic) waste sources. The sacks used for sample collection were labelled 1 to 10. The sampling program was performed for one month.

3.4.1.1 Collection of Residential Waste

Six(6) samples representing residential (domestic) waste were collected in a day using the sacks labelled 1 to 6. Three(3) samples from Zone 1, two(2) samples from Zone 2 and one(1) sample from zone 3. These sample size of each zone was based on the percentage of the population density of the zone as well as their waste generation capacity.

The samples were collected either directly from the garbage collection vehicle after it had completed pickups or from the garbage collection point as and when is appropriate. A spot of sample was picked at random, and collected in a sacks. The full sacks was emptied into the measuring box of $0.5m^3$. The box was rocked back and forth and side to side during filling to settle the contents. The waste was then emptied into the pre-weighed sack and its weight measured and recorded.

In all, 48 samples were collected.

3.4.1.2 Collection of Commercial Waste

Two(2) samples representing commercial waste were collected in a day. The samples were collected either directly from the waste bins or from the skip at the gabbage collection point as and when is appropriate. A spot of sample was picked at random, and collected in a sacks labelled 7 and 8 . The full sacks was emptied into the measuring box of $0.5m^3$. The box was rocked back and forth and side to side during filling to settle the contents. The waste was emptied into the pre-weighed sack and its weight measured and recorded. In all, 16 samples were collected.

3.4.1.3 Collection Of Institutional Waste

Two(2) samples representing institutional waste were collected in a sample collection day. The samples were collected from the garbage collection point. A spot of sample was picked at random, and collected in a sacks labelled 9 and 10. The full sacks was emptied into the measuring box of $0.5m^3$. The box was rocked back and forth and side to side during filling to settle the contents. The waste was emptied into the pre-weighed sack and its weight measured and recorded. 16 samples were collected over the sampling period. Figure 3.1 shows sample collection from a skip container at Twene Amanfo Senior High School by a sample collector.

Figure 3.3: Sample Collection from a Skip Container at Twene Amanfo Senior High School by a Sample Collector.

3.4.2 Sorting Of Waste

The measuring box containing the waste each emptied unto the sieving table and sorted into 8 labelled graduated buckets, that have been weighed, according to the predetermined components of : paper and cardboard, glass, metals, plastics, organic, wood, textiles, other.

After sorting of the oversized material was finished, the table was shaken to ensure that everything below 10 mm has fallen through. The material below 10 mm was collected by shovel into a bucket labelled ‘other’. Figure 3.2 shows sorting of sample by the researcher

Figure 3.4: Sorting Of Sample by the Researcher

3.4.3 Determination Of Weight And Volume Of Waste

As a bucket became full, volume of each waste was recorded on a data sheet. Each bucket was then emptied into the sack and weighed with the weighing balance as shown in figure 3.3. Weight (kg) were recorded on the data sheets and the total weight was subtracted from the bucket weight to find the weight of the constituents. The complete data set is available in Appendix B.

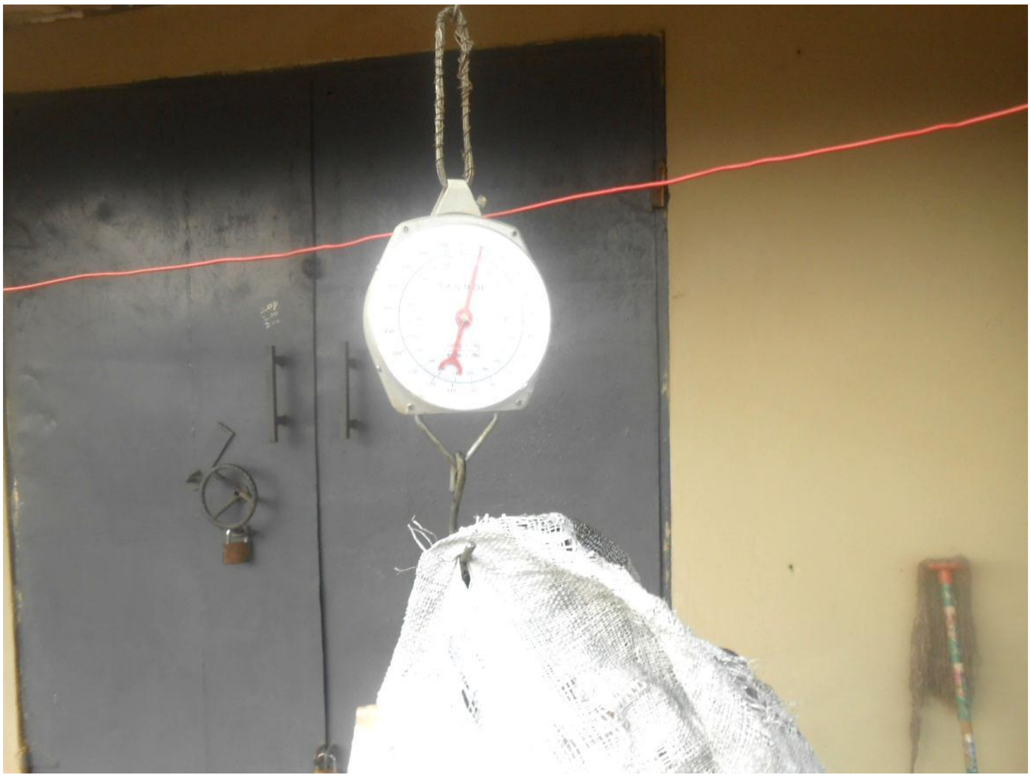


Figure 3.5: Weighing Of Sample Using Spring Balance

The buckets, with the exception of those containing plastics, were emptied into disposal facilities provided and these processes were continued until all waste were analysed.

3.4.4 Preparation of Plastic Sample

3.4.4.1 Sorting Of Plastics

After separating the plastic wastes from the sample, the plastic wastes were sorted into 8 labelled calibrated buckets, that have been weighed, according to the predetermined components of : LDPE, HDPE, PP, PET, PVC, PS, LDPE/HDPE composites (sachet water packaging) and other. Sorting of plastic waste was done by using recycling code for plastics. Sorting of plastic waste was however done manually by the use of hands to separate the plastics waste into different plastics.

3.4.4.2 Washing and Drying of Plastics

The plastic waste materials were washed manually in a washing tank using detergent and water to remove contaminants from the plastic waste and also improve the quality of the end product. The plastics were spread out in the sun to dry, and turned regularly.

3.4.4.3 Determination Of Weight And Volume Of Plastic Waste

As a bucket became full, volume of each plastic waste was recorded on a data sheet. Each bucket and contents were weighed with the weighing balance. Weight (kg) were recorded on the data sheets and the total weight was subtracted from the bucket weight to find the weight of the constituents. The complete data set is available in Appendix B.

The buckets, with the exception of the one containing LDPE/HDPE composites, were emptied into disposal facilities provided.

3.4.5 Recycling Process

3.4.5.1 Shredding/ Size Reduction

The sorted, cleaned LDPE/HDPE composites plastic waste was then sent to the shredder at DBS Ghana Limited in Fomasua-Kumasi, and was cut into small plastic flakes. The chipper is incorporated with rotating cutting blade or cutter in a cylinder. The plastic wastes were fed into the chipper and the 19 rotary blade inside the chipper then cut the plastic into the required small pieces (flakes) and these go through a passage with small holes into flakes collector(collection bin). The rotary blade of the chipper or shredder was powered by electric motor. The rotary blade is connected to the electric motor by pulley belt with the pulleys of both rotary blade and electric motor. Through the transmission of power between the two, the blade of the chipper rotated and then initiated the cutting the process. The small pieces of plastic that came out during the process were collected as seen in figure 4 below. The products were packed into bags.

3.4.5.2 Pelletizing

This was done at DBS (Gh) Ltd in Kumasi, Ghana. The shredded plastic flakes were sent to an extruder that has been connected to a pelletizer (figure 3.5). The shredded plastic flakes were fed into an extruder through the hopper. The plastic flakes in the hopper of the extruder travelled by the gravity into the feed rod and dropped onto the rotating screw. The rotation of the screw conveyed the plastic forward through the heating barrel. As the plastic was conveyed forward along the screw, the channel depth decreased forcing the plastic to a smaller area. The plastic was melted by heat generated from the friction by the combination of compression and screw rotation and the heat from the barrel system. The plastic was well mixed when the melted plastic reaches the end of the screw. At this point the screw acted as a pump to force the melted plastic out of the screw through the die and the melted plastic came out as strands. The hot plastic strands were allowed to pass through a water tank to cool and solidify the strands. As the plastic strands were cooled and solidified, strands were conveyed towards a pelletiser which then cut the plastic strands into short, uniform, cylindrical pellets. The products were packed into bags.

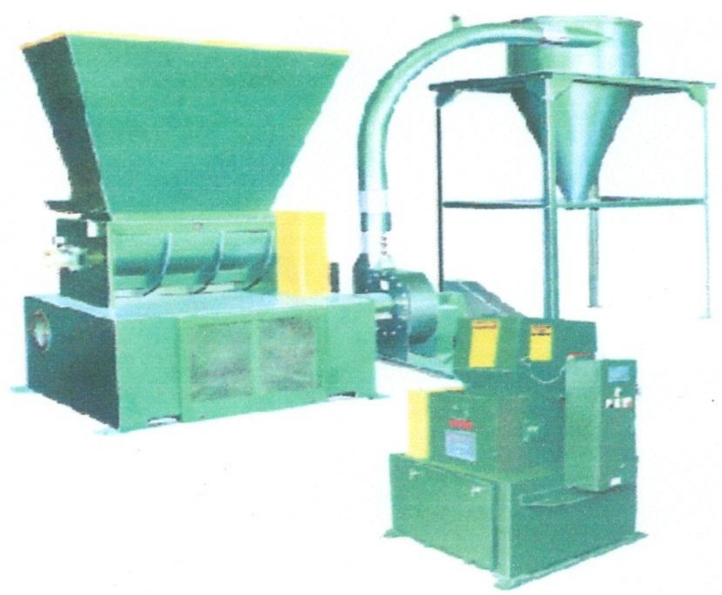


Figure 3.6: Pelletizer

3.5 Testing and Analysis

3.5.1 Fourier Transform Infrared (FTIR) Analysis

Sachet water plastic (30 % HDPE and 70 % LDPE) was selected as sample for IR analysis because it was the most abundant plastic in the MSW that was sorted and was without resin code.

The dried sample was shredded using a 0.2 mm grater and sieved with a 3.2 μm. Sieve. The IR spectrometer (Spectronic Camspec Ltd, UK, Model-Interspec 200-X), shown in figure 3.4, was switched on for a while to eliminate water vapour in the instrument that might interfere with experimental results. 200 mg potassium bromide (KBr) was placed in a mortar and ground to fine powder and used as a blank. 2 mg of the sample was mixed with another ground 200 mg of KBr in the mortar. The blank was pressed to obtain a palette. This was then repeated for the sample.

A background test was ran on the IR spectrometer. The KBr blank was placed in the sample compartment of a calibrated FTIR spectrometer to obtain a spectrum, which was added to the background. The sample was placed in the sample compartment of the calibrated FTIR spectrometer to obtain a spectrum.

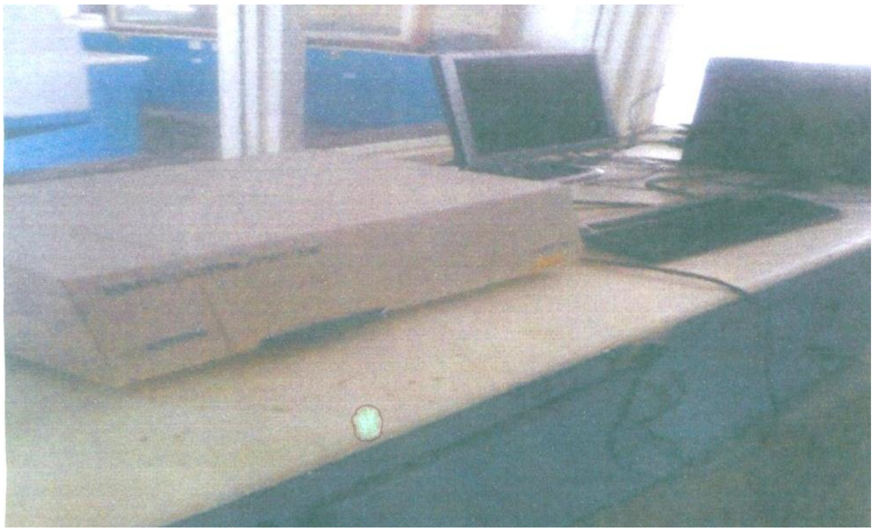


Figure 3.7: FTIR Spectrometer

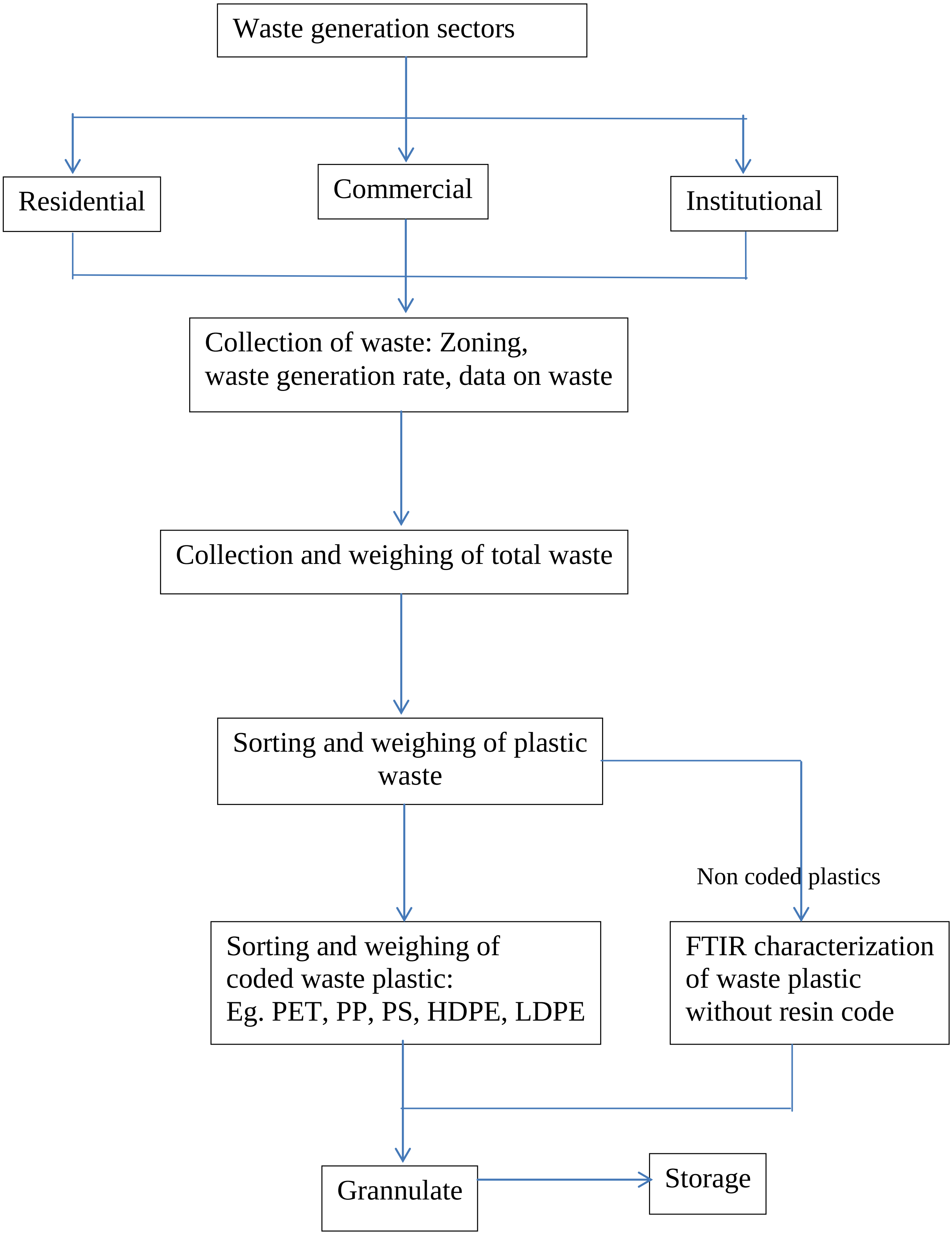


Figure 3.8: A Typical Plastic Recycling Process

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The results and discussion of the study are presented in this chapter. The results and discussion have been grouped into five namely: waste types and composition, waste generation rates, plastic waste types and composition, FTIR analysis of the uncoded plastic wastes and production of pellets (recyclates) from the plastic waste.

4.2 Waste Types and Composition

4.2.1 Composition of solid waste by mass

Table 1in appendix B provides details regarding the amount of solid waste sampled over the study period and figure 4.2 shows the amount of solid waste sampled over the study period. Out of a total of 6857.1 kg of waste collected, residential waste contributed 4218.0 kg (703.0 kg average), institutional waste, 1237.4 kg (618.7 kg average) and commercial waste constituted 1401.8 kg (700.9 kg average). Detail variation in waste types and compositions in the three waste generation sectors are shown in appendix B. Figure 4.1 shows the variation in waste types and compositions in the three waste generation sectors. The waste types identified in the waste streams were organic waste(kitchen/food waste, green waste, yard trimmings etc.), metals (ferrous and non ferrous metals, tins and cans), paper and cardboards (newspaper, A4 sheets, magazines, books, packaging boxes etc.), plastics (plastic chairs and bowls, carrier bags, sachet water plastics styrofoam etc.), wood (wood sticks and pieces, saw dust and chippings), textiles, rubber and leader(clothing, diapers, leader shoes and belt etc.), grass (bottles, jars, light bulbs, broken louver blades and bowls) and other (sand from sweeping, ashes from kitchen and burning.

Among the different types of waste generated in the study areas, organic waste recorded the highest percentages in all the three sectors representing 32.5%, 50.7% and 17.8% for residential, commercial and institutional waste generation sectors respectively. This was followed by plastic (20.7%, 31.1% and 17.0% for residential, commercial and institutional waste generation sector respectively), paper and cardboards (9.0%, 11.2% and 22.5% for residential, commercial and institutional waste generation sectors respectively), metal (11.0%, 12.2% and 6.4% for residential, commercial and institutional waste generation sectors respectively), wood (8.9%, 3.7% and 1.2% for residential, commercial and institutional waste generation sectors respectively), textile rubber and leather (6.4%, 4.7% and 7.9% for residential, commercial and institutional waste generation sectors respectively), glass (5.3%, 2.3% and 8.4% for residential, commercial and institutional waste generation sectors respectively) and others (4.5%, 4.5% and 2.9% for residential, commercial and institutional waste generation sectors respectively). Figure 4.3 shows the percent waste compositions (by mass) and variations in waste types and compositions in the three waste generation sectors.

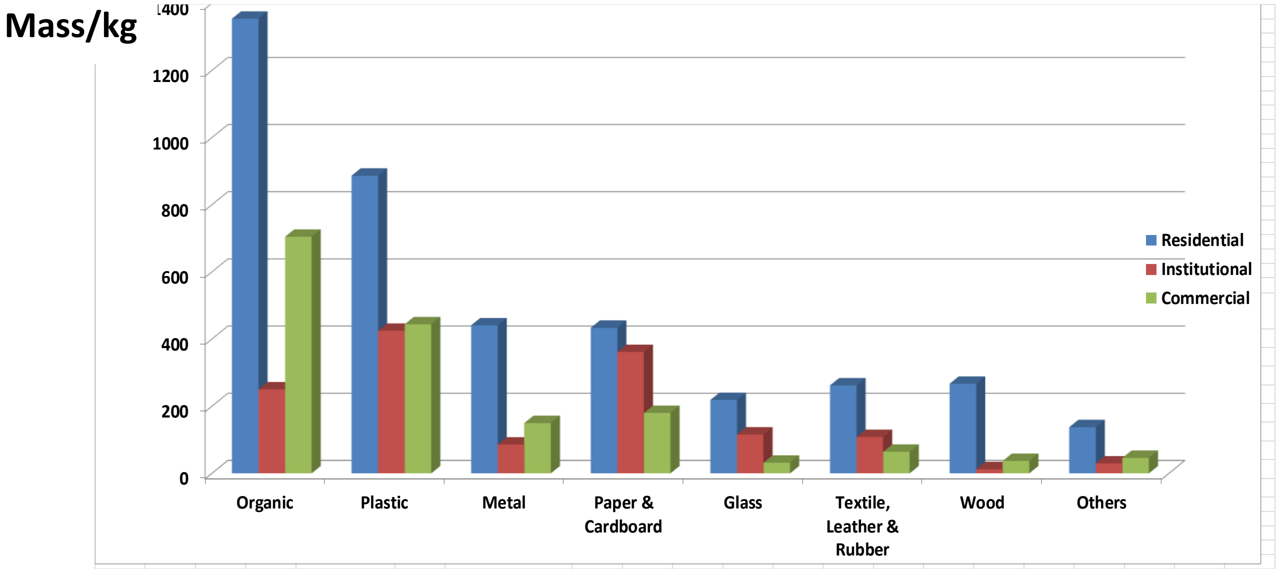


Figure 4.1: Waste Compositions and Variations for Residential, Commercial and Institutional Waste Generation Sectors

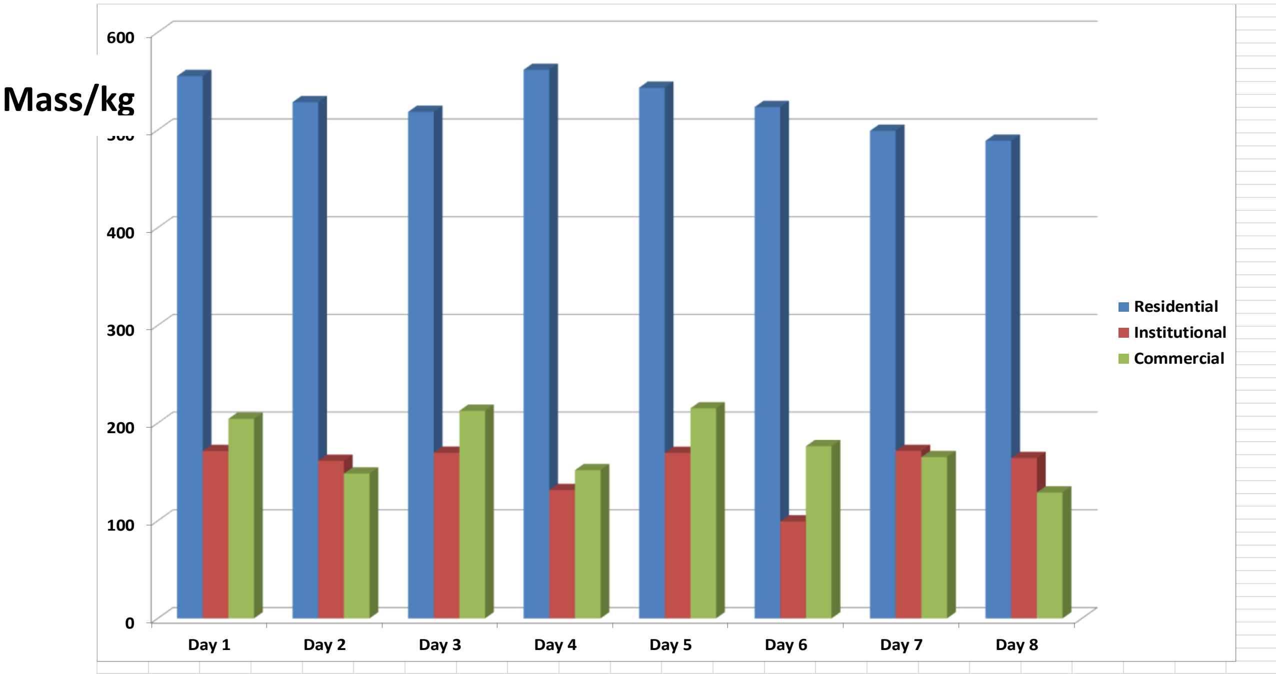


Figure 4.2: Amount Of Solid Waste Sampled Over The Study Period.

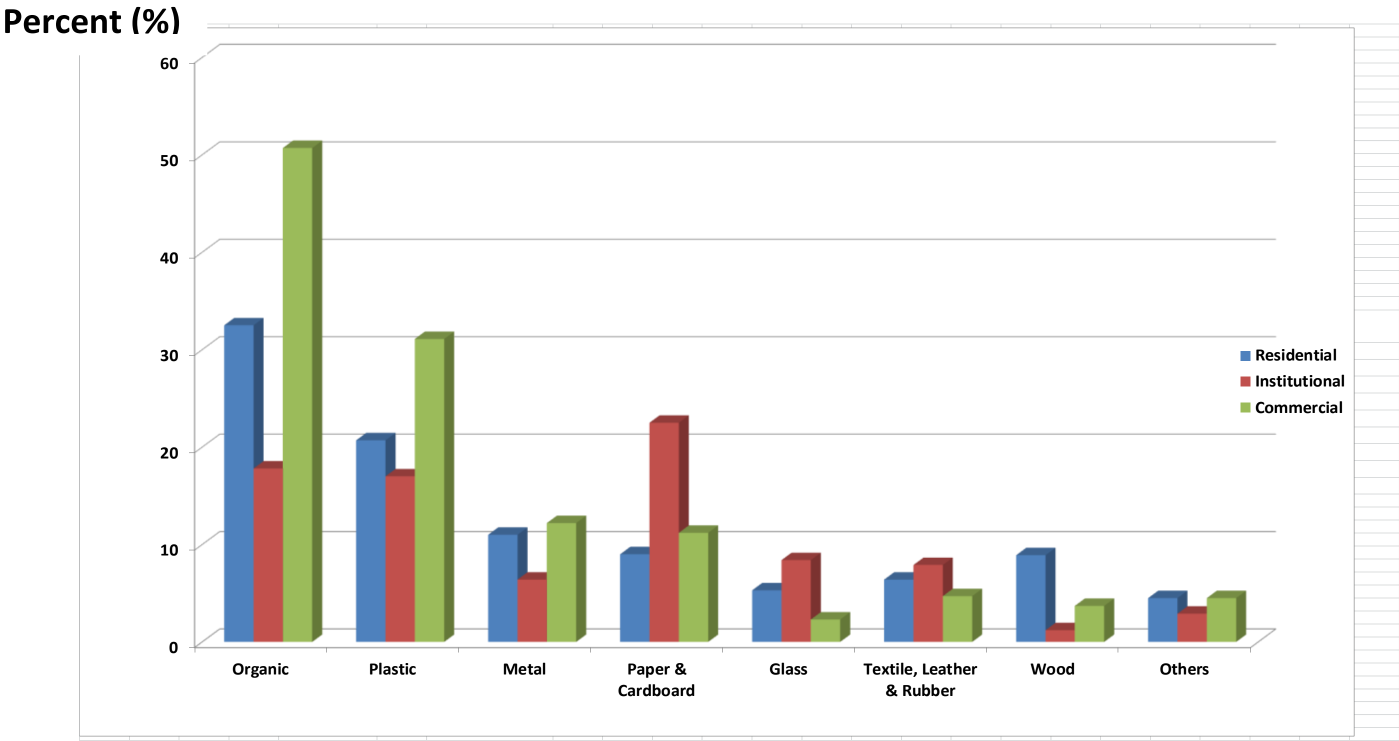


Figure 4.3: Percent Waste Compositions (By Mass) and Variations for Residential, Commercial and Institutional Waste Generation Sectors

Among the different types of waste generated in the study, it was revealed that high percentages of organic waste is generated in all sectors, representing 33.67%. This was followed by plastic waste representing 22.95%, paper and cardboards (21.92%), metals (9.87%), textile, rubber and leather (6.34%), glass (5.34%), wood (4.60%) and others representing 3.10%. The waste types identified were similar to what has been reported by Fobil *et al*., (2002) in Accra, Ketibuah (2008) in Kumasi. Figure 4.4 shows the variation in waste types and compositions in the waste generation sectors

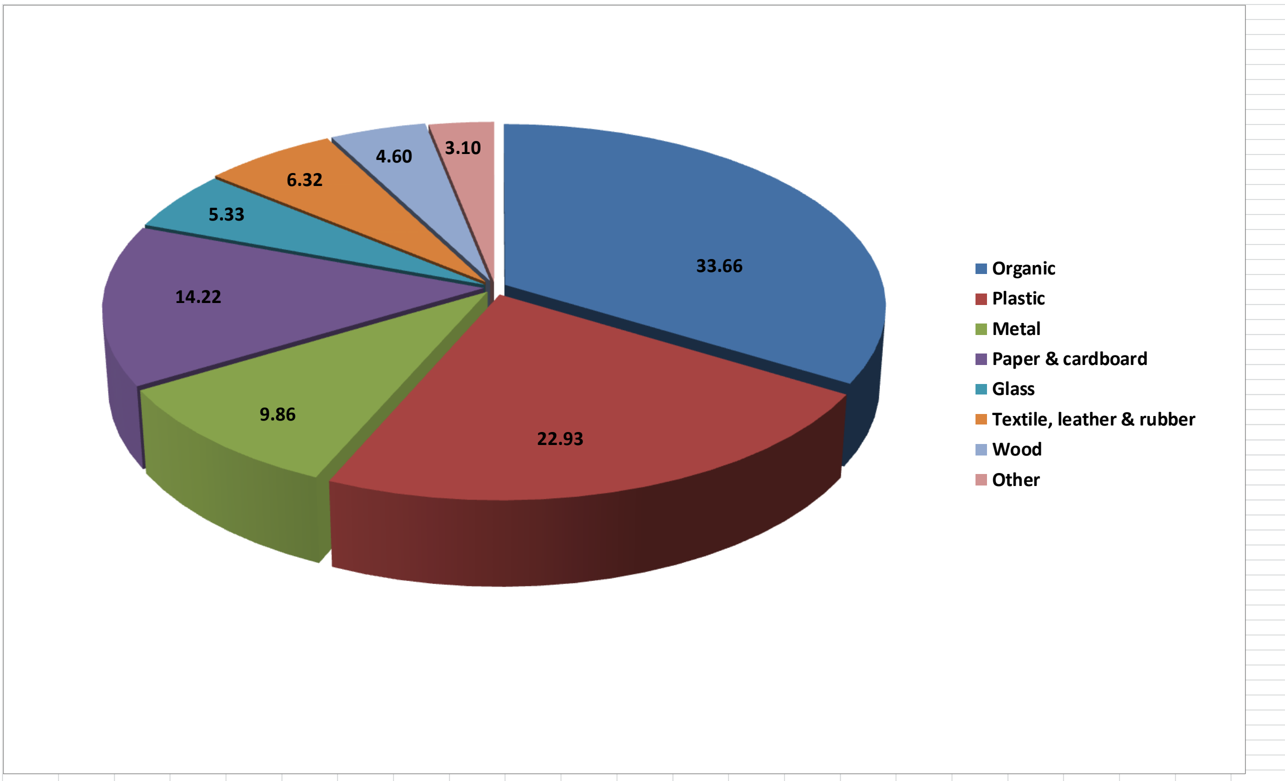


Figure 4.4: Composition of Solid Waste by Percent Weight

The percentage of organics waste recorded in the study area less than 55% for Kumasi as recorded by Ketibuah (2008). The lower percentage recorded in the study could be as a results of the collection food waste from the generation points by livestock farmers to feed their animals. This practice was observed during sample collection at some residential and commercial areas. The high organic waste being generated in the study areas require prompt conveyance of waste containers to avoid the incidence of flies and stench from rotting of waste which could impact negatively on the environment (Waldron *et al*, 2004). The high organic waste produced in these areas can be composted to serve as manure to boost agriculture in the study areas.

4.2.2 Composition of solid waste by volume

Out of a total of 40 m^3(40000 L) of waste collected over the study period, residential waste contributed 20038 L (20.038 m^3) representing 50.1%, institutional waste, 11121 L (11.121 m^3) representing 27.80% and commercial waste constituted 8841 L (8.841m^3) representing 22.10%. Detail variation in waste types and compositions in the three waste generation sectors are shown in appendix B. Figure 4.5 shows the variation in waste types and compositions in the three waste generation sector.

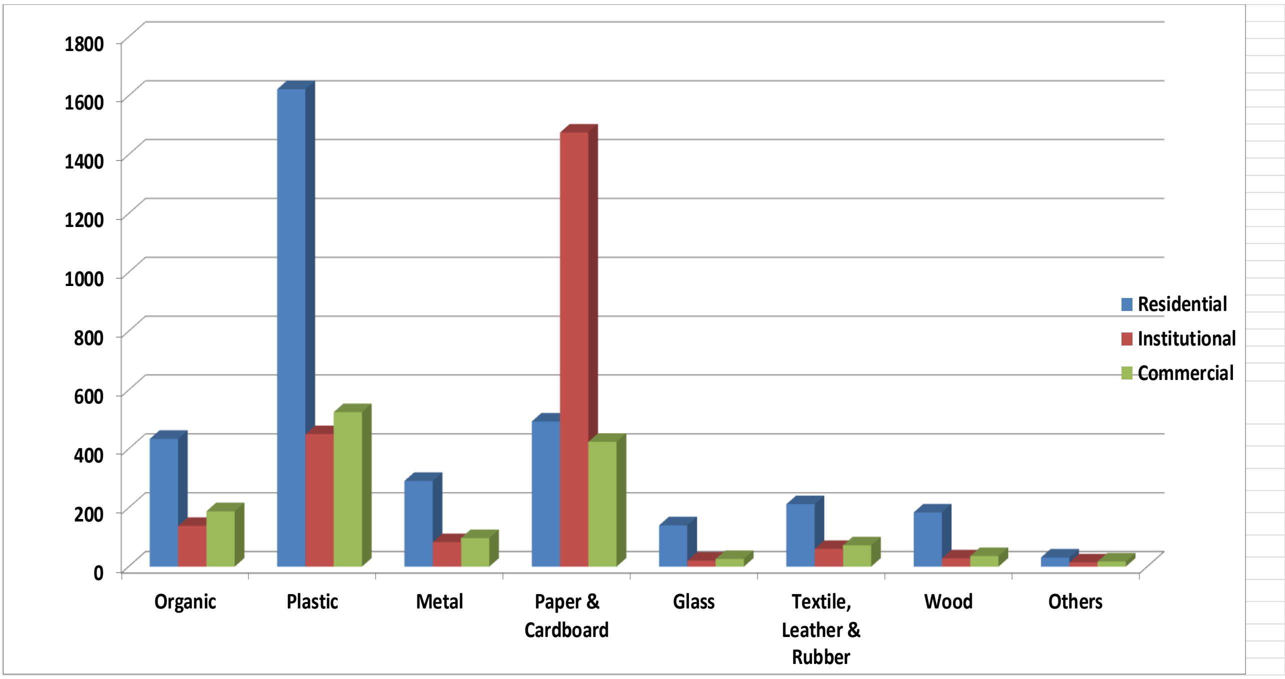


Figure 4.5: Waste Compositions by Volume and Variations for Residential, Commercial and Institutional Waste Generation Sectors

Among the different types of waste generated in the study areas, the study revealed high percentages of plastic waste in all the waste generation sectors representing 42.45%. This was followed by paper and cardboard waste representing 22.86%, organic waste (13.50%), metals (9.59%), textile, rubber and leather (3.93%), other (3.44%), wood (2.56%) and glass representing 1.67%. The waste types identified were similar to what has been reported by Butler (2008) in Berd.

Many studies on waste composition report only figures based on weight, yet volume is also important for managing some components of the waste stream, especially plastics. By weight, plastics make up only 22.93% of the waste stream. By volume, plastics represent the largest percentage (42.45%). The category "plastics" included all grades of plastic bags, bottles, packaging and many other sources. Plastic bags and very hard plastics will not be compacted from normal transportation or storage processes with low technologies. Plastic bottles have the most potential to break apart or collapse and contribute to an increase in overall density. Sunyani municipality wastes are not intentionally compacted during collection and even brittle plastics retain more volume than compacted trash. The high volume of plastic waste poses serious threat to the only landfill site of the municipality as a result of the fact that these plastics are not easily biodegradable. Figure 4.6 shows the variation in waste types and compositions by percent volume.

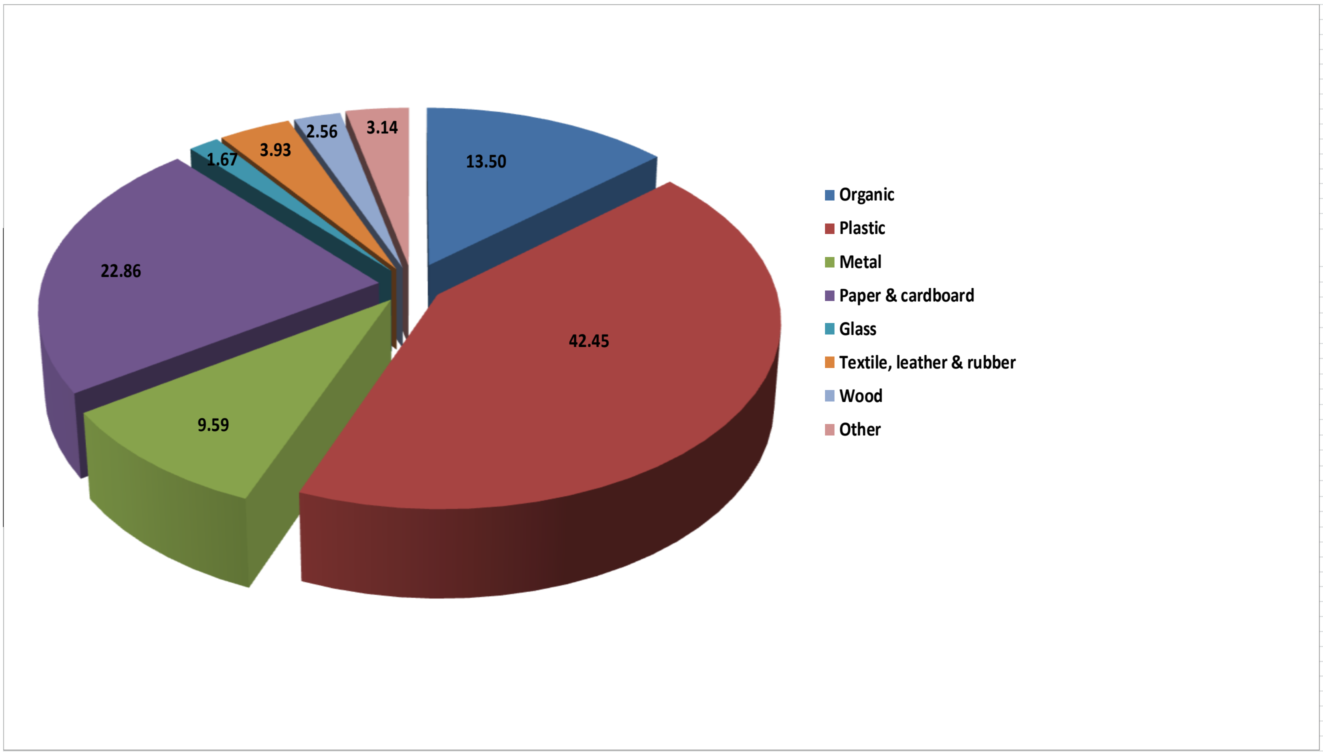


Figure 4.6: Composition of Solid Waste by Percent Volume.

4.3 Waste Generation Rates

Over the one month study period, residential waste generation sector recorded the highest mean quantity of solid waste of 4218.0 kg (20.038 m^3) from a sampled unit of 48 translating 87.9 kg per sample. This was followed by commercial,1401.8 kg (11.121 m^3) from a sampled unit of 16 translating 87.6 kg per sample. The mass of the institutional waste was1237.4 kg (8.841m^3) from a sampled unit of 16translating 77.3 kg per sample. Zoomlion Ghana Limited who is responsible for waste collection in the municipality has distributed 39 skip containers throughout the municipality. The capacity of each of this container is 12 m^3. 22 of these containers are lifted daily to the landfill site and the remaining 17 are lifted twice a week. This constitutes about 1992 m^3 of waste collected a week from the skip containers. The compact truck that is responsible for the collection of the waste in the bins also collect about 400 bins a day with each bin having a capacity of 240 litres. This means the compact truck.

Collect about 96 m^3 (96000 L) a day and 576 m^3 of solid waste a week. A total of 2568 m^3 of waste collected in a week and an average of 366.86 m^3 a day.

The average weight of 80 samples of 500 liters (0.5 m^3) is 85.71 kg. The average composition amount of 5 m^3 solid waste generated was found to be 685.68 kg per day during the study. The total weight of waste generated in Sunyani municipality that reached the landfill site is estimated by multiplying the total sample weight by 73.37 m^3, which is the number of 0.5 m^3 boxes that is equivalent to the total amount of waste that reach the landfill site daily. Assuming that the volume of garbage does not exceed capacity due to overflow (73.37 x 685.68 kg = 50309.71 kg). Waste collection service is provided to about 60% of the population of 147301 in the municipality. The total weight of solid waste collected is divided by the number of people served (88381) to calculate the total weight of waste produced by each person per day (0.57 kg/person/day). That number is multiplied by the portion of the population not being served by waste removal (58920 people not served x 0.57 kg/person = 33584.4 kg). This estimate is added to the known weight of generation for a total amount of trash generated by all the residents of Sunyani municipality. The municipality generates a total of 83894.11 kg/day. The per capita waste generation in the municipality was 0.57 kg/capita/day which is slightly above the national average per capita waste generation values of 0.5 kg/capita/day.

The total daily volume of waste collected in the municipality is estimated to be 73.37 m^3. If only 60% of the population benefits from solid waste removal service, then the total volume of waste generated in municipality is 102.72 m^3 with a total weight of 71963.3 kg/day. This assumes that there is no loss from scavenging at the collection site before collection occurred, that the density of waste did not increase due to normal compression processes while in the container, and that the 40% of residents not receiving waste removal services do not contribute to the municipal waste collected. However, it is very likely that the above three assumptions are false and that the volume is overestimated by at least one third (Rushbrook and Pugh, 1999).

4.4 Types and Composition of Plastic Waste

The composition of plastic waste is an important issue in the management of waste. This is because the types of plastic waste affects the technique in its disposal and is necessary for deciding on reuse, reduction and ultimately recycling of waste. The percent of plastic (22.93%) realised in the waste stream was higher than that reported by Mensah (2010).This high percentage of plastic could be as a results of recent widespread replacement of the existing cultural packaging methods of food, beverage, water and other products using leaf wrappers, brown paper and metal cup with plastics.

Out of a total of 6857.1 kg of waste collected, plastic waste constituted 1572.5 kg (16980 litres) representing 22.93% (42.45% by volume).Residential sector generated (886.1 kg (9696 litres), institutional sector, 242.6 kg (3090 litres) and commercial waste constituted 443.8kg (4194 litres). Detail variation in waste types and compositions in the three waste generation sectors are shown in appendix B. Figure 4.5 shows the variation in plastic waste types and compositions in the three waste generation sectors.

The waste types identified in the waste streams were PE, PP, PET bottles, PVC materials, Styrofoam packaging and LDPE/HDPE composites (sachet water packaging). The sachet water plastic constituted a total of 544.3 kg during the study period representing 34.61% of the plastic waste generated. This high value for sachet water plastic was obtained because a lot of people patronized sachet water more than any other type of packaged water in the municipality. Low density polyethylene (LDPE) contributed the highest fraction among the engineered plastics constituting 271.4 kg representing 17.26%. Polypropylene contributed

229.5 kg representing 14.59%of the total plastic waste. These plastic were made up of broken plastic chairs, plastic plates, combs water bottle tops and others. Although these fraction of plastic waste are not usually seen littering the environment, they constituted an appreciable quantity, basically because of its relatively high molecular weight. Polyethylene terephthalate (PET) constituted up to 203.6 kg representing 12.94% of the plastic waste. PVC constituted the lowest fraction contributing only 1.7 kg representing 0.01%. This low amount of PVC could be as a result of the fact that most of PVC waste is usually generated among the construction and demolishing waste. This type of waste did not end up in the MSW landfill site and for that matter, data was not collected on them. The plastic waste types identified were similar to what has been reported by Osei-Bonsu (2013) in Independence Hall of Kwame Nkrumah University of Science and Technology. Detail variation in plastic waste types and compositions in the waste stream are shown in appendix B. Figure 4.1 shows the waste types and compositions in the municipal waste stream.

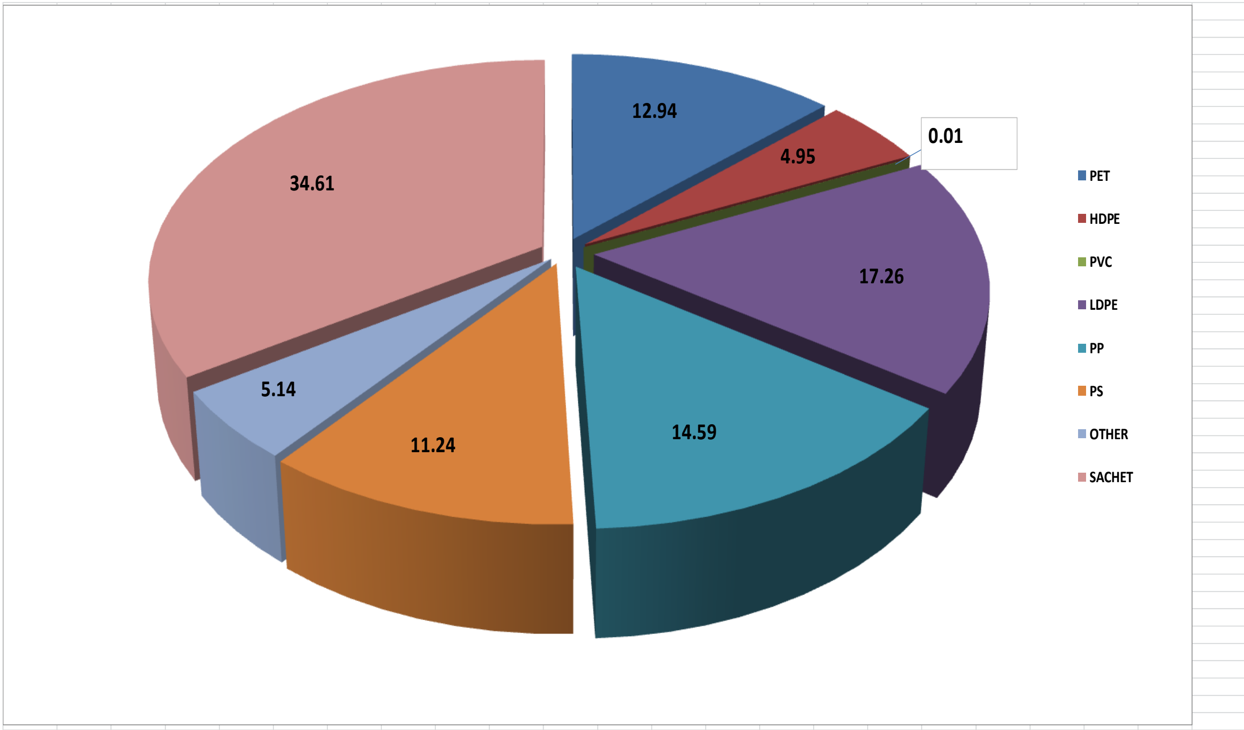


Figure 4.7: Composition of Plastics Solid Waste by Percent Mass.

4.5 Plastic Waste Generation Rates

Over the one month study period, residential waste generation sector recorded the mean quantity of plastic waste of 886.1 kg (9.7 m^3) from a sampled unit of 48. The commercial sector generated443.8 kg (4.2 m^3) from a sampled unit of 16.The mass of the institutional plastic waste was242.6 kg (3.1m^3) from a sampled unit of 16.

A total of 393.1 kg of plastic waste was collected in a week and an average of 196.6 kg a day. The average weight of 80 samples of 500 liters (0.5 m^3) is 19.65 kg. The average composition amount of 5 m^3 solid waste generated was found to be 196.6 kg per day during the study. The total weight of waste generated in Sunyani municipality that reached the landfill site is estimated by multiplying the total sample weight by 73.37 m^3, which is the number of 0.5 m^3 boxes that is equivalent to the total amount of waste that reach the landfill site daily. Assuming that the volume of garbage does not exceed capacity due to overflow (73.37 x 196.6 kg = 14424.5 kg). Waste collection service is provided to about 60% of the population. The total weight of solid waste collected is divided by the number of people served (88381) to calculate the total weight of waste produced by each person per day (0.16 kg/person). That number is multiplied by the portion of the population not being served by waste removal (58920 people not served x 0.14 kg/person = 9427.2 kg). This estimate is added to the known weight of generation for a total amount of trash generated by all the residents of Sunyani municipality. The municipality generates a total of 23851.7 kg/day.

The total daily volume of waste collected in the municipality is estimated to be 73.37 m^3. If only 60% of the population benefits from solid waste removal service, then the total volume of waste generated in municipality is 102.72 m^3 with a total weight of 23851.7 kg/day. This assumes that there is no loss from scavenging at the collection site before collection occurred, that the density of waste did not increase due to normal compression processes while in the container, and that the 40% of residents not receiving waste removal services do not contribute to the municipal waste collected. However, it is very likely that the above three assumptions are false and that the volume is overestimated by at least one third (Rushbrook and Pugh, 1999).

4.6 FTIR Analysis

The FTIR was carried out to detect the functional groups present in the sachet water plastic.

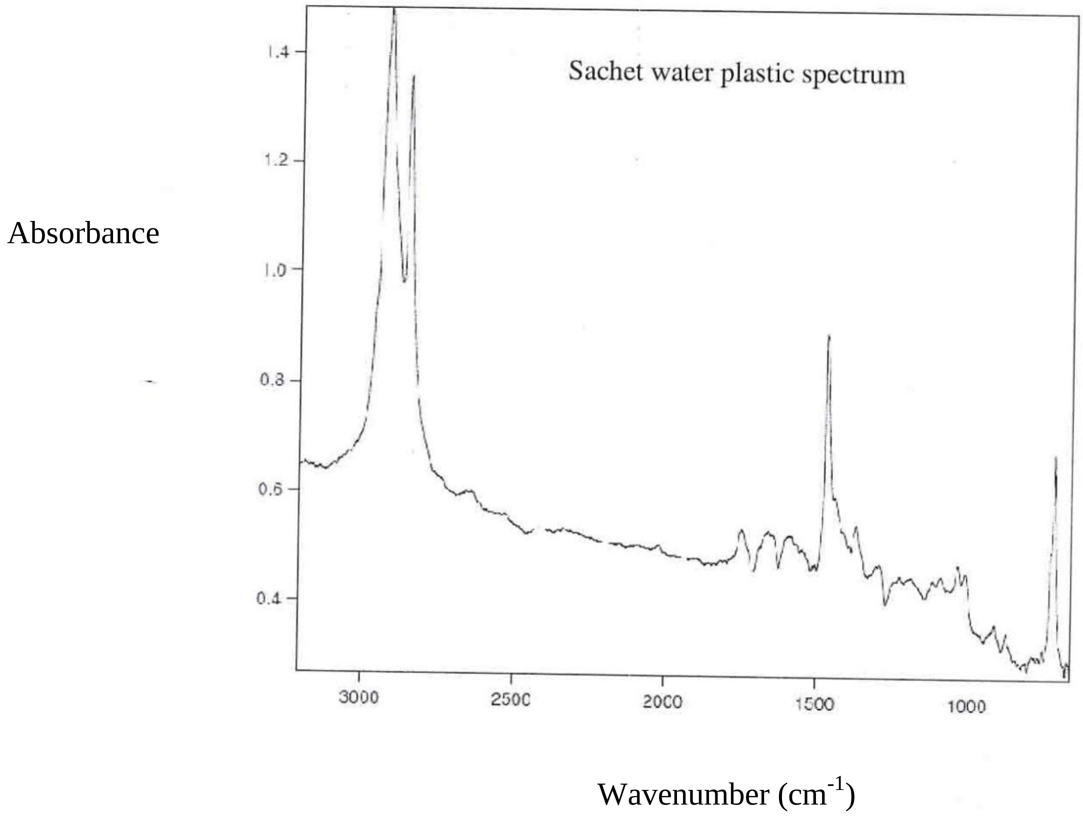


Figure 4.7Shredded HDPE/LDPE Composite (Sachet Water) Plastic Spectrum

The Figure 4.7 shows the infra-red spectroscopic analysis of the shredded LDPE/HDPE composite. The strongest peak was observed within 2850 and 2900 cm^{-1} at 2900 cm^{-1} IR frequency range. This frequency is typical of sp^3 symmetrical CH_2 stretching peak of C-H bond. The peak at 1450 cm^{-1} corresponds to the C-C information in aliphatics. The peak at

725 cm^{-1} corresponds to the CH_2 rocking vibrations. The spectrum confirms that the material is composed of aliphatic C-H and C-C bond confirming that the material is a PE materials. This ascertain that there is no formation of new bond during the formation of HDPE/LDPE composites plastics. Fig4.8 shows a typical IR spectrum of low density polyethylene

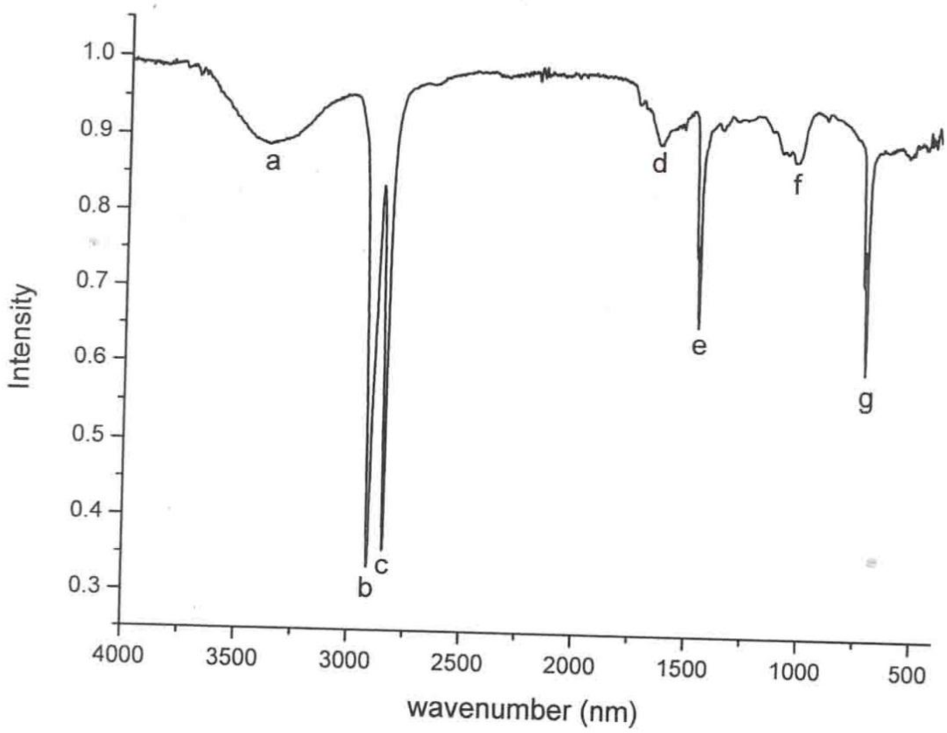


Figure 4.8 IR spectrum of low density polyethylene

4.7 Recycling Process

4.7.1 Shredding and palletisation of sachet water plastic

Shredded 1kg of the sachet water plastic produced 780g of recyclate which represent about 78% efficiency. At this percentage, 6448.6kg of plastic generated per day can produce 5028.3kg of the pellects

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Municipalities such as Sunyani are generating a significant amount of waste, and these wastes must be managed appropriately. Solid waste management depends on accurate data collection and resource-appropriate methods. The study shows that municipalities in Ghana including Sunyani are generating a significant amount waste especially plastic waste, and these wastes must be managed appropriately.

The total amount of waste collected during the study period of one month is 6857.1 kg the average amount of waste generated is per day is 685.68 kg. the solid waste generation rate is 0.57 kg/person/day. The percentage composition of plastic in the solid waste is 22.93%. Plastic waste generation rate in the municipality is 0.14 kg/person/day. The sachet water plastic (HDPE/LDPE composite) is the highest among the plastic waste recording a percentage of 34.61%. Among the engineered plastic,low density polyethylene (LDPE) recorded highest percentage of 17.26% followed bypolypropylene with the percentage of 14.59%, PET (12.94%), PS (11.24%), others (5.14%) and HDPE (4.95%). of the total plastic waste. PVC constituted the lowest fraction contributing representing 0.01%.Substantial amount of sachet water plastic waste which was the highest component of the plastic was shredded and pelletized into granules.

5.2 Recommendations

1. The quantity of plastic and other recyclable materials in the study areas present opportunity for recycling ventures in the areas by investors and the municipal assembly. Recycling of the waste can also reduce the amount of waste that has to be transported to the disposal sites. It may also encourage waste sorting among residents

if the waste is bought as raw materials. This could also improve the economic standings of the people in the study areas. The municipal assembly should institute recycling plant which can serve as a plough back venture that could be used to fund waste management and even other sectors.

2. The high organic waste being generated in the study areas require prompt conveyance of waste containers to avoid the incidence of flies and stench from rotting of waste which could impact negatively on the environment. The high organic waste produced in these areas should be composted to serve as manure to boost agriculture in the study areas.
3. Indiscriminate dumping and littering, especially into the rivers and gutters, lead to pollution that requires clean-up costs of two to three times the cost of direct collection (Cointreau-Levine, 1994). Furthermore, littering decreases aesthetic quality and tourism potential. The municipality should therefore provide bins to the waste generation sectors and at vantage points to ensure proper collection and separation of waste at source of generation.
4. Education and incentives that promote these ideas are necessary to convince the general public to participate in management processes. De Young *et al.* (1993) found that presenting a combination of environmental and economic benefits to households resulted in more behaviour change than either incentive alone. Public seminars, secondary school curriculum, brochures, radio and television advertisements should be the base of an intensive campaign to discourage plastic bag littering.
5. Differences in composition and generation of wastes between the waste generation sectors suggest local methods of data collection are more accurate at the local level. An effective waste management program should be designed around the structure of the wastes in that municipality. Municipal waste planners have a responsibility to

gather high quality local data using standard methodology. The methodology presented in this report is low cost, uses locally available materials, and requires a small labour force. The methods can be applied to any city and can be used to calculate accurate waste generation rates. The methodology presented in this report should be improved on by weighing the total truckload of wastes if possible. A truck scale should be used to weigh the empty truck first, and then the full truck should be weighed on every sample day. This is the most accurate method to obtain total daily city waste generation by weight.

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APPENDIX A

CALCULATION

Total Mass of Waste Generated for One Month

Total Mass of Waste = 930.6 + 837.9 + 900.4 + 844.5 + 927.7 + 798.8 + 835.6 + 781.6

= 6857.1 kg

Average mass of waste Mass of Waste generated Per day for One month

$$\text{Average mass of waste} = \frac{930.6 + 837.9 + 900.4 + 844.5 + 927.7 + 798.8 + 835.6 + 781.6}{8}$$

= 857.1 kg

$$\text{Waste generation per person} = \frac{6857.1}{(8 \times 88381)}$$

= 0.57 kg/person/day

Total Mass of Plastic Waste Generated for One Month

Total Mass of Waste = 181.5 + 180.7 + 246.2 + 186.6 + 210.9 + 197.6 + 174.7 + 194.3

= 1572.5 kg

Average mass of waste Mass of Waste generated Per day for One month

$$\text{Average mass of waste} = \frac{181.5 + 180.7 + 246.2 + 186.6 + 210.9 + 197.6 + 174.7 + 194.3}{8}$$

= 196.6 kg

$$\text{Plastic waste generation per person} = \frac{1572.5}{(8 \times 88381)}$$

= 0.14 kg/person/day

Total Mass of Individual Plastic Waste Generated for One Month

Mass of PET = 23.6 + 19.9 + 32.7 + 24.8 + 31.4 + 29.4 + 25.5 + 16.9

= 203.6 kg

Mass of HDPE = 77.9 kg, Mass of PVC = 1.7 kg, Mass of LDPE = 271.4 kg, Mass of PP = 229.5 kg, Mass of PS = 176.7 kg, Mass of ‘Others’ = 80.9 kg, Mass of sachet water plastic = 544.3 kg.

Average Mass of Individual Plastic Waste Generated for One Month

$$\text{Average mass of PET} = \frac{23.6 + 19.9 + 32.7 + 24.8 + 31.4 + 29.4 + 25.5 + 16.9}{8}$$

$$= 25.5 \text{ kg}$$

Average mass of HDPE = 9.7 kg, Average mass of PVC = 0.2 kg, Average mass of LDPE = 33.9 kg, Average mass of PP = 28.7 kg, Average mass of PS = 22.1 kg, Average mass of ‘Other = 10.1 kg, Average mass of sachet plastic = 68.0 kg.

APPENDIX B

Table 1: Amount of solid waste by mass sampled over the study period.

Days of Waste Collection	**Residential Waste (kg)**	**Institutional Waste (kg)**	**Commercial Waste (kg)**	**Total Waste (kg)**
Day 1	555.1	171.3	204.2	930.6
Day 2	528.4	161.3	148.2	837.9
Day 3	518.4	169.5	212.5	900.4
Day 4	561.5	131.3	151.7	844.5
Day 5	543.2	169.4	215.0	927.7
Day 6	523.4	99.2	176.2	798.8
Day 7	499.1	171.4	165.1	835.6
Day 8	488.9	164.0	128.9	781.6
Total	**4218.0**	**1237.4**	**1401.8**	**6857.1**

Table 2: Waste compositions by mass and variations for residential, commercial and institutional waste generation sectors.

Waste	Residential Waste	Institutional Waste	Commercial Waste	Total Waste	%Waste
Organic	1353.6	249.9	704.3	2307.8	33.66
Plastic	886.1	242.6	443.8	1572.5	22.93
Metal	440.7	85.5	149.6	675.8	9.86
P&C	433.3	361.1	179.7	974.1	14.21
Glass	218.3	115.3	31.6	365.2	5.33
RL&T	261.7	107.9	64.1	433.7	6.32
Wood	266.5	12.0	36.9	315.4	4.60
Others	137.3	29.5	45.8	212.6	3.10

Table 3: Composition of solid waste by percent mass for residential, commercial and institutional waste generation sectors.

	Organic	Plastic	Metal	P&C	Glass	RL&T	Wood	Other
Residential	32.5	20.7	11.0	9.0	5.3	6.4	8.9	4.5
Institutional	17.8	17.0	6.4	22.5	8.4	7.9	1.2	2.9
Commercial	50.7	31.1	12.2	11.2	2.3	4.7	3.7	4.5

Table 4: Waste compositions by volume and variations for residential, commercial and institutional waste generation sectors.

Waste	**Residential Waste**	**Institutional Waste**	**Commercial Waste**	**Total Volume**	**%Waste**
Organic	3083	983	1334	5400	13.50
Plastic	9696	3090	4194	16980	42.45
Metal	2371	675	790	3836	9.59
P&C	1884	5642	1618	9144	22.86
Glass	503	71	94	668	1.67
RL&T	968	274	330	1572	3.93
Wood	1021	155	200	1376	3.44
Others	512	231	281	1024	2.56
Total	**20038**	**11121**	**8841**	**40000**	

Table 5: Composition of solid waste by percent volume for residential, commercial and institutional waste generation sectors

	Organic	Plastic	Metal	P&C	Glass	RL&T	Wood	Wood
Residential	57.1	62.5	61.8	20.6	75.3	61.6	74.2	50.0
Institutional	18.2	17.3	17.6	61.7	10.8	17.4	11.3	22.6
Commercial	24.7	20.2	20.6	17.7	14.0	20.9	14.5	27.4

Table 6: Amount of plastic waste by mass sampled over the study period.

Days of Waste Collection	Residential Waste (kg)	Institutional Waste (kg)	Commercial Waste (kg)	Total Waste (kg)
Day 1	90.8	18.1	72.6	181.5
Day 2	90.4	16.3	74.0	180.7
Day 3	123.1	12.3	110.8	246.2
Day 4	97.0	14.9	74.7	186.6
Day 5	107.6	21.1	82.2	210.9
Day 6	102.6	10.0	85.0	197.6
Day 7	87.4	19.2	68.1	174.7
Day 8	95.2	23.3	75.8	194.3
Total	**794.1**	**135.2**	**643.2**	**1572.5**

Table 7: Amount of residential plastic waste by mass sampled over the study period

Sample Number	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
1	15.1	12.2	22.7	16.2	18.1	17.0	14.7	15.2
2	12.9	17.7	20.5	15.5	19.0	16.9	14.5	16.2
3	17.3	15.0	17.8	16.0	18.5	17.9	15.2	15.9
4	14.1	17.9	27.6	16.7	17.4	16.2	13.5	24.7
5	18.4	16.0	25.3	22.0	26.7	25.9	14.9	16.6
6	12.7	11.5	9.2	10.6	7.9	8.7	14.6	6.6

Table 8: Amount of institutional plastic waste by mass sampled over the study period

Sample Number	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
7	8.5	7.0	4.3	4.8	7.4	5.0	8.9	10.0
8	9.6	9.3	8.0	10.1	13.7	5.0	10.3	13.3

Table 9: Amount of commercial plastic waste by mass sampled over the study period

Sample Number	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
9	42.0	38.8	69.6	29.7	51.9	59.5	33.1	35.6
10	30.6	35.2	41.2	45.0	30.3	25.5	35.0	35.6

Table 10: Waste generation for day 1

SAMPLE NUMBER	MASS/kg
1	15.1
2	12.9
3	17.3
4	14.1
5	18.4
6	12.7
7	8.5
8	9.6
9	42.0
10	30.6
TOTAL WASTE	930.6
PET	23.6
HDPE	11.3
PVC	-
LDPE	34.8
PP	24.9
PS	18.5
OTHER	5.6
SACHET WATER	62.8
TOTAL PLASTIC	181.5
% PLASTIC	19.50

Table 11: Waste generation for day 2

SAMPLE NUMBER	MASS/kg
1	12.2
2	17.7
3	15.0
4	17.9
5	16.0
6	11.5
7	7.0
8	9.3
9	38.8
10	35.2
TOTAL WASTE	837.9
PET	19.3
HDPE	8.8
PVC	0.2
LDPE	28.2
PP	24.6
PS	22.1
OTHER	20.2
SACHET WATER	57.1
TOTAL PLASTIC	180.7
% PLASTIC	21.57

Table 12:Waste generation for day 3

SAMPLE NUMBER	MASS/kg
1	22.7
2	20.5
3	17.8
4	27.6
5	25.3
6	9.2
7	4.3
8	8.0
9	69.6
10	41.2
TOTAL WASTE	900.4
PET	32.7
HDPE	15.5
PVC	-
LDPE	44.3
PP	36.9
PS	22.8
OTHER	10.8
SACHET WATER	84.4
TOTAL PLASTIC	246.2
% PLASTIC	27.34

Table 13: Waste generation for day 4

SAMPLE NUMBER	MASS/kg
1	16.2
2	15.5
3	16.0
4	16.2
5	22.0
6	10.6
7	4.8
8	10.1
9	29.7
10	45.0
TOTAL WASTE	844.5
PET	24.8
HDPE	12.3
PVC	1.5
LDPE	29.1
PP	23.3
PS	21.8
OTHER	9.0
SACHET WATER	64.4
TOTAL PLASTIC	186.6
% PLASTIC	22.10

Table 14: Waste generation for day 5

SAMPLE NUMBER	MASS/kg
1	18.1
2	19.0
3	18.5
4	17.4
5	26.7
6	7.9
7	7.4
8	13.7
9	51.9
10	30.3
TOTAL WASTE	927.7
PET	31.4
HDPE	4.6
PVC	-
LDPE	41.8
PP	25.6
PS	24.3
OTHER	15.6
SACHET WATER	66.6
TOTAL PLASTIC	210.9
% PLASTIC	22.73

Table 15: Waste generation for day 6

SAMPLE NUMBER	MASS/kg
1	17.0
2	16.9
3	17.9
4	16.2
5	25.9
6	8.7
7	5.0
8	5.0
9	59.5
10	25.5
TOTAL WASTE	798.8
PET	29.4
HDPE	11.7
PVC	-
LDPE	24.0
PP	30.8
PS	26.5
OTHER	7.3
SACHET WATER	68.0
TOTAL PLASTIC	197.6
% PLASTIC	24.74

Table 16: Waste generation for day 7

SAMPLE NUMBER	MASS/kg
1	14.7
2	14.5
3	15.2
4	13.5
5	14.9
6	14.6
7	8.9
8	10.3
9	33.1
10	35.0
TOTAL WASTE	835.6
PET	25.5
HDPE	6.1
PVC	-
LDPE	31.3
PP	22.7
PS	16.4
OTHER	8.7
SACHET WATER	63.9
TOTAL PLASTIC	174.7
% PLASTIC	20.90

Table 17: Waste generation for day 8

SAMPLE NUMBER	MASS/kg
1	15.2
2	16.2
3	15.9
4	24.7
5	16.6
6	6.6
7	10.0
8	13.3
9	35.6
10	35.6
TOTAL WASTE	781.6
PET	16.9
HDPE	7.6
PVC	-
LDPE	37.9
PP	30.7
PS	24.3
OTHER	3.7
SACHET WATER	73.1
TOTAL PLASTIC	194.3
% PLASTIC	24.86

Table 18: Summary of derivations obtained from data

	Waste	PET	HDPE	PVC	LDPE	PP	PS	OTHER	SACHET
Total mass/kg	930.6	203.6	77.9	1.7	271.4	229.5	176.7	80.9	544.3
Average mass/kg	857.1	25.5	9.7	0.21	33.9	28.9	22.1	10.1	68.0
% plastic	22.93	12.94	4.95	0.01	17.26	14.59	11.24	5.14	34.61