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CHARACTERIZATION AND COMPOSTING OF SOLID WASTE GENERATED IN THE ABURI TOWNSHIP

BY

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

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Abstract

The composition of solid waste generated by 34 households was analysed over four weeks and the waste was sorted into the following fractions; Organic waste, Glass waste, Paper and cardboard, Metals and cans, Rubber and plastic. The data gathered showed that organic waste (70%) was the most abundant waste type generated daily per household followed by Rubber and plastic (16%) then Paper and cardboard (6%), Glass waste (5%) and Metals and cans (3%). The per capita generation of waste showed organic waste in the lead with 0.072 kg/week per person followed by plastic waste with 0.016 kg/week per person then paper waste with 0.006 kg/week per person followed by glass waste with 0.005 kg/week per person and metal waste trailing with 0.004 kg/week per person. A compost pile was prepared using food waste collected from the participating households with an initial C/N ratio of 37.24±0.66; the compost was ready in 35 days. The composting process was closely monitored daily by measuring the temperature and its volume. The analysis performed on the compost after composting showed that the compost had a final C/N ratio of 83.70, pH of 8.67 and contained 0.07% potassium and 0.08% of phosphorus. The levels of potassium and phosphorus were within the recommended values of 0.5-1.8 and 0.3-3.5 respectively. The C/N ratio exceeded the acceptable level of 22. Heavy metal analysis showed the level of mercury (82.14 ±3.01 ppm) to be high above the recommended level of 82.14 ppm. But the levels of copper (2.670 ±0.537 ppm), lead (40.560 ±1.245 ppm) and zinc (0.75±0.212 ppm) were within the required limits of 80, 150 and 300 respectively. The microbiological analysis of the finished compost showed that the levels of *E. coli* (4.3×10^1) and faecal coliforms (2.4×10^3) were higher than recommended levels of < 3 and < 1000 respectively. The waste management plan revealed that the organic fraction of the waste was the most abundant of the five kinds of waste that were characterised. This waste type would pose a big challenge to the town in the long term (25 years) if management of the waste is not taken seriously, which would destroy the tourism potential of the town.

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CHAPTER ONE

1.0 Introduction

For the purposes of urban development planning, the type and amount of solid waste that is produced and the behaviour of solid waste generators must be identified. A detailed characterization of solid waste is also necessary for integrated solid waste management strategies to be successful (Shakai *et al.*, 1996). The design, implementation and operation of the economical solid waste handling, collection, transport and disposal systems require accurate information on the quantities and characteristics of the solid waste to be processed (Lohani & Hartono, 1985).

In recognition of the fact that guidelines for the development of waste management plan have been made available to Districts, most of these Districts have not developed the plans because required information is absent including waste characterization information. The Akuapim south District (ASD) falls into the category of Districts who have not developed plan for the management of its solid waste and very little has been done in terms of research with the aim of developing a plan.

It is therefore necessary to carry out a waste characterization study in the town of Aburi located in Akuapim South of the Eastern Region of Ghana which has a solid waste problem because there is no appropriate plan in place for the management of solid household waste. Wastes generated in Aburi are just disposed of in open dumps by individual households which have led to environmental degradation and its attendant health problems.

In the execution of this study, one of the most accurate approaches for the characterisation of solid waste is the collection of the waste at the point of generation, which is the household and directly sorting out the various materials (Martin *et al.*, 1995).

Households are the best place to collect Household Solid Waste samples, as this makes the identification of waste materials easier and eliminates any uncertainty as to their origins (Bernache-Pérez *et al.*, 2001).

To characterize the solid waste it's necessary to access the individual wastes generated at the household level and analyse them and develop key patterns to help develop intervention measures to help improve the solid waste management system in Aburi.

1.1. Justification

There does not appear to be a planned system available to manage the waste produced in this town and waste is just disposed off at rubbish dumps most of which has not been designated by the district assembly and poses health hazards. Fobil *et al.* (2001) stated that effective sustainable waste management requires that waste management and planning authorities know and understand the materials they will be handling or disposing in order to be able to set up effective sustainable waste management programs.

Also in setting up a waste management program for a region or city it is critical to have reliable data on waste stream characteristics such as the nature, characteristics, types and quantities of waste components in the waste streams of that locality (Fobil *et al.*, 2002). It's because of the above stated reasons that Aburi's Residential waste has to be characterized to provide reliable data on the residential waste stream of the township.

1.2. Objectives

Main Objectives

- The main objective is to determine the quantity and composition of residential solid waste generated in the Aburi Township and also, to assess the compost quality of the degradable organic fraction.

Specific Objectives

- To estimate the quantity of organics (food waste), plastic, paper, metals and glass that make up the residential solid waste generated in Aburi.
- To compost the organic fraction of the waste under local conditions.
- To develop waste management plan

CHAPTER TWO

2.0 Literature review

2.1 Definition of Solid Waste

There is no such thing as waste in natural systems. Everything flows in a natural cycle of use and reuse. Living organisms consume materials and eventually return them to the environment, usually in a different form for reuse (University of California, 2009). 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 and Sources of Solid Waste

There are two basic sources of solid wastes: non-municipal and municipal as discussed below (UCCP & California University, 2009).

Non-municipal solid waste is the discarded solid material from industry, agriculture, mining, and oil and gas production. Some common items that are classified as non-municipal waste are: construction materials (roofing shingles, electrical fixtures, bricks); wastewater sludge; incinerator residues; ash; scrubber sludge; oil/gas/mining waste; railroad ties, and pesticide containers (UCCP & California University, 2009).

Municipal solid waste is made up of discarded solid materials from residences, businesses, and city buildings. Other common components are: yard waste (green waste), plastics, metals, wood, glass and food waste. The composition of the municipal wastes can vary from region to region and from season to season. Food waste, which includes animal and vegetable wastes resulting from the preparation and consumption of food, is commonly known as garbage (UCCP & California University, 2009).

Some solid wastes are detrimental to the health and well-being of humans. These materials are classified as hazardous wastes. Hazardous wastes are defined as materials which are toxic, carcinogenic (cause cancer), mutagenic (cause DNA mutations), teratogenic (cause birth defects), highly flammable, corrosive or explosive (University of California, 2009).

Categorization of solid waste generators are linked to zoning and land use. They are; Residential, Industrial, Commercial, Institutional, Construction and demolition, Municipal services, process and Agriculture. The term solid waste is all inclusive and encompasses all the source, types of classification, composition and properties (Peavy *et al.*, 1985).

2.2.1 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). Much industrial waste is neither hazardous nor toxic, such as waste fibre produced by agriculture and logging. 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).

2.2.2 Construction and Demolition Debris

Uncontaminated solid waste results from the construction, remodelling, repair, demolition of utilities, structures roads and uncontaminated solid waste results from land clearing (USEPA, 1998). Construction and demolition waste includes, but is not limited to bricks, concrete and other masonry materials, soil, rock, wood (including painted, treated and coated wood and wood products), land clearing debris, wall coverings, plaster, drywall, 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).

2.2.3 Institutional Waste

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

2.2.4 Residential (Household) and Commercial 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 whiles commercial wastes consist of paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes are generated by Stores, hotels, restaurants, markets, office buildings, etc (Hoornweg & Thomas, 1999).

2.2.5 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).

2.2.6 Process Waste

Heavy and light manufacturing, refineries, chemical plants, power plants, mineral extraction and processing are responsible for the generation of the following solid waste; industrial process wastes, scrap materials, off-specification products, slay, tailings (Hoornweg & Thomas, 1999).

2.2.7 Agricultural Waste

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).

2.3 Characteristics of Solid Waste

2.3.1 Quantity

There are very significant differences in quantity depending on many factors, such as:

- The size of the population living in the area,
- The source of the waste generated (commercial, residential, touristic, industrial, etc.)
- The number of public or private gardens,
- Whether the families living in the area are predominantly poor or rich,
- The season of the year, and the cultural aspects of the area affecting the composition, quantity and peak-days of the solid waste produced (Medcities Network, 2003).

2.3.2 Composition

Knowing the composition of waste is important for deciding the treatment systems. Numerous factors have an influence on the composition and characteristics of solid waste (Medcities Network, 2003).

- The area: residential, commercial, etc.
- The season and weather (differences in the amount of population during the year, tourist places)
- The economic level (differences between high and low-income areas). High-income areas usually produce more inorganic materials such as plastics and paper, while low-income areas produce relatively more organic waste.
- The cultural aspects of the zone.

Urban waste is normally divided into three big groups (Medcities Network, 2003).

- Inert waste: metals, glass, soil, slags and ashes
- Putrescible: food waste, yard trimmings
- Combustibles: paper, cardboard, plastics, wood, tires, leather, textiles

2.4 Physical Characteristics of Solid Waste

There are four characteristics that are absolutely necessary when setting up the treatment/disposal system (Medcities Network, 2003). These are:

2.4.1 Moisture Content

Moisture content of solid waste is the weight loss (expressed in percentage) when a sample of solid waste is dried to a constant weight at a temperature of 100 °C -105 °C. The percentage of moisture contained in a solid waste sample can be calculated on a dry or wet basis. Moisture content has a great influence on the heat of combustion as well as de-composition of organic matter. It depends on the organic content, as well as the source of waste and the weather (Medcities Network, 2003).

2.4.2 Calorific Value / Heating Value

This is a physical property and a measure of the energy released when waste is burnt. A heating value of about 11.6x106 J/Kg is needed to sustain combustion (Lee, 2005). Waste with lower heat value can be burnt, but it will not maintain adequate temperatures without addition of auxiliary fuel. Calorific values increase when there is more paper, card board and plastics because they have a high heating value, and decreases when there is a high content of organic matter, and therefore of moisture (Medcities Network, 2003).

2.4.3 Density

Density varies depending on the composition of waste. It is normally higher in residential areas where organic matter makes up a large proportion of the waste, and lower in commercial districts where waste contains more paper and cardboard. It also varies with the economic level, being less dense in high income areas where there is a higher percentage of packaging waste; the density of waste may also change during waste transportation (Medcities Network, 2003).

Therefore it is essential to indicate where density has been measured (at the point of generation, in the container, or at the disposal site), usually the density increases by 20%-25% during transport in a non-compaction truck.

The density is important for the selection of waste collection equipment. For example, compactor trucks, which press the waste together, are most effective if the waste has a low density, for example, if it has a high proportion of paper, cardboard and plastics (Medcities Network, 2003).

2.5 Chemical Characteristics of Solid Waste

Information on the chemical configuration of solid wastes is important in appraising, processing and recovery alternatives. In addition, the analysis helps in adopting and utilizing proper equipment and techniques for collection and transportation. The chemical characteristics like pH, chemical constituents like carbon content, nitrogen, phosphorus, potassium, micronutrients etc. are to be analysed for the selection of proper waste management technology (Yousof & Rahman, 2007).

2.5.1 Carbon/Nitrogen Ratio (C/N Ratio)

It is the ratio of the weight of carbon to the weight of nitrogen present in the waste. It is an important parameter in composting processes and should always be between 20 and 35. Lower ratios indicate the loss of nitrogen as ammonia gas and render composting impractical (Medcities Network, 2003).

2.6 Solid Waste Quantification and Analysis

When implementing a solid waste management program, solid waste analysis is crucial to determine which techniques, systems and procedures are suitable to the waste stream.

There are essentially two different methods of sampling:

- Continuous sampling of a low fraction of waste.
- Intensive sampling carried out over one or more relatively short periods.

Statistical reliability favours continuous sampling, but practical considerations, including cost mean that the latter method has to be considered.

At a minimum, surveys should collect data covering a period of one week. This will allow for measurement of variation of refuse within cycles of a day or week.

To take into account the changes over monthly, seasonal and year long periods, it is necessary to either:

- repeat the survey at different times , or
- spread the survey period over a long time.

The following approach is recommended for the overall sampling regime (Medcities Network, 2003):

- Surveys should be carried out over a minimum period of one week.
- Seasonal variation should be estimated by repeating the survey at different times of the year, which are generally best done over a week in the middle of each of the four seasons.
- Where baseline data is required, four surveys of one week each should be done in each season over a single year.
- Where monitoring of long-term trends is needed, a single-week survey should be done every year, in each season, over a four year cycle.
- If it is possible, it is very useful to carry out a survey differentiating between the different zones of the town, with special emphasis on waste composition.

2.7 Solid Waste Characterization

Yu & Maclaren (1995) described waste characterization as the examination of the composition of waste stream by material types (such as paper, glass, metal, etc.) or by product types (such as cans, magazines, glass containers, etc.).

Knowledge of the quantity and composition of municipal solid waste is important for the planning and management of municipal solid wastes (Fobil *et al.*, 2001). Such knowledge is important to direct waste policy and to plan for waste management options such as composting, recycling, recovery, transportation and disposal of solid wastes.

In order to describe waste, two concepts are required: waste stream amounts and the composition of the waste streams (Moore *et al.*, 1998).Residential waste can be segregated into eight (8) components based on intrinsic material properties (Fobil, 2001).

Solid waste is generally composed of organic, paper, glass, plastic, metal, textile, residues or inert wastes as well as miscellaneous or other wastes (Government of Tamil Nadu, Department of Environment, 2007).

Organic waste or biodegradable includes largely putrescible components such as food materials, leaves, garden trimmings, grasses and other easily decomposable waste. Paper waste includes newsprint paper, scrap paper, and cardboard, waste paper, paper products and packaging materials (Ontario Ministry of environment, 2010).

Glass waste consists of broken glassware, used and/or broken bottles, broken light bulbs and other glass products (Waste Watch, 2011).

Plastic wastes comprise waste plastic products such as polyethylene products and other types of plastics used as packaging material (wienaah, 2007).

Metal waste includes tin cans, both ferrous and non-ferrous scrap metal (Zero Waste America, 2010).

Textiles in municipal solid waste are found mainly in discarded clothing, although other sources include furniture, carpets, tires, footwear, and nondurable goods such as sheets and towels (Contributors, Wikipedia, 2012)[a].

Inert waste includes construction and demolition waste, dirt, rocks, debris (Contributors, Wikipedia, (2012)[b]

2.8 Approaches to Urban Solid Waste Characterization

There are three methods for determining the composition of urban solid waste streams (Brunner & Ernst, 1986):

- Waste Product Analysis
- Market Product Analysis
- Direct Sampling and Analysis

An outline of each of these methods, and an indication of when they should be used, is provided in this section.

2.8.1 Waste Product Analysis

In this method, the products of treatment processes such as incinerator bottom ash and fly ash are analysed for various chemical elements. From knowledge of the partition coefficients for these elements through the process, it is possible to infer the chemical composition of the raw waste stream (Brunner & Ernst, 1986).

It is necessary to have a waste processing facility available, and to know the details of materials balances through it in order to apply this technique. Development of the technique is on-going (Brunner & Schackermayer, 1994), and it offers a reliable and cost effective alternative to conventional direct methods where a suitable treatment process is available.

2.8.2 Market Product Analysis

In this approach, a materials balance is undertaken for a material in a region to derive the quantity of that material that would be expected to report to the waste stream (Brunner & Ernst, 1986).

Extensive studies by Franklin Associates have been undertaken in the USA; the method is quick and can be undertaken at little cost where the data is available. Normally, this is limited to regions as defined by country borders, where the data is collected by a Statistics Bureau.

This method is also likely to be of use for materials which make up a small percentage of the waste stream. For instance determining the amount of dry cell batteries in direct sampling and analysis studies is either very unreliable or very expensive. Market product analysis, if possible at a regional level would give a quicker, cheaper and more reliable result (Moore *et al.*, 1998).

2.8.3 Direct Waste Sampling and Analysis

In this conventional approach, sampling from a particular waste stream in a region is undertaken before manually sorting it into its material types. Subsequently, additional physical and chemical analysis such as moisture content, density under standard pressures, specific energy (calorific value) and elemental analysis may be undertaken (Moore *et al.*, 1998).

2.8.4 Waste Quantification Methods

According to the USEPA, (1999), there are two basic approaches to estimating quantities of municipal solid waste

The first method, which is site-specific, involves sampling, sorting, and weighing the individual components of the waste stream. This method is useful in defining a local waste stream, especially if large numbers of samples are taken over several seasons.

The second approach to quantifying and characterizing the municipal solid waste stream utilizes a material flow approach to estimate the waste stream on a nationwide basis. The material flows methodology produces an estimate of total municipal solid waste generated, by material categories and by product categories.

Sampling to quantify waste could either be done at the point of generation or at the point of disposal. However, most previous studies considered the characteristics of municipal wastes at final disposal sites (Blight *et al.*, 1999).

Because of the shift in focus of waste management strategies towards more recycling and resource recovery, determining the quantity and composition of waste at the point of generation is getting more attention (Qdais *et al.*, 1997).

2.9 Solid Waste Treatment

Once collected, municipal solid waste may be treated in order to reduce the total volume and weight of material that requires final disposal. Treatment changes the form of the waste and makes it easier to handle. It can also serve to recover certain materials, as well as heat energy, for recycling or reuse. (Encyclopædia Britannica, 2010).

2.9.1 Incineration

Furnace Operation

Burning is a very effective method of reducing the volume and weight of solid waste. In modern incinerators the waste is burned inside a properly designed furnace under very carefully controlled conditions. The combustible portion of the waste combines with oxygen, releasing mostly carbon dioxide, water vapour, and heat. Incineration can reduce the volume of uncompacted waste by more than 90 per cent, leaving an inert residue of ash, glass, metal, and other solid materials called bottom ash (Encyclopædia Britannica, 2010).

The gaseous by-products of incomplete combustion, along with finely divided particulate material called fly ash, are carried along in the incinerator airstream. Fly ash includes cinders, dust, and soot. In order to remove fly ash and gaseous by-products before they are exhausted into the atmosphere, modern incinerators must be equipped with extensive emission control devices. Such devices include fabric baghouse filters, acid gas scrubbers, and electrostatic precipitators. Bottom ash and fly ash are usually combined and disposed of in a landfill. If the ash is found to contain toxic metals, it must be managed as a hazardous waste (Encyclopædia Britannica, 2010).

Municipal solid-waste incinerators are designed to receive and burn a continuous supply of refuse. A deep refuse storage pit, or tipping area, provides enough space for about one day of waste storage. The refuse is lifted from the pit by a crane equipped with a bucket or grapple device. It is then deposited into a hopper and chute above the furnace and released onto a charging grate or stoker. The grate shakes and moves waste through the furnace, allowing air to circulate around the burning material. Modern incinerators are usually built with a rectangular furnace, although rotary kiln furnaces and vertical circular furnaces are available. Furnaces are constructed of refractory bricks that can withstand the high combustion temperatures (Encyclopædia Britannica, 2010).

Combustion in a furnace occurs in two stages: primary and secondary. In primary combustion, moisture is driven off, and the waste is ignited and volatilized. In secondary combustion, the remaining unburned gases and particulates are oxidized, eliminating odours and reducing the amount of fly ash in the exhaust. When the refuse is very moist, auxiliary gas or fuel oil is sometimes burned to start the primary combustion (Encyclopædia Britannica, 2010).

In order to provide enough oxygen for both primary and secondary combustion, air must be thoroughly mixed with the burning refuse. Air is supplied from openings beneath the grates or is admitted to the area above. The relative amounts of this underfire air and overfire air must be determined by the plant operator to achieve good combustion efficiency. A continuous flow of air can be maintained by a natural draft in a tall chimney or by mechanical forced-draft fans (Encyclopædia Britannica, 2010).

Energy Recovery

The energy value of refuse can be as much as one-third that of coal, depending on the paper content, and the heat given off during incineration can be recovered by the use of a refractory-lined furnace coupled to a boiler. Boilers convert the heat of combustion into steam or hot water, thus allowing the energy content of the refuse to be recycled. Incinerators that recycle heat energy in this way are called waste-to-energy plants. Instead of a separate furnace and boiler, a water-tube wall furnace may also be used for energy recovery (Encyclopædia Britannica, 2010).

Such a furnace is lined with vertical steel tubes spaced closely enough to form continuous sections of wall. The walls are insulated on the outside in order to reduce heat loss. Water circulating through the tubes absorbs heat to produce steam, and it also helps to control combustion temperatures without the need for excessive air, thus lowering air-pollution control costs (Encyclopædia Britannica, 2010).

Waste-to-energy plants operate as either mass burn or refuse-derived fuel systems. A mass burn system uses all the refuse, without prior treatment or preparation. A refuse-derived fuel system separates combustible wastes from non-combustibles such as glass and metal before burning. If a turbine is installed at the plant, both steam and electricity can be produced in a process called cogeneration (Encyclopædia Britannica, 2010).

Waste-to-energy systems are more expensive to build and operate than plain incinerators because of the need for special equipment and controls, highly skilled technical personnel, and auxiliary fuel systems. On the other hand, the sale of generated steam or electricity offsets much of the extra cost, and recovery of heat energy from refuse is a viable solid-waste management option from both engineering and an economic point of view (Encyclopædia Britannica, 2010).

2.9.2 Composting

Another method of treating municipal solid waste is composting, a biological process in which the organic portion of refuse is allowed to decompose under carefully controlled conditions. Microbes metabolize the organic waste material and reduce its volume by as much as 50 percent. The stabilized product is called compost or humus; it resembles potting soil in texture and odour and may be used as a soil conditioner or mulch (Encyclopædia Britannica, 2010).

Composting offers a method of processing and recycling both garbage and sewage sludge in one operation. As more stringent environmental rules and siting constraints limit the use of solid-waste incineration and landfill options, the application of composting is likely to increase. The steps involved in the process include sorting and separating, size reduction, and digestion of the refuse (Encyclopædia Britannica, 2010).

Sorting and Shredding

The decomposable materials in refuse are isolated from glass, metal, and other inorganic items through sorting and separating operations. These are carried out mechanically, using differences in such physical characteristics of the refuse as size, density, and magnetic properties. Shredding or pulverizing reduces the size of the waste articles, resulting in a uniform mass of material. It is accomplished with hammer mills and rotary shredders (Encyclopædia Britannica, 2010).

Digesting and Processing

Pulverized waste is ready for composting either by the open windrow method or in an enclosed mechanical facility. Windrows are long, low mounds of refuse. They are turned or mixed every few days to provide air for the microbes digesting the organics. Depending on moisture conditions, it may take five to eight weeks for complete digestion of the waste. Because of the metabolic action of aerobic bacteria, temperatures in an active compost pile reach about 150 °F (65 °C), killing pathogenic organisms that may be in the waste material (Encyclopædia Britannica, 2010).

Open windrow composting requires relatively large land areas. Enclosed mechanical composting facilities can reduce land requirements by about 85 percent. Mechanical composting systems employ one or more closed tanks or digesters equipped with rotating vanes that mix and aerate the shredded waste. Complete digestion of the waste takes about one week (Encyclopædia Britannica, 2010).

Digested compost must be processed before it can be used as a mulch or soil conditioner. Processing includes drying, screening, and granulating or pelletizing. These steps improve the market value of the compost, which is the most serious constraint to the success of composting as a waste management option. Agricultural demand for digested compost is usually low because of the high cost of transporting it and because of competition with inorganic chemical fertilizers (Encyclopædia Britannica, 2010).

2.9.3 Sanitary landfill

Land disposal is the most common management strategy for municipal solid waste. Refuse can be safely deposited in a sanitary landfill, a disposal site that is carefully selected, designed, constructed, and operated to protect the environment and public health. One of the most important factors relating to landfilling is that the buried waste never comes in contact with surface water or groundwater. Engineering design requirements include a minimum distance between the bottom of the landfill and the seasonally high groundwater table. Most new landfills are required to have an impermeable liner or barrier at the bottom, as well as a system of groundwater monitoring wells.

Completed landfill sections also must be capped with an impermeable cover to keep precipitation or surface runoff away from the buried waste. Bottom and cap liners may be made of flexible plastic membranes, layers of clay soil, or a combination of both (Encyclopædia Britannica, 2010).

Constructing the Landfill

The basic element of a sanitary landfill is the refuse cell. This is a confined portion of the site in which refuse is spread and compacted in thin layers; several layers may be compacted on top of one another to a maximum depth of about 10 feet (3 meters). The compacted refuse occupies about one-quarter of its original loose volume.

At the end of each day's operation, the refuse is covered with a layer of soil to eliminate windblown litter, odours, and insect or rodent problems. One refuse cell thus contains the daily volume of compacted refuse and soil cover. Several adjacent refuse cells make up a lift, and eventually a landfill may comprise two or more lifts stacked one on top of the other. The final cap for a completed landfill may also be covered with a layer of topsoil that can support vegetative growth (Encyclopædia Britannica, 2010).

Daily cover soil may be available on-site, or it may be hauled in and stockpiled from off-site sources. Various types of heavy machinery, such as crawler tractors or rubber-tired dozers, are used to spread and compact the refuse and soil. Heavy steel-wheeled compactors may also be employed to achieve high-density compaction of the refuse (Encyclopædia Britannica, 2010).

The area and depth of a new landfill is carefully staked out, and the base is prepared for construction of any required liner and leachate collection system. Where a plastic liner is used, at least 12 inches (30 cm) of sand is carefully spread over it to provide protection from landfill vehicles. At sites where excavations can be made below grade, the trench method of construction may be followed.

Where this is not feasible because of topography or groundwater conditions, the area method may be practiced, resulting in a mound or hill rising above the original ground. Since no ground is excavated in the area method, soil usually must be hauled to the site from some other location. Variations of the area method may be employed where a land-fill site is located on sloping ground, in a valley, or in a ravine; the completed landfill eventually blends in with the landscape.

Controlling By-Products

Organic material buried in a landfill decomposes by anaerobic microbial action. Complete decomposition usually takes more than 20 years. One of the by-products of this decomposition is methane gas. Methane is poisonous and explosive when diluted in the air, and it can flow long distances through porous layers of soil.

If it is allowed to collect in basements or other confined areas, dangerous conditions may arise. In modern landfills methane movement is controlled by impermeable barriers and by gas venting systems. In some landfills the methane gas is collected and recovered for use as a fuel.

A highly contaminated liquid called leachate is another by-product of decomposition in sanitary landfills. Most leachate is the result of runoff that infiltrates the refuse cells and comes in contact with decomposing garbage. If leachate reaches the groundwater or seeps out onto the ground surface, serious environmental pollution problems can occur, including the possible contamination of drinking-water supplies.

Methods of controlling leachate include the interception of surface water in order to prevent it from entering the landfill and the use of impermeable liners or barriers between the waste and the groundwater. New landfill sites should also be provided with groundwater monitoring wells and leachate collection and treatment systems (Encyclopædia Britannica, 2010).

2.9.4 Recycling

Separating, recovering, and reusing components of solid waste that may still have economic value is called recycling. One type of recycling is the recovery and reuse of heat energy, a practice discussed separately in Incineration. Composting can also be considered a recycling process, since it reclaims the organic parts of solid waste for reuse as mulch or soil conditioner. Still other waste materials have potential for reuse. These include paper, metal, glass, plastic, and rubber, and their recovery is discussed here.

Separation

Before any material can be recycled, it must be separated from the raw waste and sorted. Separation can be accomplished at the source of the waste or at a central processing facility. Source separation, also called curb side separation, is done by individual citizens who collect newspapers, bottles, cans, and garbage separately and place them at the curb for collection. Many communities allow "commingling" of non-paper recyclables (glass, metal, and plastic). In either case, municipal collection of source-separated refuse is more expensive than ordinary refuse collection (Encyclopædia Britannica, 2010).

In lieu of source separation, recyclable materials can be separated from garbage at centralized mechanical processing plants. Experience has shown that the quality of recyclables recovered from such facilities is lowered by contamination with moist garbage and broken glass. The best practice, as now recognized, is to have citizens separate refuse into a limited number of categories, including newspaper; magazines and other waste paper; commingled metals, glass, and plastics; and garbage and other non-recyclables (Encyclopædia Britannica, 2010).

The newspaper, other paper wastes, and commingled recyclables are collected separately from the other refuse and are processed at a centralized material recycling facility, or MRF (pronounced "murf" in waste-management jargon). A modern MRF can process about 300 tons of recyclable wastes per day.

At a typical MRF commingled recyclables are loaded onto a conveyor. Steel cans ("tin" cans are actually steel with only a thin coating of tin) are removed by an electromagnetic separator, and the remaining material passes over a vibrating screen in order to remove broken glass. Next, the conveyor passes through an air classifier, which separates aluminium and plastic containers from heavier glass containers. Glass is manually sorted by colour, and aluminium cans are separated from plastics by an eddy-current separator, which repels the aluminium from the conveyor belt (Encyclopædia Britannica, 2010).

2.9.5 Reuse

Recovered broken glass can be crushed and used in asphalt pavement. Colour-sorted glass is crushed and sold to glass manufacturers as cullet, an essential ingredient in glass making. Steel cans are baled and shipped to steel mills as scrap, and aluminium is baled or compacted for reuse by smelters (Encyclopædia Britannica, 2010).

Aluminium is one of the smallest components of municipal solid waste, but it has the highest value as a recyclable material. Recycling of plastic is a challenge, mostly because of the many different polymeric materials used in its production. Mixed thermoplastics can be used only to make lower-quality products, such as "plastic lumber" (Encyclopædia Britannica, 2010).

In the paper stream, old newspapers are sorted by hand on a conveyor belt in order to remove corrugated materials and mixed papers. They are then baled or loose-loaded into trailers for shipment to paper mills, where they are reused in the making of more newspaper (Encyclopædia Britannica, 2010).

Mixed paper is separated from corrugated paper for sale to tissue mills. Although the processes of pulping, de-inking, and screening waste paper are generally more expensive than making paper from virgin wood fibres, the market for recycled paper should improve as more processing plants are established (Encyclopædia Britannica, 2010).

Rubber is sometimes reclaimed from solid waste and shredded, reformed, and remoulded in a process called revulcanization, but it is usually not as strong as the original material. Shredded rubber can be used as an additive in asphalt pavements, and discarded tires may be employed in "tire playgrounds" (Encyclopædia Britannica, 2010).

In general, the most difficult problem associated with the recycling of any solid-waste material is finding applications and suitable markets. Recycling by itself will not solve the growing problem of solid-waste management and disposal. There will always be some unusable and completely valueless solid residue requiring final disposal (Encyclopædia Britannica, 2010).

2.10 Composting

Composting is a naturally occurring phenomenon that works under controlled conditions in which air, temp, moisture content are regulated for the growth of microorganisms and multiplication through, which organic material is converted into more usable form of organic matter (Chapman, 2005), it involves the mineralization and partial humification of the organic matter, leading to a stabilized final product (Bernal *et al.*, 2009).

2.10.1 Outline of Available Composting Technologies

The two main types of composting processes are

Interventional Processes

These are essentially processes in which some form of agitation is used either as the sole form of aeration or in combination of forced aeration system. Examples of this type are windrows, agitated bays, stirred vessels and multi-floor towers. The great advantage of these systems is that initial mixing conditions are not critical as in their non-interventional counterparts (Basnayake, 2001).

Basnayake (2001) stated that Mixing and adding dry materials could adjust non-homogenous materials or moisture contents. The leachate production can be controlled in such systems. Windrowing in tropical conditions requires some form of shelter to prevent excessive moisture, leading to higher amounts of leachate formation.

Non-Interventional Processes

The principal processes in this category are the aerated static piles (ASP) and the silo. Several problems are associated with these systems such as excessive odour, high strength leachate production and excessive drying. ASP too requires shelter to protect from rain. A greater knowledge of the substrates and the processes conditions are required with these systems because once established, the mass remains unmoved until the completion of the process two or three weeks later (Basnayake, 2001).

Depending on the mixture, a significant change of bulk density can occur in the first week. It has been shown that in ASP's a 30% of volume reduction takes place in 5 days. This has great significance in terms of aeration and can lead to both channelling and the creation of anaerobic pockets (Basnayake, 2001).

2.10.2 Factors Affecting Composting

There are five major factors that affect composting process. These factors coordinate with each other, and also with organic materials and begin decaying process by the action of decomposers (Mahfooz *et al.*, 2006).

Air Control

Composting is an aerobic process (in the presence of oxygen). Air should regularly be provided by exhausts, fans and blower or by continuous stirring or mixing the organic material (Chapman, 2005).

Nutritional Traffic

Compost should have a definite ratio of incoming and out-going nutrient traffic in order to maintain the balance. This process is mostly successful when the pile contains 20 - 40 parts of Carbon to oxygen (Eldridge, 1995) i.e. C/N ratio as 20/1 and varies to 40/1 (Korner, *et al*., 2003).

If Nitrogen is too high, excess nitrogen is converted to ammonia and escapes into the air cause odour and air pollution. On the other hand if this ratio is too high, the process reduces.

Suitable Temperature

Temperature is an integral factor of every decomposing process like composting in order to regulate the breakdown of organic material by microbial activity. The process begins when the outer temperature is up to 45 °C for two days (Morrow, 2001). The optimum temperature to maximize composting is between 35-45 °C and for global market production 40 °C for three days to destroy all weed seeds, parasites and un-necessary microbes (Mahfooz *et al.*, 2006).

It is well documented that a minimum height of 1.5 m and width of 2.5 m is necessary to retain enough heat in composting mass to promote the desirable thermophillic activity (Biddlestone *et al*., 1987), although Mathur *et al*., (1985) showed that a height of 1 m was sufficient where the medium of composting is peat and mixtures of peat with fibre containing manure, both of high thermal insulation capacities.

Moisture Contents

Moisture contents are essential to integrate the composting process; however, it also depends on continuous mixing. The stabilizing rate for moisture content is between 40-60%. Below 40%, the process reduces and beyond 60 it becomes more anaerobic. Overall 50% moisture contents can be maintained by adding water in case of dryness (Bonhotal, 2003).

2.10.3 Physical Characteristics

The physical characteristics of the ingredients must also be considered when developing a compost mix. Different physical characteristics affect aeration, the amount of decomposition and the ability of a pile to maintain aerobic conditions. Three main physical characteristics of the compost mix of main concern are:

Porosity

Porosity is a measure of the air space within the compost mix and influences the resistance to airflow through the pile. If the pores become filled with water because of high moisture content, then the resistance to airflow increases. Less oxygen reaches the micro-organisms and anaerobic activity begins to dominate (Mahfooz *et al*., 2006).

According to Mahfooz *et al*. (2006) porosity is improved by a more uniform mix of material that provides continuity of air spaces, proper moisture to allow adequate free air space and larger particles to increase the pore size and reduce the resistance to airflow. Larger particles are desirable to promote the flow of air, but they also diminish the surface area of the particles.

Majority of the microbial activity occurs on the surface of the compost particles within a thin liquid layer. Greater the amount of surface area exposed, the greater the amount of decomposition (Mahfooz *et al*., 2006).

Texture

Texture is the relative proportion of various particle sizes of a material and is descriptive of the amount of surface area that is available to the micro-organisms. The finer the texture, the greater the surface area exposed to microbial activity (Su *et al*., 2003).

Minimizing the particle size by such methods as selection and grinding also increases the overall surface area of the material in the pile that is exposed to microbial decomposition. Structure refers to the ability of a particle to resist compaction and settling. It is a key factor in establishing and maintaining porosity during the composting process (Mahfooz *et al*., 2006).

Hoare, (1987) stated that Structure is important because even a mix that has all of the necessary components may not be able to sustain rapid composting. If the pile begins to settle and close off air spaces as the material decomposes, the compost process slows down.

Highly absorbent material tends to maintain better structure than less absorbent ones. The ideal particle size of the compost material must therefore be a compromise between maximizing porosity, maximizing surface area and increasing structure (Hoare, 1987).

2.10.4 Compost Quality Parameters

A number of important compost parameters can also be determined by laboratory testing some of which are as follows.

Gradation

Gradation or particle size is determined by passing the compost through a set of sieves and then determining the weight fraction retained on each sieve size. For turf or landscape establishment all the particles should pass a one-inch screen with a minimum of 90% of the material by weight passing a ½ inch screen. Although fine textured compost is generally preferred, excessive dust fraction (particles less than 500 micron) can cause difficulties in handling and can also be an indication of low organic content (Darlington, 2001).

Organic Content

Organic matter is the measure of carbon based materials in the compost. High quality compost will usually have a minimum of 50% organic content based on dry weight. Another means of expressing organic content is to list the weight of organic matter per unit volume of compost. Most high quality composts will have a minimum of 250 pounds of organic material per cubic yard (Darlington, 2001).

Carbon to Nitrogen Ratio

The carbon to nitrogen ratio is a parameter used to determine if compost is nitrogen stable. Composts that are derived primarily from wood by-products have high carbon to nitrogen ratios unless additional nitrogen is added during the composting process. Biosolids and manures generally have low carbon to nitrogen ratios since these materials are nitrogen rich.

In general, a carbon to nitrogen ratio of 35 or lower is preferred if the material is claimed to be nitrogen stabilized. At higher carbon to nitrogen ratios, nitrogen can be tied as the compost further decomposes. Nitrogen is then less available to plant material, and high levels of nitrogen fertilization are required to maintain optimum plant colour and growth. Products with low carbon to nitrogen ratios (less than 20) can supply significant quantities of nitrogen as they decompose (Darlington, 2001).

pH

pH is a numerical measure of the acidity or alkalinity of the soil. The pH scale ranges from 0 to 14 with a pH of 7 indicating neutrality. Most compost has a pH between 6 and 8. Products derived from wood residuals or peat moss can have pH values as low as 4.5, while manures are frequently alkaline (pH 8.0-8.5). Since specific plant species sometimes prefer a specific pH range, knowledge of both soil and compost pH can be important.

pH can be further adjusted through the use of such materials as lime (to increase pH) and sulphur or iron sulphate (to decrease pH). Composts with very low pH (<4.0) should be used with caution since the low pH can be an indication or poor composting practices which result in the formation of potentially toxic organic acids (Darlington, 2001).

Soluble Salts (Salinity)

Soluble salt concentration is the concentration of soluble ions in solution. It is usually expressed as electrical conductivity (dS/m) of a saturated extract of either soil or compost. Soluble salt levels in compost can vary considerably, depending on feed stock and processing. Compost may therefore contribute to or dilute the accumulative soluble salt content in the amended soil (Darlington, 2001).

Knowledge of soil salinity, compost salinity, and plant tolerance to salinity is necessary for the successful establishment of plant material. For most turf and landscape plantings the final salinity (EC) of the amended soil should be less than 4.0 dS/m. Higher soluble salt levels would likely require leaching irrigations. Soluble nutrients, particularly potassium, calcium and nitrogen typically account for most of the salinity in compost products. Sodium is an undesirable soluble salt. This element should ideally account for less than 25% of the total soluble salts in compost (Darlington, 2001).

Moisture Content

Moisture content should be between 35% and 60%. The moisture content of compost affects its bulk density and therefore may affect transportation cost. Moisture content can also affect product handling. Compost which is too dry can be dusty and irritating to work with while compost which is excessively wet can be heavy and difficult to uniformly apply (Darlington, 2001).

Contaminants

Compost materials used for horticultural application should be as free as possible of inert contaminants such as glass, metal and plastic (Darlington, 2001).

Maturity and Stability

Maturity is the degree to which the compost is free of organic phytotoxic substances that can adversely affect seed germination or plant growth. Maturity and stability also relate to the level of biological activity in compost. Stable compost consumes almost no nitrogen or oxygen and generates little carbon dioxide or heat (Darlington, 2001).

Maturity and stability are difficult parameters to evaluate. Physical characteristics that are suggestive of mature compost include a dark brown to black colour and a soil-like or musty odour. There should be little or no recognizable grass or leaves. Compost that has a sour or putrid smell should not be accepted or if the pile becomes very hot after rewetting then the product is not stable (Darlington, 2001).

Nutrient Content

Although the nutrient content of compost is low compared to synthetic fertilizer products, compost is usually applied at greater rates and therefore nutrient contribution can be significant. The most commonly required nutrients are nitrogen, phosphorus and potassium (Darlington, 2001).

Composts are often analysed for total and available nutrients. Wood residuals have relatively low nutrient content. Manure products are typically high in phosphorous and potassium. Yard waste products are often high in potassium. Materials derived from bio solids often have substantial nitrogen (Darlington, 2001).

Heavy Metal Trace Elements

Heavy metals are trace elements whose concentrations are regulated by the EPA due to the potential for toxicity to humans, animals, and plants. Regulations governing the heavy metal derived from specific feed stocks have been promulgated on both the State and Federal levels (Darlington, 2001).

Trace elements referred to as heavy metals include arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc. Many of these elements are actually needed by plants for normal growth. Commercial compost producers are required to routinely test for heavy metals. This data is usually available from compost producers upon request (Darlington, 2001).

Weed and Disease

Commercial production of compost usually entails high temperature aerated composting which kills most weed seed along with diseases of animal and plant concern. Compost producers and users need to be careful not to reintroduce weed seed into compost prior to use. If compost is properly processed, there has been very little evidence of plant disease carry over. In fact, there has been considerable interest in the ability of compost to suppress soil-borne plant diseases (Darlington, 2001).

2.11 Existing Solid Waste Management Conditions

No detailed data on waste types has been collected before September 2010, to facilitate the design of a solid waste management plan for Aburi.

Some work has been done recently involving residential solid waste stream. The total quantity of solid waste generated in the township is not known, neither is the rate at which the waste is generated, collected or disposed off. Information available currently is on residential solid waste generated which is mainly made up of organic (food waste), plastic & rubber, metals & cans, paper & cardboard and glass waste.

Available information shows that organic waste tops the list of most generated solid waste followed by packaging material such as plastic waste, paper waste, glass waste and finally metal waste.

2.12 Government Response to Solid Waste Problem

The government of Ghana in her efforts to address the waste management problems has developed various strategies and solutions which are still very relevant. These measures include the following:

2.12.1 Policy, Legal and Institutional Frameworks

In an effort to address the problem of waste management, Government has over the years put in place adequate national policies, regulatory and institutional frameworks. An Environmental Sanitation Policy was formulated in 1999. This policy has currently been amended and strategic action plans developed for implementation. Various relevant legislations for the control of waste have also been enacted (Government of Ghana, 2010). These include the following

- Local Government Act, 1990 (Act 462);
- Environmental Assessment Regulations, 1999 (LI 1652);
- Criminal Code, 1960 (Act 29);

- Water Resources Commission Act, 1996 (Act 522)
- National Building Regulations, 1996 (LI 1630).

In addition to the above policies and legislations, the Ministry of Environment, Science and Technology, the EPA, Ministry of Local Government and Rural Development and the Ministry of Health have prepared the following guidelines and standards for waste management:

- National Environmental Quality Guidelines (1998)
- Ghana Landfill Guidelines (2002)
- Manual for the preparation of district waste management plans in Ghana (2002)
- Guidelines for the management of healthcare and veterinary waste in Ghana (2002)
- Handbook for the preparation of District level Environmental Sanitation Strategies and Action Plans (DESSAPs).

The District Assemblies are the key institutions responsible for the management of sanitation and waste at the local and community level. They are however, supported in this task by a number of other institutions and organizations (Government of Ghana, 2010).

For instance, the Environmental Protection Agency (EPA) gives technical support to the District Assemblies by setting environmental standards and guidelines on waste management; administration of Environmental Assessment Regulations; undertaking environmental education and awareness programs; and monitoring environmental quality (Government of Ghana, 2010).

Ghana Environmental Assessment Regulations, 1999 (LI 1652) make provisions for existing undertakings, which are required to submit Environmental Management

Plans. A National Environmental Sanitation Policy Co-ordination Council has been established within the Ministry of Local Government and Rural Development to oversee to the implementation of the policy objectives (Government of Ghana, 2010).

2.12.2 Environmental Education and Awareness Creation

Various capacity building programs, seminars and workshops have been organized and/or are still on-going. For example, the 35th Annual General Meeting of the Ghana Institute of Engineers organized lectures held in March 2004 on "Sanitation and Waste management in Ghana: Way Forward"; the Inter-Faith Waste Management Initiative – November 14, 2005 etc.

All of these workshops came out with very practicable solutions to the waste management menace, however, the evidence on the ground points to the fact that there is still a lot to be done. A National Environmental Sanitation Day has been established and observed annually to sensitize the general public in keeping their environment sound and clean (Government of Ghana, 2010).

2.12.3 Waste Recovery, Recycling and Reuse

Waste recycling has become a viable economic option in the country despite the considerable cost of collection. Waste recycling technologies are being used by some few industries to circumvent the need for treatment and the discharge and disposal of large volumes of waste and to reduce demand for raw materials, energy and water (Government of Ghana, 2010).

In many instances, these industries have found waste recycling as effective ways of improving the economic competition of their products. For example Guinness

(Ghana) Limited, Kumasi, derives part of its revenue from the sale of yeast and spent grain used as animal feed. However, most major industrial establishments still practice very little recycling (Government of Ghana, 2010).

Generally, scavenging has often been considered a hindrance to municipal waste disposal operations; however they play a vital role in the waste recycling process. Ways of officially incorporating scavengers into municipal waste operations should be seriously considered. For example, they can be designated as official used-materials merchants and given training and status upgrading (Government of Ghana, 2010).

2.12.4 Financing Waste Management

Poor national economic policies and poverty of the rural communities make financial considerations one of the most obvious constraints to developing appropriate waste management systems for the country. As the urban areas grow, they exhaust the capacity of existing traditional disposal sites so that wastes must be transported greater distances to sites outside the city. Householders often complain of unsatisfactory or unreliable waste management services (Government of Ghana, 2010).

As a result they often resist paying the charges levied and instead preferring to dispose by informal dumping. The collection agencies have then less funding for their services. There is thus a clear need for more appropriate methodologies or financing mechanisms for waste management (Government of Ghana, 2010).

Currently, it costs about six Ghana Cedis (¢6.00) for every ton of waste collected in Accra. The private contractors provide containers to store the waste and see to it that all wastes are cleared from the various points of collection (Government of Ghana, 2010).

However, because the AMA is not able to pay regularly for the refuse they collect, they are also not able to maintain their trucks and as a result, most of them are broken down leaving a lot of waste uncollected within the metropolis. The Metropolitan Assembly spends an amount of about ¢250,000 alone on solid waste management every month (Government of Ghana, 2010).

2.12.5 Waste Management Projects and Programs

Several waste management projects and other related programs have been implemented and some still being implemented in the country. For examples, the government of Ghana with the support of the World Bank implemented different phases of an Urban Development Project (i.e. Urban I, II, and III) in the 1990s, and the "Urban Environmental Sanitation Project (UESP) 1996-2000" in Accra, Kumasi, Tamale, Takoradi and Tema including construction of sanitary infrastructure such as night soil treatment plant and private toilets. DFID also supported the "Accra Waste Management Project" designed to address wastewater and night soil treatment options in the city. The installed capacity of the plant was 11,010 kg BOD_5 per day equivalent to 222,020 kg COD (biological organic load) per day (Government of Ghana, 2010).

CHAPTER THREE

3.0 Methodology

This involved both field work and laboratory work.

3.1 Field work

The field work included studying the location of interest which aided in the design of a system for the selection of candidate households, the distribution of bin bags, collection of bin bags and the sorting of the collected waste.

3.1.1 Study Area

The town of Aburi is located on the Akuapim Ridge (5°51N, 0°11W), with a population of 18,477 with an annual growth rate of 1.4%. The town is at an elevation of 457 meters above sea level; due to the altitude of Aburi it has a cool climate. The town lies within the wet semi-equatorial zone which is characterized by double maxima rainfall in June and October (Asubonteng, 2010).

The first rainy season is from May to June, with the heaviest rainfall occurring in June while the second season is from September to October, the relative humidity which is high throughout the year varies between 70 – 80% (Asubonteng, 2010).

3.1.2 Selection of Sample Size

A sample size of 40 households was selected and samples were taken 4 times on a weekly basis from these households. The survey of the whole population was not done for two reasons; the cost is too high, and the population is dynamic, in that the individuals making up the population may change over time through migration, births and deaths of individuals. The three main advantages of sampling is that the cost is lower, data collection is faster and since the data set is smaller it is possible to ensure homogeneity and to improve the accuracy and quality of the data (Adèr *et al*., 2008).

3.1.3 Selection of Households

This was done by random sampling. The study area comprises of 3 zones namely Aburi East (AE), Aburi North (AN), Aburi South /Aburi West (AS/AW) based on the Electoral zones, 13 households including those residing in multi-family dwellings and single family dwellings were chosen in each zone using random sampling (where house numbers were written down on paper and mixed in a bag and selections made).

Plate 3.1. Waste disposed close to a residence

3.1.4 Distribution, Collection and Sorting

Distribution

The site-specific waste quantification method was used (USEPA, 1999). All households involved were provided with disposable bin bags of 5 different colours of dimension 750 mm×950 mm. Each coloured bag was labelled for a particular kind of waste as indicated in Table 3.1.

Table 3.1. Different coloured bin bags and their respective material group

Colour	Material Group
Black	Organic (Food Waste)
Blue	Plastic and Rubber
Green	Metals and Cans
Orange	Paper and Cardboard
Yellow	Glass

Residents were educated on the aim of the exercise and encouraged to help by participating in the sampling exercise. They were provided with the necessary information to sort out their waste according to the respective colours as indicated in Table 3.1. The incentive for participation was the free disposal of their household waste for 4 weeks.

Collection

There was a 6 day interval between distribution of the bin bags and collection of the bin bags. The samples were collected over 4 consecutive weeks thus in all 4 samples were taken. Garbage was picked up on Saturday mornings (Plate 3.2).

Plate 3.2: Collection of solid waste

Sorting

The waste was sorted by hand into the following categories; organic (food waste), plastic &rubber, paper& cardboard, metal & cans and glass. Each category was then weighed (wet weight in kg) using a SHJMARU® spring platform scale. The collected waste was hauled to the Akuapim South District Assembly (ASDA) managed garbage dumpsite.

3.2 Additional Calculations

3.2.1 Per Capita Generation of Waste

The formula stated below was used (UNESCAP, 2010);-

$$Cap\ waste = \frac{\Sigma\ HH\ Waste / HH}{HM}$$

Cap waste: Per capita waste generation (kg/ day)

HH waste: Average waste generation of one household (kg/day)

HH: Number of households surveyed

HM: Average number of household members

3.2.2 Extrapolation of the Amounts of the Waste Material Groups

The formula stated below was used (UNESCAP, 2010)

$$A = Cap\ waste \times P$$

A: Average waste generation of the entire township (kg/day)

Cap waste: Per capita waste generation (kg/ day)

P: Entire Population

3.2.3 Projection of Waste to Be Generated In The Future

Compound rate of growth method of population projection (UNESCAP, 2010)

$$P_n = Po\left(1 + \frac{R}{100}\right)^n \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

$$A_n = P_n \times Cap\ waste \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

P_n: Population of requisite year

P_o: Population in the current year

A_n: Average waste generation of the Township (kg/day)

n: Number of intermediary years

R: Rate of Growth

3.3 Statistical Data Analysis

The data compiled was analysed using the Minitab statistical software (version 15.1.3) and Microsoft Excel (version 14). All data compiled on selected waste material groups were analysed using descriptive statistics to determine the mean, standard deviation, minimum and maximum values and percentage composition. Results were presented in tables, charts and figures.

3.4 Physicochemical Analysis

Analysis was conducted on two samples; the organic (food waste) fraction of the garbage and the product of composting the organic fraction as shown in Table 3.2. After the determination of the moisture content of the garbage, the sample was dried and milled for further analysis. All analysis was conducted in triplicate.

Table 3.2. Parameters to be measured before and after composting

SAMPLE	PARAMETER
Before composting	Moisture Content, Total Nitrogen, Total Carbon & pH.
After composting	Total Nitrogen, Total Carbon, pH, Potassium, Phosphorus.

3.4.1 Moisture Content

The moisture content of a grab sample of the feed stock and unsorted garbage (food waste &packaging material) were determined as follows;

The particle size of the waste was reduced by cutting with a knife. A grab sample of the size-reduced waste was weighed and recorded as wet weight of sample. The sample was then dried to a constant weight in an oven at a temp of 105 °C. The sample was allowed to cool in a dry atmosphere after which the sample was weighed again and recorded as dry weight of sample (Delaware Department of Transportation, 2009).

The Calculation is;

$$\%W = \frac{A - B}{A} \times 100$$

$\%W$ = Percentage of moisture in the sample,

A = Weight of wet sample (grams),

B = Weight of dry sample (grams)

3.4.2 Total Nitrogen Content

The Kjeldahl method was adopted, at the end of digestion, all organic and inorganic salts were converted into ammonium form, which was distilled and estimated by titration using standard acid (Motsara & Roy, 2008).

The Procedure

One gram of the feed stock was placed in a Kjeldahl flask and 0.7 g of copper sulphate, 1.5 g of K_2SO_4 and 30 ml of H_2SO_4 was added. The sample was gently heated until the frothing ceased. The solution was boiled briskly until it became clear and then digestion was continued for 30 more minutes. The flask was then removed from the heater and allowed to cool after which 50ml of water was added and transferred to a distilling flask.

20 ml of standard acid (0.1M HCl) was placed in the receiving conical flask such that there was an excess of at least 5ml of the acid. 3 drops of methyl red indicator was added to the acid and enough water was added to cover the end of the condense outlet tubes. Tap water was then run through the condenser.

30 ml of 35% NaOH was added in the distilling flask such that the contents did not mix. The contents of the flask were heated for about 30-45 minutes to distil the ammonia. The receiving flask was removed and the outlet tube rinsed into the receiving flask with a small amount of distilled water. Excess acid was titrated in the distillate with 0.1M NaOH. Blank on reagents were determined using the same quantity of standard acid in a receiving conical flask.

The Calculation

$$Percent\ N = \frac{1.401[(V1M1 - V2M2) - (V3M1 - V4M2)]}{W} \times df$$

Where:

- *V1* – millilitres of standard acid put in receiving flask for samples;
- *V2* – millilitres of standard NaOH used in titration;
- *V3* – millilitres of standard acid put in receiving flask for blank;
- *V4* – millilitres of standard NaOH used in titrating blank;
- *M1* – molarity of standard acid;
- *M2* – molarity of standard NaOH;
- *W* – Weight of sample taken (1 g);
- *df*– dilution factor of sample (100).

3.4.3 Total Organic Carbon

The loss of Weight on Ignition method was used (Motsara& Roy, 2008).

The Procedure

One gram of milled feed stock was weighed into an ashing vessel of known weight and placed in a muffle furnace set at 450°C and ashed for 4 hours. The crucible was removed from the furnace and placed in a dry atmosphere for it to cool after which it was weighed to the nearest 0.01 g (Motsara & Roy, 2008).

The percentage of organic carbon is given by:

$$Percent\ Ash(A) = ((W2 - W1))/W1 \times 100 \cdots\cdots\cdots\cdots (1)$$

$$Percentage\ Organic\ Matter(OM) = 100 - A \cdots (2)$$

$$Organic\ \ Carbon = \frac{OM}{2} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

Where

- *W1* is the weight of crucible;
- *W2* is the weight of Ash and crucible

.

3.4.4 pH of Garbage

The Procedure

The pH meter was calibrated using two buffer solutions, the first buffer solution chosen had a pH of 7.0 and the second had a pH of 9.0.

The buffer solutions were put in beakers and the electrodes of the pH meter was inserted into the beakers of buffer solutions alternately whiles adjusting the pH meter until it indicated the pH as per the buffer solutions (Motsara & Roy, 2008).

5.0 g of a milled sample of the feed stock was placed into a 25 ml of distilled water and then the sample was allowed to absorb the water without stirring and then thoroughly stirred for 10 seconds using a glass rod. The suspension was then stirred for 30 minutes and the pH recorded using the calibrated pH meter (Motsara & Roy, 2008).

3.4.5 Phosphorus

Spectrophotometric vanadium phosphomolybdate method was used where the Phosphorus (P) content of the compost sample is converted to orthophosphates by digestion with an acid mixture (di-acid or tri-acid), after which the digested sample was used for P estimation (Motsara & Roy, 2008).

The Procedure

Standard solutions (50 µg P/ml) of 0, 1, 2, 3, 4, 5 and 10 ml were put in 50ml volumetric flasks. 10 ml of vanadomolybdate reagent was added to each flask to make up the volume. The P contents that were in the flasks were 0, 1, 2, 3, 4, 5 and 10 µg P/ml, respectively. The standard curve was prepared by measuring these concentrations on a spectrophotometer (470 nm) and the corresponding absorbance's recorded.

One g of milled feed stock was taken and digested as per the wet digestion method and the volume was made up to 100 ml. 5 ml of digest was put in a 50 ml volumetric flask and 10ml of vanadomolybdate reagent was added. The volume was made up with distilled water and shook thoroughly and it was allowed to sit for 30 minutes after which a yellow colour developed, which was read on the spectrophotometer at 470 nm. The P content was determined from the standard curve for the observed absorbance.

The Calculation

$$(\%\ P) = \frac{C \times df \times 100}{1000\ 000} = \frac{C \times 1000 \times 100}{1000\ 000} = \frac{C}{10}$$

Where;

- % P = P content (g) in 100 g sample
- C = concentration of P (µg/ml) as read from the standard curve;
- df = dilution factor, which is 100 × 10 = 1 000, as calculated below:

1 g of sample made to 100 ml (100 times);

5 ml of sample solution made to 50 ml (10 times).

1 000 000 = factor for converting µg to g.

3.4.6 Potassium

The Atomic Absorption Spectrometer (AAS) method was used to estimate the amount of potassium present in the sample after the sample was acid-digested (Motsara & Roy, 2008).

The Procedure

The AAS was standardized using the relevant parameters for potassium estimation which are stated below;

- Lamp current = 6 m A°
- Wavelength = 766.5 nm
- Linear range = 0.4–1.5 µg/ml
- Slit width = 0.5 nm
- Integration time = 2 seconds
- Flame = air acetylene

A standard curve was prepared using 0, 5, 10, 15 and 20 μg K/ml. 1 g of feed stock was digested in acid and made up to 100 ml by the addition of water. The sample was kept in the range of 5–10 mg K/kg (5–10 μg K/ml) by further diluting as appropriate. A blank was prepared in the same way without adding compost digested material. An aliquot of 5 ml was taken as estimation and made up to 100 ml. The samples were atomized on the calibrated AAS on which the standard curve had also been prepared. The absorbance of each sample was recorded. The standard curve was then used to note the concentrations of potassium for the particular absorbance observed for the sample.

The relevant calculation is:

$$(\%\,K) = \frac{C \times df \times 100}{1000\,000} = \frac{C \times 2000 \times 100}{1000\,000} = \frac{C}{5}$$

Where;

K% = K content (g) in 100 g sample

C = concentration of K (μg/ml) as read from the standard curve;

df = dilution factor, which is 100 × 20 = 2 000, as calculated below:

1 g of sample made to 100 ml (100 times);

5 ml of sample solution made to 100 ml (20 times).

1 000 000 = factor for converting μg to g.

3.5 Heavy Metal Analysis

Analysis was carried out on the finished product (compost) to determine if it meets the standard quality to make it safe to be used as a soil conditioner.

Before digestion to analyse heavy metals, the compost sample was dried at 65 °C for 48 hours. The digestion method applied was the nitric acid digestion method. The method was done in triplicate

3.5.1 Nitric Acid Digestion

One gram of sample was placed in a 250 ml digestion tube and 10 ml of concentrated HNO_3 was added. The sample was heated for 45 min at 90°C, and then the temperature was increased to 150°C at which the sample was boiled for at least 8 hours until a clear solution was obtained. Concentrated HNO_3 was added to the sample (5 ml was added at least three times) and digestion occurred until the volume was reduced to about 1 ml.

The interior walls of the tube were washed down with a little distilled water and the tube was swirled throughout the digestion to keep the wall clean and prevent the loss of the sample. After cooling, 5 ml of 1% HNO_3 was added to the sample. The solution was filtered with Whitman No. 42 filter paper and <0.45 lm Milli-pore filter paper. It was then transferred quantitatively to a 25 ml volumetric flask by adding distilled water.

3.6 Heavy metal analysis

The concentrations of Hg, Cu, Pb and Zn in the final solutions were determined by an atomic absorption spectrometer (AAS) (Hitachi Z-8100, Japan).

3.7 Microbiological Analysis

Analysis was carried out on the finished product (compost) to determine if it meets the standard quality to make it safe to be used as a soil conditioner.

The most probable number method (MPN) was used to determine total, E. coli and faecal coliforms in the sample.

3.7.1 Faecal Coliforms

Serial dilutions of 10^{-1} to 10 were prepared by picking 1 ml of sample into 9 ml of sterile distilled water. One millimetre aliquots from each of the dilutions were inoculated into 5 ml of Maconkey Broth with inverted Durham tubes and incubated at 35 ºC for total coliforms and 44 ºC for faecal coliforms for 18-24 hours.

Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24 hours were identified as positive for both total and faecal coliforms. Counts per 100 ml were calculated from Most Probable Number (MPN) tables.

3.7.2 E. coli

From each of the positive tubes identified a drop was transferred into a 5 ml test tube of trypton water and incubated at 44 ºC for 24 hours. A drop of Kovacs' reagent was then added to the test tube of trypton water. All tubes showing a red ring colour development after gentle agitation denoted the presence of indole and recorded as presumptive for thermo tolerant coliforms (*E.coli*). Counts per 100 ml were calculated from Most Probable Number (MPN) tables.

3.8 Composting

The organic solid waste (food waste) was collected from 16 households randomly as the material to be used for the composting process. The total wet weight of waste composted was 111.9 kg.

The windrow method of composting was employed where the organic material was heaped on the bare ground under the shade of trees (Basnayake, 2001).

Plate 3.3. Heap of decomposing organic matter under the dense shade of trees

The windrow was mechanically stirred every evening after the temperature had been read and occasionally watered when moisture content reduced below the optimal level for microbial activity. The moisture content was estimated based on a rule of thumb that states that a mixture of organic wastes that contains 50 per cent moisture feels damp to the touch but is not soggy (Hansen *et al.*, 1995).

The temperature of the pile of compost was recorded (at the centre of the heap) using a Ray Temp 3™ non-contact infrared thermometer twice daily; 6 am and 6 pm respectively from which an average daily temperature was calculated. The compost heap which took the form of a cone was measured weekly for its height and base circumference used to compute the volume of the compost remaining weekly.

The volume was calculated using the following equation

$$V = \frac{1}{3}\pi r^2 h$$

V = Volume

r = Radius

H =Height

3.8.1 Data Analysis

Microsoft Excel version 14 was used in the analysis of the data on the change in temperature and volume of the compost pile. Results were presented in graphs, tables and figures.

CHAPTER FOUR

4.0 Results

Presented in this chapter are the results of data that was collected during waste characterisation, the fractions obtained were organic, paper, plastic, glass and metal as well as the results of composting the organic fraction of the solid waste collected during the solid waste characterisation which are represented in tables and figures below. Also presented in this chapter is a waste management plan developed for Aburi.

4.1 Waste Characterisation

4.1.1 Waste Composition

Figure 4.1 below represents the percentages of the various waste types generated daily.

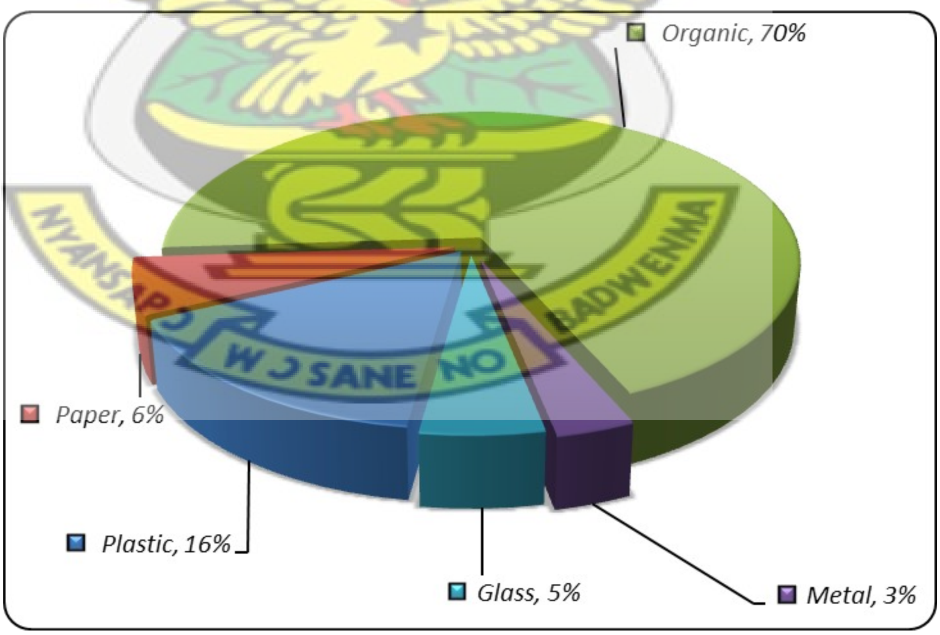

Figure 4.1. Aburi Residential MSW Composition

The largest quantity of waste generated per households was organic waste (70%), followed by plastic waste at 16% then next in line was paper waste at 6% followed by glass waste at 5% and metal waste being the least generated with 3%.

Figure 4.2 below shows the mean amounts of waste types generated daily per household.

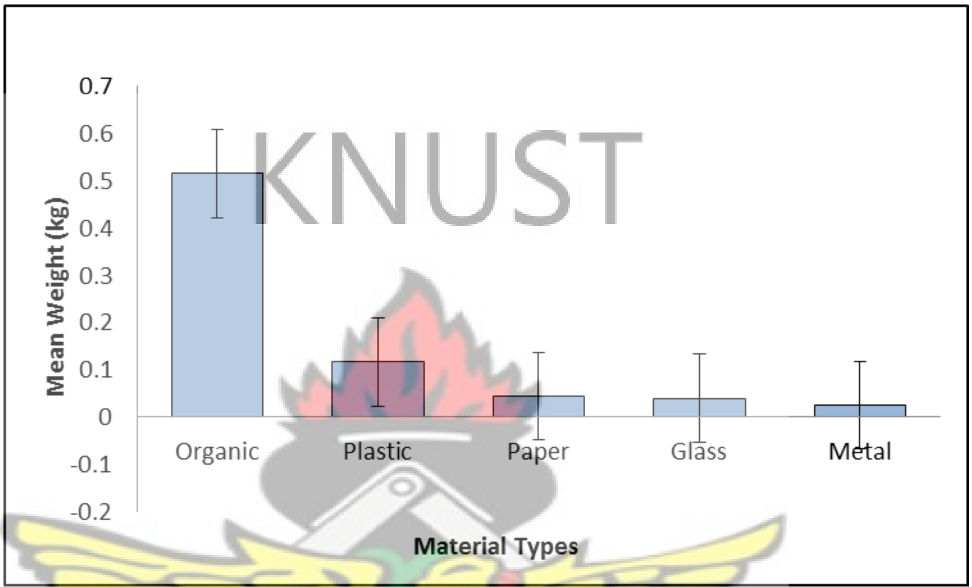

Figure 4.2. Mean amounts of Residential MSW generated per day per household (kg).

The waste type that was generated the most per household per day was organic waste (0.516 kg) followed by plastic waste (0.117 kg) and then paper at (0.045 kg) and glass waste (0.040 kg) and with metal waste trailing at 0.026 kg.

Table 4.1 below shows the per capita generation of the various waste types

Table 4.3. Per capita generation of waste of the town of Aburi

Waste Type	Mean person^{-1} kg/week
Organic Waste	0.07187
Plastic Waste	0.01626
Metal Waste	0.00355
Paper Waste	0.00622
Glass Waste	0.00555

Every individual in each of the households generates a mean of 0.072 kg/day of organic waste followed by plastic waste with 0.016 kg/day then paper waste with 0.006 kg/day followed by glass waste at 0.006 kg/day with metal waste trailing with 0.004 kg/day.

Figure 4.3 below represents the amounts of waste generated by the entire population per day.

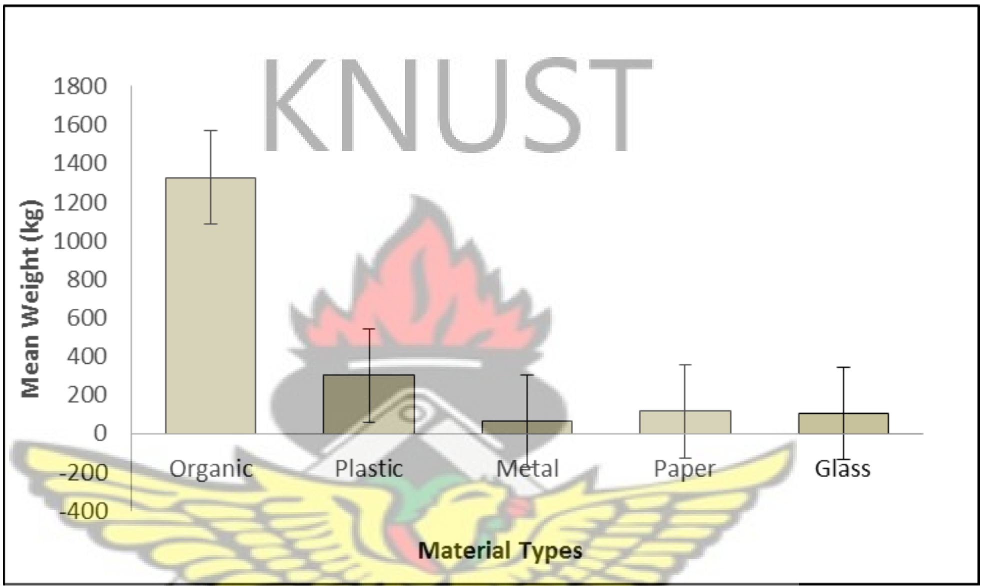

Figure 4.3. Residential MSW generated per day by the entire population (kg)

Daily the entire population generates more organic waste than any other waste type (1327.94 kg) followed by plastic waste (300.44 kg) and then paper (114.93 kg) followed by glass waste (102.55 kg) and with metal waste trailing at 65.59 kg.

Figure 4.4 below represents daily production of waste to be generated in the short, medium and long term.

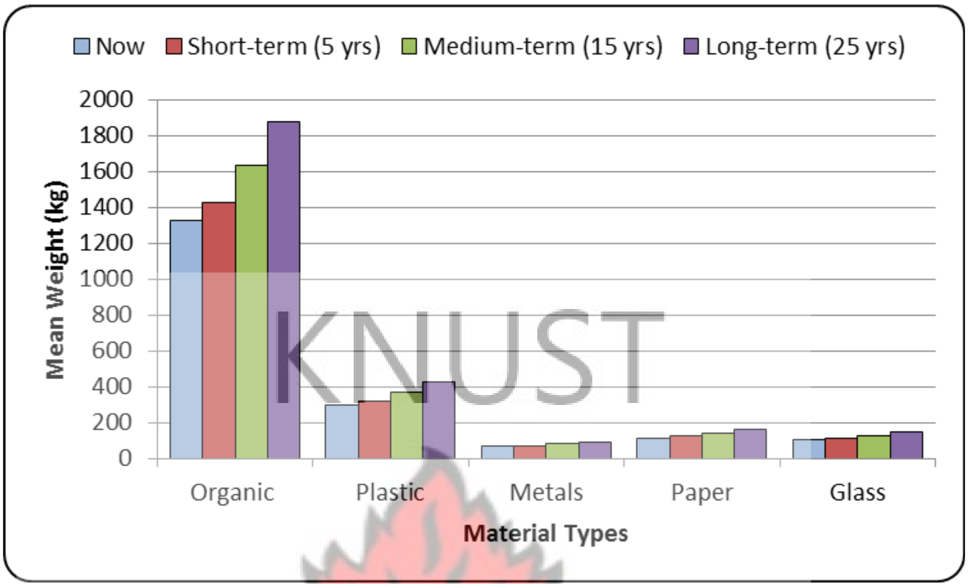

Figure 4.4. Residential MSW to be generated in the short, medium and long term

In the next five years the largest amount of waste to be generated by the entire population daily would be organic waste with an amount of 1423.53 kg followed by plastic waste with an amount of 322.06 kg then paper waste with an amount of 114.93 kg followed by glass waste with an amount of 102.55 kg and metal waste trailing with 65.59 kg.

The amount of waste to be generated in the medium term by the entire population daily would be organic waste with an amount of 1635.83 kg followed by plastic waste with an amount of 370.094 kg then paper waste with an amount of 141.57 kg followed by glass waste with an amount of 126.32 kg and metal waste trailing with 80.80 kg.

The amount of waste to be generated in the long term by the entire population daily would be organic waste with an amount of 1879.83 kg followed by plastic waste with an amount of 425.30 kg then paper waste with an amount of 162.69 kg followed by glass waste with an amount of 145.17 kg and metal waste trailing with 92.85 kg.

4.2 Composting

4.2.1 Physicochemical Analysis of Feed Stock

Table 4.2 below shows results of physicochemical analysis carried out on the feed stock before composting.

Table 4.4. Physicochemical analysis performed on the feed stock used for composting compared with recommended levels by the USEPA.

Parameter	Value	Min	Max	Recommended Levels
pH	5.867 ± 0.058	5.8000	5.9000	Neutral
Moisture (%)	69.63% ± 0.057	69.650	76.680	60
Carbon (%)	44.32% ± 0.0231	44.050	44.450	20-40
Nitrogen (%)	1.19% ± 0.035	1.1600	1.2300	1
C/N ratio	37.24 ± 0.66	36.58	37.90	21:1- 40:1

The feed stock had a pH of 5.867 ± 0.058 with a moisture content of 69.63% ± 0.057. It had carbon content of 44.32% ± 0.0231 and a nitrogen content of 1.19% ± 0.035 in addition to a C/N ratio of 37.24.

4.2.2 Physicochemical Analysis

Table 4.3 below shows results of physiological analysis performed on the compost.

Table 4.5. Results of physicochemical Analysis carried out on the **compost**

	Temp (ºC)	**pH**	**C:N**	**C %**	**N %**	**P %**	**K%**
Compost	27.48± 4.39	**8.67**±0.057	**83.7±50.0**	**41.00**±0.250	**0.49**±0.0057	**0.08**±0.000	**0.07**±0.000
Min	22.250	8.6000	**33.70**	40.750	0.49000	0.080000	0.070000
Max	40.100	8.7000	**133.7**	41.250	0.50000	0.080000	0.070000
Recommended levels		**8.0**	22[b]	**8-50**[a]	**0.4-3.5**[a]	**0.3-3.5**[a]	**0.5-1.8**[a]

a. Gotaas, 1956 b. World Bank ,1997

The compost is moderately alkaline with a pH value of 8.67. The amount of nitrogen left after composting is 0.49 %. The remaining carbon after composting is 41.00 % and the amount of potassium and phosphorus present is 0.07% and 0.08% respectively.
Table 4.4 below represents the comparison of carbon, nitrogen and C: N ratio before and after composting.

Table 4.6. Comparison of carbon, nitrogen and C: N ratio before and after composting

	pH	Carbon	Nitrogen	C:N Ratio
After composting	8.67	41.00%	0.49%	83.7

The pH before composting was 5.867 but after composting the pH increased to 8.67. Before composting the amount of carbon was 44.32% but after composting the amount of carbon reduced to 41.00%. The amount of nitrogen before composting was 1.19% but after composting it reduced to 0.49%. Initial C: N ratio was 37.24 but after composting it increased to 83.7.

4.3 Heavy Metal Analysis

Table 4.5 below summarises the means of selected heavy metals analysed to determine compost quality.

Table 4.7: Selected heavy metals analysed to determine compost quality

	Heavy Metals			
	Cu	**Hg**	**Pb**	**Zn**
Values (ppm)	2.67±0.537	82.14±3.01	40.56±1.245	0.75±0.212
Minimum	2.290	80.01	39.680	0.600
Maximum	3.050	84.26	41.440	0.900
Proposed standards in developing countries (ppm)	80	1	150	300

a. World bank, 1997

Copper (Cu) gave a value of 2.67±0.537 with a min- max range of 2.290 - 3.050.

Mercury (Hg) gave a value of 82.14±3.01 with a min- max range of 80.01- 84.26.

Lead (Pb) gave a value of 40.56±1.245 with a min- max range of 39.680- 41.440.

Zinc (Zn) gave a value of 0.75±0.212 with a min- max range of 0.600 - 0.900

4.4 Microbiological Analysis

Table 4.6 below shows the results of the microbiological analysis performed on the compost.

Table 4.8. Microbiological analysis of compost to determine quality

	Value	Standard
Faecal coliforms/100 ml CFU parameter	2.4×10^3	< 1000
E coli/100 ml CFU	4.3×10^1	< 3

a. Canadian Council of Ministers of the Environment,2005

The results of the microbial analysis indicated the levels of faecal coliforms and E. coli as 2.4×10^3/ 100 ml CFU, 4.3×10^1/ 100 ml CFU respectively.

4.5 Composting Performance

4.5.1 Temperature Patterns

Figure 4.5 below represents the temperature variation experienced during composting.

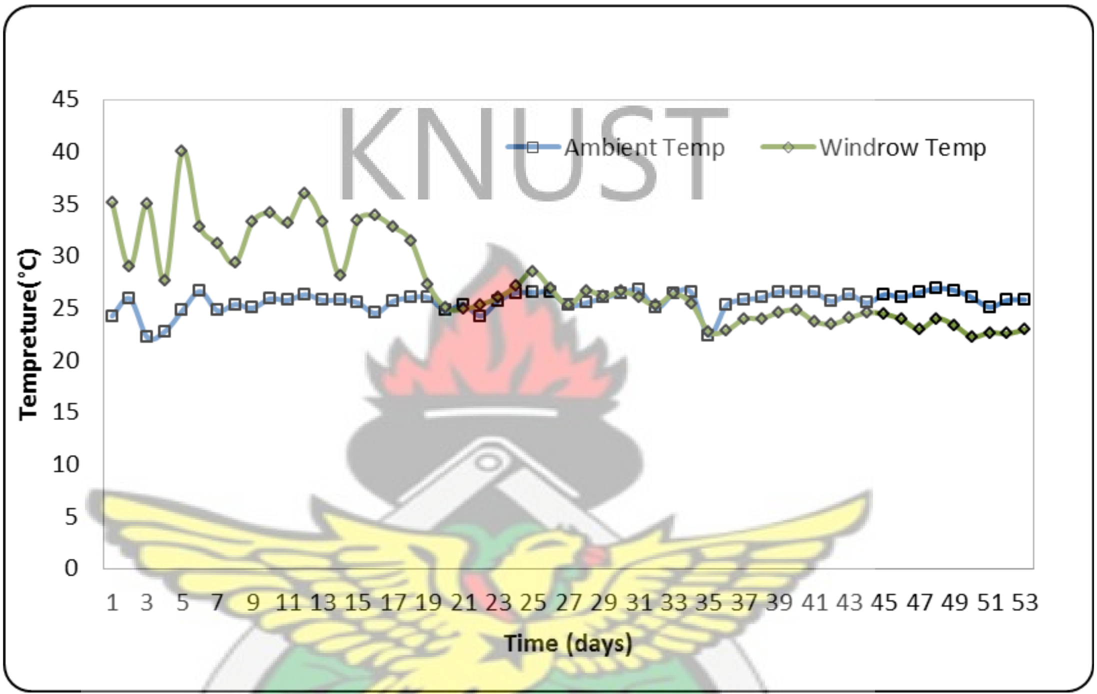

Figure 4.5. Temperature profile during composting

The first temperature recorded was 35°C then it declined to 29°C then increased to 35°C again then the temperature declined to 27.7°C before increasing up to 40.1°C in the first five days of composting, and then it plunged to 29.3°C. From day 9 temperatures increased steadily to 36°C over the next two days followed by a reduction to 28.15°C. Over the next couple of days the temperature increased to 33.9°C and fell to a record low of 25°C after 5 days. The temperature began stabilizing from the 21st day and ended at 22.75°C on the 35th day.

Figure 4.6 below shows the gradual reduction in volume experienced during composting.

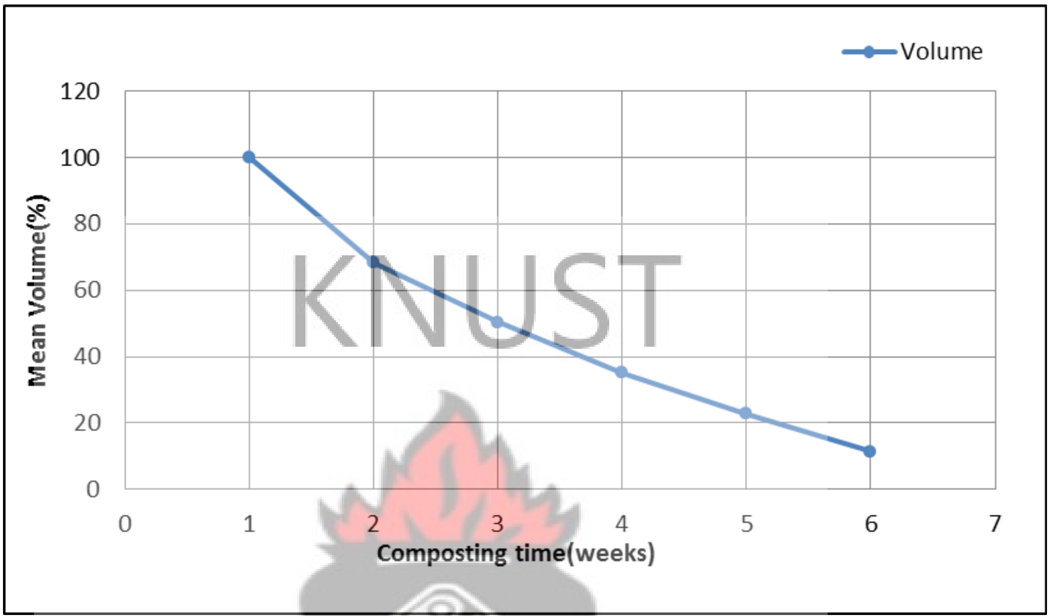

Figure 4.6. Volume of windrow per week

Volume reduced progressively, starting at 100 % in the first week then reduced to 68.27% then to 50.31% followed by 35.12% then 22.73% and finally stabilized at 11.38% in the sixth week.

CHAPTER FIVE

5.0 Discussion

5.1 Waste Characterisation

5.1.1 Organic Waste (food waste)

Organic waste was the largest fraction of the sampled household waste generated daily (70%), this is consistent with the trend that countries located in the West African Region generate organic (food waste) more than the other wastes types (Silva, *et al*., 2006).

Organic waste makes up the largest fraction of the sampled household waste because still widespread in many developing countries is the buying of unprocessed food to be prepared and cooked at home, thus generating a significant amount of putrescible waste. In contrast, people in developed countries often buy processed, ready-to-eat food, leading to a lower representation of food waste in HSW but a higher percentage of packaging materials such as paper, plastics, metals and glass (Bernache-Pérez *et al.*, 2001).

Organic waste is mainly composed of kitchen waste materials such as vegetables, fruits, food leftovers, etc. The high proportion of food and plant waste is due to the fact that Ghana's economy largely depends on agricultural products for export and domestic consumption (Anomanyo, 2004).

5.1.2 Plastic & Paper

Plastics waste (16%) was the second largest waste form generated after organic waste; this is not consistent with the trend in countries within the West African Region. According to Silva Alves, *et al.* (2006) in West Africa plastic waste usually comes third to organic waste.

Paper makes up 6% of the household garbage generated; this is not consistent with the trend that the West African Region generates a higher percentage of paper waste (Silva Alves *et al*., 2006).

Also it can be noted that the percentage of paper in the waste (6%) is relatively low compared with plastic waste (16%), this is due to the fact that plastics rather than paper is widely used in packaging. It is less likely that residential solid waste contains significant proportions of office/commercial waste that consists almost entirely of paper and cardboard (Yang *et al.*, 2005).

Paper waste included all paper products (printed or plain paper, newspapers and notebooks), all types of corrugated and non-corrugated carton boxes and packages, etc. Plastic waste was composed mainly of packaging, plastic products, hard and flexible plastic household items, PET bottles.

5.1.3 Metal

Metals formed 3% of household garbage generated; this is in agreement with the work done by Silva Alves, *et al*. 2006 which indicated that the West African Region has metal being the least of the MSW generated.

Most of the waste consisted of tin-cans used to package processed foods which were not much because in developing countries the buying of unprocessed food to be prepared at home is a common practice as pointed out by Bernache-Pérez *et al* (2001).

5.1.4 Glass

The glass waste mainly consisted of beer bottles, liquor bottles, medicine, and other beverage and juice bottles. Although broken glass bottles were also observed, most of the glass bottles were not broken.

Even though households were specifically asked not to refuse to give any recyclable waste materials at home during the survey period; few unbroken bottles were observed in the samples suggesting that recyclables were in fact removed from the sample waste stream for reuse or for sale. This may account for the amount of glass waste.

The articles of glass collected over the 4 weeks were not many but it weighed more because the density of glass is high and according to the laws of physics the density of a material is directly proportional to its mass hence the reason for the weight of glass collected during the survey.

5.2 Composting

5.2.1 Physicochemical Analysis of Feed Stock

The pH was moderately acidic because of lactic acid production as the food wastes underwent fermentation during the one week in storage, because according to Yang et al (2005) food wastes are typically wet and contain high levels of fermentable carbohydrate.

The moisture content and carbon was high for both samples because food wastes are usually wet and contain high levels of carbohydrate (Yang *et al.*, 2005). The amount of nitrogen containing wastes is small as their diet is dominated by carbohydrates such as plantain, cassava, cocoyam, sweet potatoes, maize and rice, this therefore accounts for why the C/N ratio is high.

5.2.2 Physicochemical Analysis of Compost

pH

The sample is moderately alkaline as compared to the initial reading which indicated a moderately acidic sample, pH drops during initial stages of composting as a result of the activity of acid-forming bacteria which break down complex carbohydrate material (polysaccharides and cellulose) to organic acid fermentation intermediates under anaerobic conditions (Hansen *et al*., 1995).

The microorganisms that produce the acids also can utilize them as food after higher oxygen concentrations are established. This typically occurs within a few days after the most readily biodegradable substances have been destroyed. The net effect is that the pH begins to rise after a few days. The rise continues until a level of 7.5 to 9.0 is reached, and the mass becomes alkaline (Hansen *et al*., 1995).

Total Nitrogen

Nitrogen is reduced as a result of its conversion to ammonia during the composting process. Due to the nature of the process, aerobic composting usually leads to the loss of at least some nitrogen. The loss is associated with high temperatures, low moisture content and eventual alkaline conditions that are attained during the process (Hansen *et al*., 1995). These above discussed conditions could have resulted in the decrease in the amount of nitrogen in the compost.

Carbon

The amount of carbon left in the compost sample is smaller than the amount of carbon in the waste sample before composting started, because the carbon serves both as a source of energy and as an element in the cell protoplasm, much more carbon than nitrogen is needed.

Generally, organisms respire about two-thirds of the carbon they consume as CO_2, while the other third is combined with nitrogen in the living cells (Washington State University-Whatcom County Extension, 2005).

Phosphorus and Potassium

The levels of phosphorus and potassium in the compost sample was low because according to literature plant residue which is generally known to have low levels of plant nutrients which includes phosphorus and potassium is what was used as the feed stock for the compost (Darlington, 2001).

Heavy Metal Analysis

The levels of Cu, Pb, Zn were satisfactory because they fell below the recommended amounts that is deemed safe for use whiles Hg level was way above acceptable levels. These levels in heavy metals must have been a result of the source of the food stuffs from which the waste was produced (BodSch, 1998) (Journal of Zhejiang University Science B, 2007).

Microbiological Analysis

The results of the microbial analysis was not satisfactory because the test for E. coli and faecal coliform were below the recommended values for which compost is deemed fit for use as a soil conditioner which is in line with the standards that the

California Department of Resources Recycling and Recovery (Cal Recycle), 2004 stated.

5.2.3 Composting Performance

Temperature Patterns during Composting

The temperature increase that occurred during composting process resulted from the breakdown of organic material by bacteria, actinomycetes, fungi and protozoa. Hansen *et al.*, (1995) mentioned that the microorganisms decompose (oxidize) organic matter, heat is generated and the temperature of the compost rises as a result.

Temperatures sometimes dropped intermittently during the period of composting until maturation initiated at day 26, this could have been as a result of low moisture content of the compost medium which could have occurred during decomposition which in turn reduced microbial activity (Hansen *et al.*, 1995).

Changes in Volume of Compost Heap

The steady reduction in the volume of the food waste was as a result of the reduction of the carbon in the food waste into CO_2 into the atmosphere as a by-product of the process of decomposition by the responsible microorganisms. The volume became constant after decomposition was complete because all available carbon had been exhausted.

CHAPTER SIX

6.0 Conclusion and Recommendations

6.1 Conclusion

The objective to characterise the solid waste of Aburi as well as composting the organic fraction of the waste was accomplished.

1. Organic waste is the most abundant waste type and metal waste is the least in terms of the quantity of waste generated.
2. Compost matures within 35 days of composting the feed stock. The study showed that the compost was of low quality because of a high C/N ratio and high levels of mercury, low levels of potassium and phosphorus, and high levels of faecal coliform and *E. coli* after composting.

6.2 Recommendations

Research findings and pertinent conclusions has led to the following recommendations.

1. The segregation of the waste types at source using bin bags of different colours was a success hence it is recommend for waste to be segregated at source.
2. Co-composting research studies should be done in Aburi to compensate for the high C/ N ratio.
3. The municipal Assembly should consider the waste management plan in their effort to manage waste in the district.

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APPENDICES

APPENDIX A

Waste Management Plan for Aburi

Existing Solid Waste Management Conditions

No detailed data on waste types has been collected before September 2010, to facilitate the design of a solid waste management plan for Aburi.

Some work has been done recently involving residential solid waste stream. The total quantity of solid waste generated in the township is not known, neither is the rate at which the waste is generated, collected or disposed off. Information available currently is on residential solid waste generated which is mainly made up of organic (food waste), plastic & rubber, metals & cans, paper & cardboard and glass waste.

Available information shows that organic waste tops the list of most generated solid waste followed by packaging material such as plastic waste, paper waste, glass waste and finally metal waste (Figure 4.7). The Per capita generation of the various waste materials is as indicated in the (Table 4.7). Future projections show exponential increase in population and its corresponding increase in solid waste (Figure 4.8).

Table 0.9. Per capita generation of the various waste materials

Material Group	Mean kg/day per person	Mean kg/day per township
Organic (Food Waste)	0.07187	1327.942
Plastic &rubber	0.01626	300.436
Metals & cans	0.00355	65.59335
Paper & cardboard	0.00622	114.9269
Glass	0.00555	102.5474

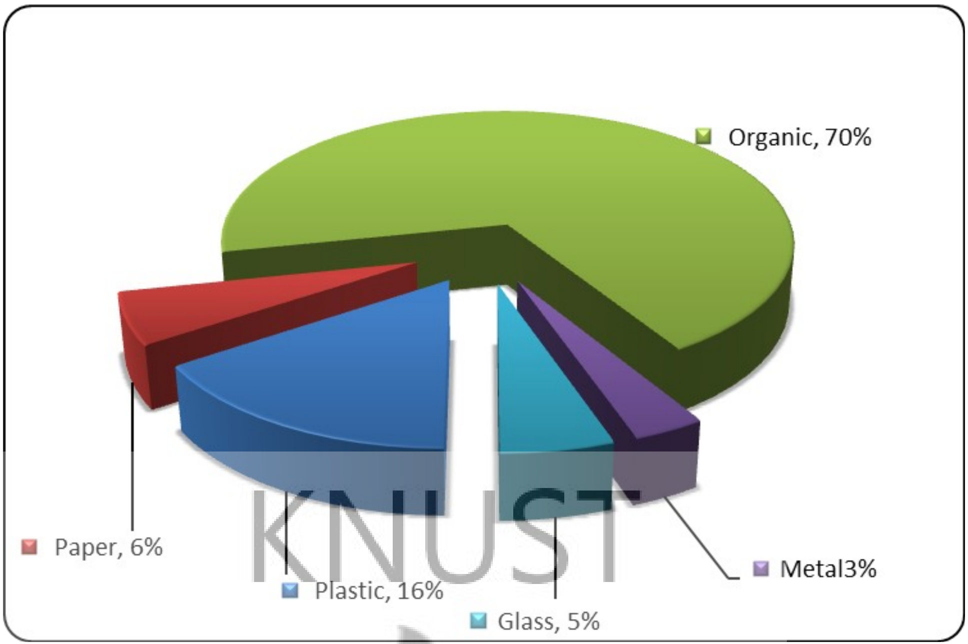

Figure 0.7. Aburi Residential MSW Composition

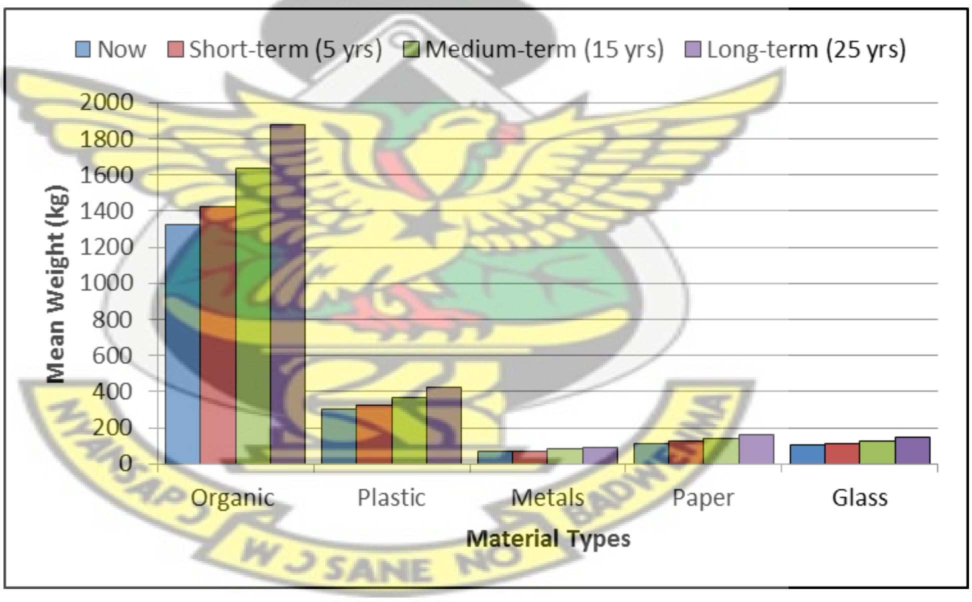

Figure 0.8. Future projections

The Municipal Assembly takes no active part in the collection and disposal of refuse, as a result residential solid wastes are managed by individual residents in their homes, there is no segregation of solid waste at source and they dispose of the waste they generate in their own convenient ways.

Most of the solid waste ends up at public dump sites, where the solid waste is dumped and burned in the open because there is no container to accumulate for final disposal. Some residents just dispose of their waste anywhere they deem convenient without considering the health and environmental implications of their actions.

Future Conditions and Problem Definitions

Dump sites are maintained by workers of the municipal assembly even though they were not commissioned by the Assembly; to be frank these sites are poorly positioned. One of the current dump sites pollutes a well which serves as a source of drinking water for the town with its runoff every time it rains.

Because of the improper handling and disposal of waste there is the potential for disease outbreaks, further degradation of soil, water and air quality. The town will lose its aesthetic appeal which will be attributed to garbage dumps which will form part of the landscape and the stench it will create. This will very much hurt the tourism and hospitality industry for which the town is noted.

Objectives

Acceptable methods for storage, segregation of recyclable waste
Acceptable methods for primary collection of wastes
Acceptable waste processing practices
Acceptable methods of waste disposal
Provision of sufficient financial support for solid waste management

Recommendations for Solutions

This section offers suggestions which the assembly should consider in order to help solve its solid waste management problems.

System Improvement

Collection of Garbage

Communal collection of waste is a viable option that should be considered since the township is poorly developed, in this system householder or entrepreneurial contractors are required to place the waste in strategically positioned containers for collection and disposal by large motorized refuse vehicles.

The waste should be sorted out at into Plastic & rubber, Paper & Cardboard, Glass, and Metal using a colour coded system where a rubber sac of a particular colour carries a specific waste type. Only disposal bins should be provided for the storage of organic (food waste). The collection of waste should be thrice a week with a day set aside for collection of only packaging materials, since organic (food waste) is the bulk of solid waste generated.

These disposal points could be specifically designed masonry structures with embankments, or ready-made containers strategically placed. Should the option of fixed structures be selected, these would need to be cleared either by manual labour or mechanical means and the waste transferred to suitable vehicles for transport to the disposal site.

The ideal transportation option for the waste is a tip truck considering the amount of waste generated weekly in Aburi and the fact that they have low maintenance costs as compared to the rear-end loader which would have been preferred. With the tip-truck, the weight of the refuse is used for compaction and normally has a capacity up to 10 m_3.

Two different tip trucks are recommended for garbage collection operations in the township as shown in Table 4.8.

Table 0.10. Suggested waste collection method

TRUCK	WASTE MATERIAL
TRUCK 1	Organic waste(food waste)
TRUCK 2	Plastic & rubber, Paper & Cardboard, Glass, Metal

Transfer Station

A transfer station will have to be constructed to receive all waste types; in this particular case the transfer station will be the final disposal site. From this site recyclable waste such as plastics & rubber, paper & cardboard and glass that have already been sorted out at the household level will be collected and shipped to the various processing locations that will be made available by the municipal assembly.

Short Term Waste Management

As at now there is no appropriate garbage disposal site, all four sites currently in use have been created by the inhabitants of Aburi over time to meet their needs as a result of population increase.

These waste dump sites have to be shut down as soon as possible because of their proximity to the human settlement and the fact that runoff from one of these sites contaminates a well source of drinking water for the town when it rains.

As it stands the town has no land set aside for solid waste management as such, appropriate steps must be taken to acquire a suitable tract of land where the solid waste of the town can be managed. The most fitting waste management scheme to implement is the 3R (Reduce, Reuse and Recycle) approach.

This approach can be applied to food waste, plastic waste, metal waste, paper waste and glass waste.

Food Waste (Organic)

This forms the largest percentage of the residential solid waste in this town. This kind of waste should be recycled through open windrow composting as incineration and land-filling are more expensive options of waste management. As per the results of my study of composting under the local conditions employing the windrow method, food waste with carbon nitrogen ratio of 1: 44 and moisture content of 66.3 % produces compost of moderate quality over a period of 21 days. The mature compost can then be processed (drying, screening, and granulating or pelletizing) before using it as a mulch or soil conditioner.

Plastic Waste

This being the second largest waste produced should be reused and those that are not reused recycled. Plastic containers that once held a product can be used to store other materials or package other products for sale; plastic bags used to carry bought items can be stored and reused several times.

Recently some manufacturers of plastic products in Tema have begun buying used water sachet bags and black plastic carrier bags for recycling, with this new development water sachet bags and black plastic carrier bags which forms a representative section of plastic waste can be separated from the residential waste at source and stored till significant amounts are reached then they can be sold at these recycling plants.

Even if the cost of transportation is just balanced by the revenue generated it would be worth it since it will save the environment. Plastic waste material that does not get re-cycled should be stored at designated disposal sites awaiting long term disposal methods such as incineration and then after landfilling of the residue.

Paper Waste

Paper and cardboard boxes used as packaging material can be stored and used as pack-aging for other materials. Newspapers and used sheets of paper can be used for art and craft activities to generate revenue and also used as packing material for protecting fra-gile items during transportation to reduce breakage. Non-reusable paper can be burnt at the dump sites.

Glass Waste

Glass packaging containers can be reused as storage vessels to preserve food items. It can be recycled into glass beads which are locally produced and used as jewellery. It can also be used in building construction where broken glass is incorporated into terrazzo designs.

Metal Waste

Packaging material of this nature should be reused in packaging if possible. There are other types of ferrous scrap metal that can be collected and exchanged for cash. As for those without any current use they can be stored until a more suitable use is found for them.

Medium to Long Term Waste Management

An engineered Landfill must be constructed to take care of non-recyclable and non-reusable municipal solid waste.

Financial Support

The financing of a plan like this is not likely to be cheap; funds could be generated from fines in addition to the monies made available by the District Assembly. Residents can contribute by paying a fee for waste disposal, be it to the assembly or a private entrepreneur.

The town could also generate funds by signing a contract with Blowplast Ghana limited to supply them on a weekly basis with used sachet rubber bags and bagging bags. One kilo of waste will earn them 1000 Ghana cedis upon delivery to the company dump site.

By-laws could also be passed to penalize littering in order to make people aware of their responsibility in maintaining their town's cleanliness, a fine of GH₵0.50 could be imposed for every offence of littering and the amount doubled for every subsequent offence.

APPENDIX B

Rate of volume reduction of compost heap

Week	Height(m)	Circumference(m)	Radius(m)	*Volume(m^3)*
Week 1	0.535	3.6576	0.5821	**0.1898**
Week 2	0.43	3.0684	0.4884	**0.1074**
Week 3	0.365	3.0657	0.4879	**0.0909**
Week 4	0.37	2.747	0.4372	**0.0741**
Week 5	0.34	2.744	0.4367	**0.0679**
Week 6	0.34	2.749	0.4375	**0.0681**

APPENDIX C

Daily temperature profile of compost heap compared with daily ambient temperature during composting.

Time		Windrow	Daily			
Week	**Day**	**Date**	**6am**	**6pm**	**°C**	**°C**
WEEK 1	1	18/10/10	**33.1**	**37.1**	***35.1***	24.25
	2	19/10/10	**35.1**	**22.9**	***29.0***	25.9
	3	20/10/10	**38.0**	**32.0**	***35.0***	22.2
	4	21/10/10	**28.4**	26.9	***27.65***	22.75
	5	22/10/10	**44.1**	36.1	***40.1***	24.75
	6	23/10/10	**42.9**	22.7	***32.8***	26.6
	7	24/10/10	**33.1**	29.2	***31.15***	24.75
WEEK 2	8	25/10/10	**36.3**	22.3	***29.3***	25.35
	9	26/10/10	**35.5**	31.1	***33.3***	25.0
	10	27/10/10	**38.1**	30.2	***34.15***	25.9
	11	28/10/10	**38.4**	27.9	***33.15***	25.75
	12	29/10/10	**34.8**	37.2	***36.0***	26.3
	13	30/10/10	**34.9**	31.7	***33.3***	25.75
	14	31/10/10	**32.3**	**24.0**	***28.15***	25.8
WEEK 3	15	1/11/10	**31.5**	**35.4**	***33.45***	25.5
	16	2/11/10	**33.4**	**34.3**	***33.85***	24.5
	17	3/11/10	**32.7**	**32.9**	***32.8***	25.65
	18	4/11/10	**35.6**	**27.4**	***31.5***	26.0
	19	5/11/10	**28.0**	**26.6**	***27.3***	26.0
	20	6/11/10	**24.5**	**25.6**	***25.05***	24.75
	21	7/11/10	**24.0**	**25.8**	***24.9***	25.35
WEEK 4	22	8/11/10	**24.6**	**26.1**	***25.35***	24.25
	23	9/11/10	**25.8**	**26.2**	***26.0***	25.7
	24	10/11/10	**26.3**	**27.9**	***27.1***	26.45
	25	11/11/10	**27.6**	**29.5**	***28.55***	26.5

	26	12/11/10	27.3	26.4	26.85	26.5
	27	13/11/10	24.9	25.6	25.25	25.25
	28	14/11/10	26.4	27.0	26.7	25.5
WEEK 5	29	15/11/10	26.0	26.2	26.1	26.0
	30	16/11/10	26.3	26.9	26.6	26.4
	31	17/11/10	26.1	26.0	26.05	26.75
	32	18/11/10	24.4	26.1	25.25	25.0
	33	19/11/10	26.4	26.3	26.35	26.4
	34	20/11/10	24.8	26.1	25.45	26.5
	35	21/11/10	21.6	23.9	22.75	22.4
WEEK 6	36	22/11/10	21.4	24.3	22.85	25.25
	37	23/11/10	23.8	24.1	23.95	25.8
	38	24/11/10	24.0	24.0	24.0	26.0
	39	25/11/10	24.3	24.9	24.6	26.55
	40	26/11/10	24.3	25.3	24.8	26.5
	41	27/11/10	24.6	22.9	23.75	26.5
	42	28/11/10	23.4	23.5	23.45	25.65
WEEK 7	43	29/11/10	23.2	24.9	24.05	26.3
	44	30/11/10	23.7	25.4	24.55	25.5
	45	1/12/10	23.9	25.0	24.45	26.3
	46	2/12/10	23.8	24.0	23.9	26.05
	47	3/12/10	23.1	22.8	22.95	26.5
	48	4/12/10	23.6	24.4	24.0	26.9
	49	5/12/10	22.9	23.8	23.35	26.7
WEEK 8	50	6/12/10	21.8	22.7	22.25	26.0
	51	7/12/10	21.7	23.6	22.65	25.1
	52	8/12/10	22.3	22.8	22.55	25.75
	53	9/12/10	21.5	24.4	22.95	25.8

APPENDIX D

Residential solid waste composition by material group

		Mean	Standard Deviation	Limits	
Material Group	**Week**	***kg***	***kg***	***Minim-um***	***Maxim-um***
Organic (Food Waste)	Week 1	4.04	6.24	0.00	26.50
	Week 2	3.297	5.696	0.000	18.800
	Week 3	3.229	5.655	0.000	18.900
	Week 4	3.88	5.98	0.00	25.60
Plastic & Rubber	Week 1	1.174	1.851	0.000	9.700
	Week 2	0.626	0.986	0.000	4.700
	Week 3	0.684	1.396	0.000	5.900
	Week 4	0.785	1.612	0.000	8.400
Metal & Cans	Week 1	0.415	1.025	0.000	5.800
	Week 2	0.0971	0.2181	0.0000	0.8000
	Week 3	0.1103	0.2648	0.0000	1.4000
	Week 4	0.0926	0.1759	0.0000	0.8000
Paper & Cardboard	Week 1	0.510	0.746	0.000	3.200
	Week 2	0.1882	0.5364	0.0000	2.8000
	Week 3	0.266	0.601	0.000	2.600
	Week 4	0.2853	0.5769	0.0000	2.4000
Glass	Week 1	0.500	1.269	0.000	6.400
	Week 2	0.1794	0.5381	0.0000	2.4000
	Week 3	0.416	1.222	0.000	6.600
	Week 4	0.0206	0.0914	0.0000	0.5000

APPENDIX E

Per capita waste generation of the selected waste types

Material Group	Mean person^{-1} kg/day	Mean Township^{-1} kg/day
Organic (Food Waste)	0.07187	1327.942
Plastic &rubber	0.01626	300.436
Metals & cans	0.00355	65.59335
Paper & cardboard	0.00622	114.9269
Glass	0.00555	102.5474

APPENDIX F

Quantities of waste to be generated in the short, medium and long term

Material Group	Short-term (5yrs.)	Medium-term (15yrs.)	Long-term (25 yrs.)
Organic (Food Waste)	1423.52909	1635.83307	1879.83172
Plastic &rubber	322.06182	370.09386	425.29656
Metals & cans	70.31485	80.80155	92.8538
Paper & cardboard	123.19954	141.57342	162.69032
Glass	109.92885	126.32355	145.1658

APPENDIX G

Characterization of Waste Types

Persons per Home	ORGANIC				PLASTIC				METAL				PAPER				GLASS			
	1	2	3	4	1	2	[illegible]	[illegible]	[illegible]	[illegible]	3	4	1	2	3	4	1	2	3	4
2	7.2	0	0	9	0	0	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0.2	0	0	0	0
6	0	0.3	0.2	0.5	0.3	0.2	0.05	0.9	0	0	0	0	1	0.1	0.1	0.1	0	0	0	0
9	2.9	1.6	0	0	1.1	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0
6	3	0	4.1	0	0.7	0	0.35	0.6	0.4	0	0	0.2	0.5	0	0	0	0	0	0.7	0
4	7.1	18.5	0	0	1.5	0.4	0	0	0	0	0	0	0.2	0	0	0	3.3	1.8	0	0
9	19.7	0	0	0	1.2	0	0	0	0.4	0	0	0	0.2	0	0	0	0	0	0	0
7	0.9	0	1.6	0	0.2	0	0	0	0.2	0	0.15	0	0.9	0	0	0	0	0	0	0
8	0	0	0.6	0	0.9	0.3	0	0.3	0	0.2	0	0.1	0	0.1	0	0.1	0	0	0	0
5	0	0.5	0	0	1.4	0.3	0.1	0.4	0.3	0	0.1	0	2.2	0	0	0.2	0	0	0.15	0
4	0	0	0.1	0	0.9	0.5	1.4	0.6	0	0	0.2	0.05	0	0	0.1	0.8	0	0	0	0
3	0	0	0	0	0	0	0.4	0.3	0	0	0	0	0	0	1.8	0	0	0	0	0
9	11.8	15.6	0	25.6	9.7	0.9	0	3.6	0	0	0	0.3	0	0.1	0	1.2	0	0	0	0
4	4.8	0.6	1.1	6.7	1.9	2.8	5.9	3	1.3	0	0.6	0.1	0.4	1.3	1.6	1.4	6.4	0	6.6	0.2
36	0	7.2	13.5	12.45	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0.6	0.5	0.6	0.3	0	0	0	0	0.05	0	0	0	0.3	0	0	0
3	0.2	0	3.2	0	0.6	0	1.8	0.8	0	0	0	0	0.6	0.7	2.6	1.8	0	0	0	0
2	0	0.9	0	3.3	0.1	1.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0.5	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0
10	4.6	0	1.3	2.7	1.8	0	0.15	0.3	0.8	0	1.4	0.5	0.8	0	0.5	0	0.9	0	0.7	0
7	0.8	3.4	1.7	6.2	0.1	1	0.1	0.1	0.2	0.7	0.1	0.1	0.5	0.6	0.25	0.5	0	0.2	0	0
3	1.9	1.5	2.8	3	1	0.7	0.9	0.7	0.2	0.4	0.3	0.1	2.4	0.2	0.4	0.3	0.1	0.4	1.7	0
3	2.4	2.2	0	2	0.9	1	0	0.2	0.5	0.8	0	0.2	0.7	0.5	0	0.1	1.9	1.2	0	0
5	14	1.4	0	0	0.8	0.2	0	0	0.1	0	0	0	0.2	0	0	0	1.6	0	0	0
4	0	14	11.9	13.7	0.2	1.5	2	0.9	0	0	0	0	0.5	0	0.15	0	0	2.4	0	0