

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF ENVIRONMENTAL SCIENCE

COLLEGE OF SCIENCE

**CO-COMPOSTING OF ORGANIC WASTE AND SEWAGE SLUDGE- A WASTE
MANAGEMENT OPTION FOR CHIRANO GOLD MINES LIMITED,
WESTERN REGION**

**A Thesis Submitted to the Department of Theoretical and Applied Biology in partial
fulfillment of the requirement for the award of the Master of Science Degree in
Environmental Science**

BY

DANIEL KOJO BARIKUN YINMARAH (BSc. Chemistry)

JUNE, 2014

DECLARATION

I, Daniel Kojo Barikun Yinmarah, hereby certify that this report is a true outcome of the research carried out at Chirano Gold Mines Limited (CGML), a Kinross Company on co-composting organic waste and sewage sludge as a waste management option. I hereby declare that, except for reference to other people's work which has been duly acknowledged, this research work consists of my own work produced from research undertaken under the supervision of Dr. Bernard Fei-Baffoe (Department of Theoretical and Applied Biology –K.N.U.S.T.) and that no part has been presented for any degree elsewhere. This report is submitted in partial fulfillment for the award of MSc. (Hons.) Environmental Science.

Daniel Kojo Barikun Yinmarah
(Student's Name)	Signature	Date

Dr. Bernard Fei-Baffoe
(Supervisor's Name)	Signature	Date

Rev. Stephen Akyeampong
(Head of Department)	Signature	Date

ACKNOWLEDGEMENT

First and foremost, I give thanks to God Almighty who provided the life, strength, and academic enthusiasm needed to undertake this project to this end.

I also thank my project supervisor, Dr. Bernard Fei-Baffoe and other lecturers at the Biological Science Department of K.N.U.S.T, whose technical expertise in co-composting organic waste and sewage sludge as a waste management option and tireless contributions ensured the success of the work.

I also want to use this opportunity to express my gratitude to my dear wife, Ruth Baloroo Yinmarah, for her support and understanding during the entire period that this noble academic exercise was undertaken.

Last but not least; I thank the staff of the Health, Safety and Environment department of Chirano Gold Mines Limited (CGML) for all the assistance they offered me throughout this academic exercise. In addition, I thank my colleagues in the clinic for all the constructive advice and criticisms.

ABSTRACT

The study investigated the ratios of organic solid wastes and dewatered sewage sludge that were appropriate for producing a good compost as a management option for reducing waste at Chirano Gold Mines Ltd. Chirano Gold Mines Ltd produces on a daily bases an average of 1300 kg of solid wastes (of which about 65% is compostable). And sewage sludge is produced on a daily bases from a Sewage Treatment Plant (STP) on site. Grab sample of organic solid waste was collected from the dump site. Dewatered Sewage sludge was also collected from the sewage treatment plant (STP). Sanitary pads and other objects were removed from it. The organic wastes were shredded and mixed uniformly using a cutlass and a shovel. Sample was taken to laboratory for physicochemical and biological parameters as well as heavy metals. Based on the results, the feedstock (organic solid waste and dewatered sewage sludge) were mixed according to volume-to-volume ratio and piled in a shape of a cone. These were 1:0; 1:1; 2:1; 3:1 and 0:1 (organic solid waste/ dewatered sewage sludge). Temperature of each pile was measured daily over the entire composting period. At the end of the study, the concentrations of all the heavy metals analyzed were within normal international standards. All the piles produced at the end of the composting period were sanitized for use except the pile with 0:1 ratio (organic solid waste/ dewatered sewage sludge) which could not attain the right thermophilic temperature for the destruction of pathogens present in the composting material due lack of readily degradable carbon and poor aeration. The highest mean temperature was attained by pile 3:1 (organic solid waste/ dewatered sewage sludge) with a temperature of 63°C. Statistically, there were significant differences in all the treatments (compost piles) in the final compost for Nitrogen, Potassium and Phosphorus which are very important in compost. Piles A (1:0), B (1:1), C (2:1), D (3:1) and E (0:1) ended with $(1.61 \pm 0.07) \%$, $(2.59 \pm 0.13) \%$, $(2.03 \pm 0.24) \%$, $(2.94 \pm 0.45) \%$ and $(3.08 \pm 0.16) \%$ respectively for Nitrogen.

TABLE OF CONTENTS

DECLARATION-----	ii
ABSTRACT -----	iv
TABLE OF CONTENTS -----	v
LIST OF TABLES -----	ix
LIST OF FIGURES-----	x
ACRONYMS -----	xii

CHAPTER ONE ----- 1

1.0 INTRODUCTION ----- 1

1.1 Background -----	1
1.2 Problem Statement/ Justification-----	3
1.3 Objectives -----	4

CHAPTER TWO ----- 5

2.0 LITERATURE REVIEW ----- 5

2.1 Solid Waste -----	5
2.2 Problems of Solid Waste Management -----	7
2.2.1 Rapidly Growing Urban Population-----	7
2.2.2 Lack of Finances and Infrastructures -----	8
2.2.3 Waste Composition-----	10
2.2.4 Health Problems-----	11
2.2.5 Environmental Problems-----	13
2.2.6 Institutional Problems -----	16
2.3 Integrated Solid Waste Management -----	17
2.3.1 Reduction in Waste Generation -----	19
2.3.2 Reuse and Repair-----	20
2.3.3 Recycle -----	21
2.3.4 Incineration -----	22
2.3.5 Sanitary Landfills -----	24
2.3.6 Composting -----	25

2.4	Co-Composting as a Waste Management Option -----	28
2.4.1	What is Composting?-----	29
2.4.2	Anaerobic Composting-----	30
2.4.3	Aerobic Composting-----	30
2.4.4	Vermicomposting -----	32
2.5	Limiting Factors of Composting -----	32
2.5.1	The Biological Processes -----	32
2.5.2	The Chemical Properties -----	34
2.5.3	The Physical Properties -----	40
2.5.4	Others -----	42
2.6	Compost Quality -----	43
 CHAPTER THREE -----		46
3.0 MATERIALS AND METHODS -----		46
3.1	Study Area -----	46
3.2	Waste Collection and Characterisation -----	47
3.3	Feedstock Formulation for Composting -----	48
3.4	Sampling and Monitoring of Compost Piles -----	50
3.4.1	Sampling and Analysis -----	50
3.4.2	Monitoring Temperature (T) -----	50
3.4.3	Determination of moisture content (MC) and Total Solids (TS)-----	50
3.4.4	Determination of Total Organic Matter (OM) and Ash Content -----	51
3.4.5	Determination of Total Nitrogen -----	52
3.4.6	Monitoring of volumetric Change of Compost Piles -----	53
3.4.7	Determination of pH-----	54
3.4.8	Electrical Conductivity (EC) Determination -----	54
3.4.9	Determination of Potassium -----	55
3.4.10	Determination of Phosphorus -----	57
3.4.11	Calcium Determination -----	58
3.4.12	Determination of Magnesium -----	59
3.4.13	Total and Faecal Coliform determination -----	59

3.4.14	<i>E. coli</i> (Thermotolerant Coliforms) determination	60
3.4.15	Heavy metals determination	60
3.5	Statistical Analysis	61
CHAPTER FOUR		62
4.0 RESULTS		62
4.1	Waste Characterization	62
4.2	Physicochemical Properties, Heavy Metal Content and Biological Properties of piles before Composting	62
4.3	Physicochemical Properties, Heavy Metal Content and Biological Properties of piles after Composting	65
CHAPTER FIVE		80
5.0 DISCUSSIONS		80
5.1	Physicochemical Parameters	80
5.1.1	Temperature	80
5.1.2	pH	82
5.1.3	Moisture content and Total Solids	83
5.1.4	Organic Matter and Ash content	84
5.1.5	Carbon, Nitrogen and Carbon-to-Nitrogen ratio (C/N)	86
5.1.6	Volume of Piles	87
5.1.7	Electrical Conductivity	88
5.1.8	Macronutrients	89
5.1.9	Heavy Metals	90
5.2	Biological Properties	90
CHAPTER SIX		92
6.0 CONCLUSION AND RECOMMENDATION		92
6.1	Conclusion	92
6.2	Recommendations	93
REFERENCES		94
APPENDIX A		105

APPENDIX B -----	106
APPENDIX C -----	107
APPENDIX D -----	108
APPENDIX E-----	109
APPENDIX F-----	110
APPENDIX G -----	111
APPENDIX H -----	112
APPENDIX I -----	113
APPENDIX J -----	114
APPENDIX K -----	115
APPENDIX L -----	116
APPENDIX M-----	117
APPENDIX N -----	118
APPENDIX O -----	118
APPENDIX P-----	118
APPENDIX Q -----	119
APPENDIX R -----	119
APPENDIX S -----	119
APPENDIX T-----	120
APPENDIX U -----	120
APPENDIX V -----	120
APPENDIX W-----	121
APPENDIX X -----	121
APPENDIX Y -----	121
APPENDIX Z-----	122
APPENDIX AB -----	122

LIST OF TABLES

Table 2.1:Some organic materials used for composting and their corresponding Nitrogen content and Carbon-to-Nitrogen (C/N) ratios-----	36
Table 2.2:Permissible metal ranges in compost for EC states and USA -----	44
Table 2.3: The main constituents of nutrients in a matured compost -----	45
Table 3.1: Material Formulation for Composting-----	48
Table 4.1:Mean results of initial physicochemical parameters in each pile before Composting.....	63
Table 4.2:Mean results of initial Metal content in each pile before composting. -----	64
Table4.3:Mean results of initial content of biological parameters (Coliforms and E. coli) in each pile before composting. -----	65
Table 4.4:Mean results of physicochemical parameters in each pile at the end of the composting period -----	75
Table 4.5:Mean results of Metal content in each pile at the end of the composting Period -----	76
Table 4.6:Mean results of content of biological parameters (Coliforms and E. coli) in each pile before and after the composting period with percentage reduction (-) or increase (+)-----	77

LIST OF FIGURES

Figure 2.1: Global landfill methane emissions in 2000-----	14
Figure 3.1: Location Map of project in Ghana -----	47
Figure 3.2: The shape of the compost heap indicating parameters measured for pile volume calculations.....	54
Figure 4.1:Weekly mean pH in the different compost piles of Organic Solid Waste/ Dewatered Sludge -----	66
Figure 4.2:Weekly mean Moisture content (%) in the different compost piles of Organic Solid Waste/ Dewatered Sludge -----	67
Figure 4.3:Weekly mean Total Solids (%) in the different compost piles of Organic Solid Waste/ Dewatered Sludge -----	68
Figure 4.4:Weekly mean Ash content (%) in the different compost piles of Organic Solid Waste/ Dewatered Sludge -----	69
Figure 4.5:Weekly mean Organic Matter content (%) in the different compost piles of Organic Solid Waste/ Dewatered Sludge -----	70
Figure 4.6:Weekly mean Organic Carbon content (%) in the different compost piles of Organic Solid Waste/ Dewatered Sludge -----	71
Figure 4.7:Weekly mean Carbon- to-Nitrogen ratio (C/N) in the different compost piles of Organic Solid Waste/ Dewatered Sludge -----	72
Figure 4.8:Weekly mean Magnesium (Mg) content (%) in the different compost piles of Organic Solid Waste/ Dewatered Sludge.-----	73
Figure 4.9:Weekly mean Changes in Volume in the different compost piles of Organic Solid Waste/ Dewatered Sludge. -----	74
Figure 4.10:Temperature profile of each pile with respect to time (days) -----	79

LIST OF PLATES

Plate 3.2:	Shed for Housing of Compost Piles-----	49
------------	--	----

ACRONYMS

AOAC	Association of Official Analytical Chemists
CGML	Chirano Gold Mines Limited
US EPA	United States Environmental Protection Agency
UNEP	United Nations Environment Programme
UNECA	United Nations Economic Commission for Africa
MMTCE	Million Metric Tons of Carbon Equivalent
OMRI	Organic Materials Review Institute
NRAES	Natural Resource, Agriculture and Engineering Service
WHO	World Health Organization
mg/kg	milligrams per kilogram
cm ³	cubic centimeter
<i>E. coli</i>	<u>Escherichia coli</u>
EC	Electrical Conductivity
EC	European Council
<i>SD</i>	Standard Deviation

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Throughout the centuries composting has been an essential part of growing our food. However, since World War II and the advent of large scale farming, the focus on composting has declined. As people are becoming more aware or sensitive to their environment and the foods they consume, the importance of composting is again becoming apparent. Composting at home of yard waste and food scraps is a good beginning in solving the solid waste crisis facing most of our landfills, saves people money, improves the quality of the earth and gives people a simple way to become directly involved in their immediate environment. To be effective, composting at home needs to be part of a “life style” and must be an on-going process (Edwards and Fletcher, 1988). And soil which is much more than simply pulverized rock is teeming with many forms of life, each of which plays a vital role in the overall productivity and quality of the soil. A whole world of animals, plants and microorganisms derive their existence from the decomposition process. Most of the work is done by the decomposer bacteria, molds and fungi. These organisms are even able to release the inorganic forms of some minerals such as potassium and phosphorus by the action of the organic acids they produce. These smaller microorganisms are aided in their work by a group of larger animals known as detritivores. These are the commonly seen, but generally despised bugs, beetles, mites, worms, etc. They eat just about anything, and in the process, break up the materials to expose many more surfaces to the microorganisms. By adding organic materials to the soil, gardeners improve the structure of the soil (better aeration

and moisture retention) and feed the beneficial organisms in the soil (Edwards and Fletcher, 1988).

Compost, which is a dark, crumbly and earthy-smelling form of decomposed organic matter, is much more teeming with several life forms. It is composed of organic material ranging from leaves and wood chips to household refuse. When broken down, these materials become one of nature's best garden fertilizers and richest mediums for potted plants and amendment of oil contaminated soils. It is made up of waste material that is generally high in either carbon or nitrogen. It improves soil water-holding capacity. Compost loosens clay soils and helps sandy soils retain water by binding soil particles together. Adding compost to soil improves the fertility of the latter and stimulates healthy root development in plants. Nutrients in compost provide food for microorganisms, which keep the soil in balanced healthy conditions. Nitrogen, potassium, and phosphorus are produced naturally by the activities of microorganisms. Compost also increases the soil content in compounds of agricultural value (Nitrogen, Sulphur, Magnesium, etc.), which are gradually released than in the case of mineral fertilizer and therefore available to crops for a longer period (Gershuny, 2011). Sewage sludge is a product of sewage treatment and this is rich in nutrient and trace elements which can be used as fertilizer. And because of its high odour emission, high level of heavy metal and toxic compounds and the presence of pathogenic micro-organisms require that it is pre-treated before application in agricultural activities (Tiquia *et al.*, 2002).

The use of sludge for agriculture is the best alternative if the pollutants in the sludge are below the allowable limit. And according to McCarthy (2002) drying, composting and co-composting with other materials can render sludge a usable material for agricultural activities.

According to Strauss *et al.* (2003) co-composting is a term used to describe the composting of a mixture of materials to provide a sustainable and cost effective disposal and re-use method for the co-composted materials. Composting is the controlled aerobic degradation of organics using more than one material (Faecal sludge and Organic solid waste). Faecal sludge has a high moisture and nitrogen content while biodegradable solid waste is high in organic carbon and has good bulking properties (i.e. it allows air to flow and circulate). By combining the two, the benefits of each can be used to optimize the process and the product (United States Composting Council, 2000).

1.2 Problem Statement/ Justification

Putrescible waste (i.e. food scraps) and rubbish are generated by the mine in offices, workshops, laboratories, medical centre, accommodation areas, kitchens and mess areas. Inert industrial wastes (i.e. tires, lumber, steel scraps) are generated through project and operations activities. Potential hazardous wastes are also produced in workshops, laboratories, and the processing plant.

On a daily basis, Chirano Gold Mines Limited, a Kinross Company, generates approximately the following wastes: 19% of paper, 8% of yard trimmings, 36% of food scraps, 16% of plastics, 1% of metals, 4% of textiles, 9% of glass, 2% of wood and others

recorded 5%. Thus approximately 65% of Chirano's wastes generated is compostable since paper, yard trimmings, wood and food scraps are compost materials. Sewage sludge which is very good for composting is also a waste product from the Sewage Treatment Plant operated on the mine site which must be disposed appropriately.

The company's landfill site was decommissioned in June, 2013 as a result of it being filled up. The decomposable portion could be used as composting material to reduce the stress on the newly constructed landfill which could go a long way to reduce the problems associated with landfills such as; the cost involved in constructing new landfills and land use with its attendant issues. Co-composting the organic solid waste and sewage sludge offers a better option for waste management in the mine. The compost produced could be used for bioremediation of oil contaminated soils and land reclamation that is being pursued by the company.

1.3 Objectives

The main objective is to co-compost organic waste and sewage sludge at Chirano mines as a waste management option.

Specific objectives of the project were to:

- i. Conduct baseline analysis on the organic waste and sewage sludge.
- ii. Formulate desired ratios of organic waste and sewage sludge for composting on site.
- iii. Monitor the composting process by measuring some physicochemical parameters.
- iv. To determine the quality of compost produced.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Solid Waste

Solid waste is broadly comprised of non-hazardous domestic, commercial and industrial refuse including household organic waste, hospital and institutional garbage, street sweepings, and construction wastes (Zerbock, 2003). Domestic solid waste includes all solid wastes generated in the community and generally includes food scraps, containers and packaging, discarded durable and non-durable goods, yard trimmings, miscellaneous inorganic debris, including household hazardous wastes (for instance insecticides, pesticides, batteries, left over paints etc., and often, construction and demolition debris. A report prepared by World Bank (1999) lists eight major classifications of solid waste generators:

- Residential: Includes waste generated in household units, such as food and fruit peels, rubbish, ashes etc.
- Industrial: Has two components hazardous, which is toxic; corrosive; flammable; a strong sensitizer or irritant and may pose a substantial present or potential danger to human health or the environment when improperly processed, stored, transported, or disposed of or otherwise managed. Non-hazardous which includes inert and essentially insoluble industrial solid waste, usually including, but not limited to, materials such as rock, brick, glass, dirt, and certain plastics and rubber, etc., that are not readily decomposable
- Commercial: Waste produced by wholesale, retail or service establishments, such as restaurants, stores, markets, theaters, hotels and warehouses.

- Institutional: Waste that originates in schools, hospitals, research institutions and public buildings.
- Construction and demolition: Waste building material and rubble resulting from construction, remodeling, repair, and demolition operations on houses, commercial buildings, pavements and other structures
- Municipal services: Sludge from a sewage treatment plant which has been digested and dewatered and does not require liquid handling equipment etc.
- Process: Treatment plant wastes principally composed of residual sludge and
- Agricultural: Spoiled food wastes, agricultural wastes, rubbish, hazardous wastes.

In a developed country framework the waste generated from different sectors are generally treated separately while, in developing countries separate treatment of wastes generated from different sectors is usually not undertaken (Chakrabarti and Sarkhel, 2003). Improper handling and disposal of solid waste has multi-dimensional impact on human and environmental well-being. Improper dumping can lead to pollution of air, soil, and water, contamination of surface and ground water supplies, clogging of drains, creation of stagnant water for insect breeding, floods in the plains and landslides in the hilly areas during rainy seasons. Improper incineration and burning of wastes contributes significantly to urban airpollution; greenhouse gases (GHGs) generated from the landfills and untreated leachate pose threat to human as well as environmental well-being (Hoornweg *et al.*, 1999).

2.2 Problems of Solid Waste Management

2.2.1 Rapidly Growing Urban Population

The problems associated with SWM in a developing country framework are multi-dimensional and more acute when compared to the developed nations (Zerbock, 2003), the severest of them being the rapidly growing population. The growth in population causes tremendous increase in the concentration of population in the urban centers due to migration and immigration of people from rural areas and nearby countries in search of livelihood. The impact of rapidly growing urban population is reflected in two ways:

Growth in waste generation

Several studies have shown that growing urban population leads to huge increase in waste generation (Zerbock and Zurbrugg, 2003). Especially in case of developing country scenario, the rate of waste generation far exceeds the infrastructural provision (Pradhan, 2008).

Growth in slums with no waste management system

Urbanization in the developing nations is accompanied by the expansion of slum areas and the creation of new ones as the migrants usually come from poorer regions and do not have the ability to live in /buy decent housing in the city, which leads to the development of slums. The pressure of ever-growing population on urban infrastructure in many cities overburdens the provision of urban services. Urban municipal governments are under intense pressure to meet the demand for basic services such as water, sanitation and solid waste management (Medina, 2002). Most of the slums grow in an unplanned manner, and the local municipalities are ill prepared to provide basic

facilities (like garbage collection) to the ever growing population. This causes garbage to be dumped in open spaces, leading to disastrous effect on the social, economic and environmental health of the area (Zerbock, 2003); consequently this has resulted in financial and institutional constraints to manage the resulting solid wastes (Chakrabarti and Sarkhel, 2003). Even those enjoying decent housing dump garbage in the open space, due to lack of organized waste collection system.

2.2.2 Lack of Finances and Infrastructures

In a developing country framework, though solid waste management accounts for 20 to 50 per cent of the municipal budget according to Bartone (2000), the service is provided to only about 50 per cent of the urban population; actual collection only accounts for around 60 to 70 per cent of the refuse (Khawas, 2003). For instance, Latin American countries were generating approximately 275,000 tons of solid waste per day in urban areas, necessitating a fleet of 30,000 trucks and 350,000 m³ of land a day to properly collect and dispose the waste (Chakrabarti and Sarkhel 2003). The insufficiency of services results in the deterioration of the urban environment in the form of water, air, and land pollution; which not only poses risks to human health but to the environment as well (Medina, 2002). Another impact of the increasing population is the creation of a vicious cycle of pollution. Rise in population is not met by equal increase in infrastructural facilities, which leads to increase in the filth and garbage. As filth gets accumulated, less and less number of inhabitants are willing to pay for the retrieval services leading to loss of revenue to the municipality and further deterioration of the quality of services rendered (Zerbock, 2003). The impact of deteriorating services are

directly felt, as there is visible increase in waste being dumped right beside the human habitats, which causes tremendous risk to both environment and human health. The present situation is expected to deteriorate even more due to rapid unchecked urbanization and growth in human population (Zurbrugg, 2003).

Lack of finances and infrastructure has multi-level impacts. Nowhere are these impacts more evident than in the case of waste disposal. In most of the developing countries the main disposal method for solid waste is open dumping; more often than not the dumping sites are very near to areas of human habitation (Medina, 2002). Little care is given to the status of water table, water pollution and emission of hazardous and toxic gases. The disposal of hazardous, biomedical, or slaughter house wastes are rarely controlled and in very few cases certain sections of the dumping grounds are designated for slaughter house and biomedical wastes (Inanc *et al.*, 2004). Illegal disposal of wastes in water bodies is a common practice that not only causes toxins to get dispersed in the environment (Hoornweg *et al.*, 1999, Zurbrugg, 2003) but also often ends up coagulating the water.

The infrastructural problems are not just confined to waste disposal. Frequently, developing countries lack facilities for proper handling, collection and transportation of the generated wastes. Inadequate planning and layout due to rapid urbanization causes urban centers in the developing countries to be more congested and populated. Often the waste collection trucks cannot reach every part of the town, compelling the residents to throw their garbage in open dumping spaces near human settlement. Congestion of traffic

makes transportation of waste more time consuming and as a result more expensive and less efficient (Zerbock, 2003). Another problem associated with handling of waste relates to lack of “standardized containers” to store waste before being picked up causing the wastes to be infested by animals, pests or blown out in the street (Zerbock and Zurbrugg, 2003). In many towns in India, there is no “standardized container” to store waste; old oil cans are used to store wastes, before dumping it into nearby jhoras (small streams). Lack of proper transportation vehicles for waste also adds to the problem. For instance in Kumasi, Ghana, the municipality uses open trucks to transport waste and often some portion of waste ends up being dropped on the road during transportation. Most of the vehicles used for transporting wastes are often outdated, improper and non-functional. Zerbock (2003) points out that the vehicles used for transporting wastes in developing countries do not function efficiently and often break down, thus adding further to the problem.

2.2.3 Waste Composition

One of the most significant differences between the waste generated in developed and developing nations is in terms of its composition. The wastes generated in developed countries are mainly inorganic in nature, whereas organic contents form a large portion of waste in developing countries (Hoornweg *et al.*, 1999; Medina, 2002; Zerbock, 2003 and Zurbrugg 2003). In the developing country scenario, the proportion of organic contents in waste is almost three times higher than that in developed countries (Medina, 2002 and Zerbock, 2003). Even though the volume of waste generated in developing countries is much lower as compared to that in developed countries, the nature of waste is denser and has very high humidity content (Hoornweg *et al.*, 1999; Medina, 2002; Zerbock, 2003

and Zurbrugg, 2003). The nature and composition of waste is highly dependent on income and lifestyle of the population. Being highly organic and humid in nature, solid waste management in developing countries presents both opportunities and constraints that are entirely different than the developed countries (Hoornweg *et al.*, 1999; Zurbrugg 2003 and Inanc *et al.*, 2004).

2.2.4 Health Problems

Serious public health problems arise due to uncollected solid waste. This uncollected waste could be the source of many infectious diseases including water borne diseases such as cholera and dysentery (Mark, 1995). Such incidence of diseases puts additional burden on the scanty health services available in resource poor developing countries. Insect and rodent vectors are attracted to the waste and one may recall that as many as 200,000 people had to flee after the outbreak of pneumonic plague in Surat in Western India in 1994 (Pradhan, 2008). The outbreak is attributed to the uncontrolled fermentation of wastes which created favorable conditions for the breeding and growth of rodents and insects that acted as vectors of diseases (Venkateshwaran, 1994). A similar study by world health organization observed in 1994 that 616,960 cases of cholera resulting in 4389 deaths were reported in Angola, Malawi, Mozambique and Tanzania (UNECA, 1996) which can be linked to the fact that in Northern Africa as much as 20 to 80 per cent of urban solid wastes are dumped in open spaces (Chakrabarti and Sarkhel 2003). Contamination of ground water by disease causing organisms from water seeping through dumps is likely to include the viruses of hepatitis, poliomyelitis and gastroenteritis (Medina, 2002); thus such water contamination may have long run health effects apart

from dysentery and cholera. In US, the Public Health Service identified 22 human diseases that are linked to improper solid waste management (Hoornweg *et al.*, 1999). The most immediate health threat due to solid waste in developing countries is to the waste workers, rag pickers and scavengers. Waste workers and rag pickers in developing countries are seldom protected from direct contact and injury. The co-disposal of hazardous and medical wastes with municipal wastes pose serious health threat. Exhaust fumes from waste collection vehicles, dust stemming from disposal practices, and open burning of waste also contribute to overall health problems (Hoornweg *et al.*, 1999).

The magnitude of the health problems due to solid waste in case of developing countries are particularly alarming where the proper collection and disposal of solid waste is impeded by paucity of funds and technological capacity. The areas, which are not serviced, are left with clogged sewers and litters which create serious health problems for the resident population (Khawas, 2003). Crowding and unsanitary conditions are important amplifiers of the transmission of infectious diseases. Many infectious diseases thrive where there is a lack of water, and inadequate drainage, sanitation and solid waste removal (McMichael, 2000). In a report prepared for the World Health Organization (WHO), Chang *et al.*, (2001) recognized seven different ways, through which pollutants can transport back to affect human health.

Waste soil human.

Waste soil plant human.

Waste soil plant animal human.

Waste soil atmosphere human.

Waste soil surface runoff surface water human.

Waste soil vadose zone groundwater human.

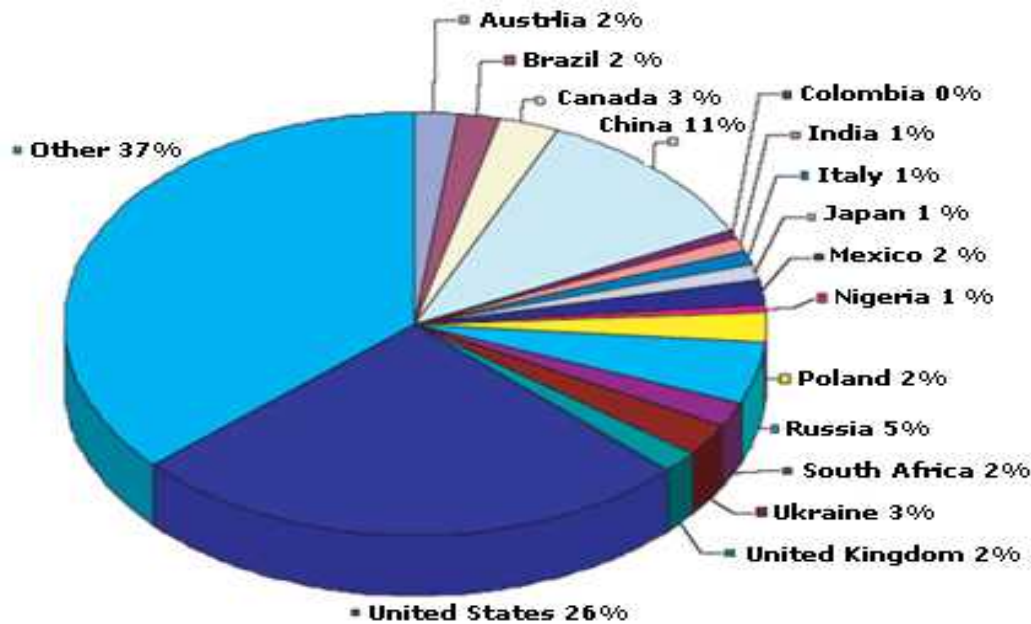
Waste soil animal human, waste soil airborne particulate human

Hence, we find that in case of improper handling waste will eventually move back into the system and cause further harm to human health through the biomagnifications of toxins.

2.2.5 Environmental Problems

The impacts of solid waste on the environment are immense, from release of harmful greenhouse gases to contamination of ground water. The most serious environmental problem in terms of solid wastes is the emission of greenhouse gases. According to Thorneloe *et al.* (2002), the waste management sector represents 4% of total anthropogenic greenhouse gas emissions and landfills contribute the largest anthropogenic source of methane, contributing 90% to the total greenhouse gases released from the waste sector in the United States (Pradhan, 2008). Methane is a primary constituent of landfill gas and a potent greenhouse gas when released to the atmosphere. Landfill gas is created as a natural byproduct of decomposing organic matter, such as food and paper disposed of in these landfills and it consists of about 35-50 % methane (CH₄) and 35-50 % carbon dioxide (CO₂), and a trace amount of non-methane organic compounds. Each day millions of tons of municipal solid waste are disposed of in sanitary landfills and dump sites around the world. According to Methane to Markets Partnership, website (2004); “globally, landfills are the third largest anthropogenic (human influenced) emission source, accounting for about 13 percent of global methane

emissions or over 223 million metric tons of carbon equivalent” (MMTCE). The status of solid waste management system thus considerably influences the problems associated with climate change and global warming. Figure 2.1 identifies some of the countries with significant methane emissions from landfills.



Source: Methane to Markets Partnership 2004.

Figure 2.1: Global landfill methane emissions in 2000

It is to be noted that global landfill methane emissions are more prevalent in developed countries as compared to the developing countries. Further, it has been observed that the major factors driving landfill gas emission levels are the amount of organic material deposited in landfills, the type of land filling practices, and the extent of anaerobic decomposition (Jokela *et al.*, 2002). The higher the organic content, the higher is the level of methane emission; considering the fact that the wastes generated in developing nations

have high organic content, the potential for environmental damage is immense. Although methane can be trapped and used as alternative energy source (Jokela *et al.*, 2002), the lack of technology and finance impedes the trapping of methane in the developing nations. Besides the emission of greenhouse gases, solid waste cause ground and surface water contamination; as water filters through any material, chemicals in the material may dissolve in the water, this process is called leaching and the resulting mixture is called leachate (McMichael, 2000).

As water percolates through solid waste, it makes a leachate that consists of decomposing organic matter combined with iron, mercury, lead, zinc, and other metals from rusting cans, discarded batteries and appliances. It may also contain insecticides, cleaning fluids, paints, pesticides, newspaper inks, and other chemicals. Contaminated water can have a serious impact on all living creatures, including humans, and the ecosystem as a whole. Generally in developing countries, dump sites are managed by indiscriminately burning the wastes. Burning causes heavy metals like lead, toxic gases and smoke to spreads over residential areas. The wind also carries waste, dust and gases caused by decomposition. Air pollution due to burning of waste and spreading of toxic fumes causes large number of damage to both environment and human health (Medina, 2002). Putrefaction of waste in sunlight during daytime results in bad smells and reduced visibility and it ruins the ambience of the place.

2.2.6 Institutional Problems

The most serious impediment for a sustainable solid waste management is that, there is a wide range of individuals, groups and organizations that are involved with waste as service users, service providers, intermediaries and/or regulators (Zerbock, 2003). The interests, agendas and roles of these actors form a complicated web, which defines and designs the prevalent waste management system in any developing nation (Piccinin *et al.*, 1996). Collection and disposal of refuse within an urban area has been traditionally perceived as the responsibility of the local municipal government (formal public sector). However, in a developing country scenario the provision of waste management system by the local government is generally inadequate, centralized, top-down and in most cases inefficient (Cointreau, 1982). Following which, many developing nations have a dynamic informal sector that has evolved around wastes, which supports the livelihood of a large number of the urban poor. The most common occupations are informal refuse collection and scavenging, which are undertaken by unemployed, women, children, recent migrants, etc for their sustenance and livelihood (Medina, 2002). The informal sector consists of many “actors” such as waste-pickers, itinerant-buyers, small scrap dealers, and wholesalers. In India, the informal sector is attributed with recycling about 10–15% of the solid waste generated in the cities (Piccinini *et al.*, 1996). Though a formal private sector (private companies dealing with all aspects of waste management) is emerging strongly in many developing countries, for instance Zoom lion in Ghana, however, it is yet to be an alternative to the current formal public sector. In many cases it has been seen that private sectors are generally motivated by the idea of profit maximization; the poorer section of the society in many developing countries lack the financial resources to

subscribe to the services provided by private waste management companies (Piccinini *et al.*, 1996). The interactions between these formal and informal sectors design the existing waste management system in most of the developing countries. The economic well-being of the general public in developed countries allows the formal sector to operate without much glitz. However, a large section of population in the developing countries cannot afford to subscribe to the services of the formal sector, which undoubtedly will require some financial contribution for the services rendered (Pradhan, 2008).

2.3 Integrated Solid Waste Management

Given the huge complexity of issues and problems in various solid waste management systems across developing nations, it is apparent that the top-down solutions and management strategy will no longer be effective. Rather, a much broader and more integrated set of solutions will be needed to ensure long term sustainability of the waste management system. In the developed countries the most compatible environmentally sustainable development approach to waste is the “Integrated Waste Management” (Cole and Sinclair 2002; Medina, 2002 and Zerbock, 2003). An integrated approach to waste management consist of a hierarchical and coordinated set of actions (Medina, 2002) that seek to reduce pollution, maximize recovery of reusable and recyclable materials, and protects human health and the environment. It will take into account community and region specific issues and needs and formulate an integrated and appropriate set of solutions unique to each context (Daskalopoulos *et al.*, 1998; Medina, 2002 and Zerbock, 2003). According to Medina (2002), the integrated waste management aims to be socially desirable, economically viable and environmentally sound. In case of solid waste

management in a developing country framework, it is to be noted that solutions which work for some countries or areas may not be appropriate or applicable for others. Specific issues, problems, environmental conditions and existing socio-economic framework will determine the appropriateness of various strategies and technologies in solving the problem of solid waste. However, various studies on solid waste issues bring about possibilities of certain approaches as being at least adaptable to many developing country scenarios. The main emphasis is on the four R"s – reduce, reuse, repair and recycle (creation of less waste and increased material recovery) and finding appropriate disposal options (Medina, 2002 and Zerbock, 2003). Zerbock (2003) lists out a series of questions as developed in the International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management that needs to be asked while developing or evaluating integrated solid waste management plan or framework:

- Is the proposed technology likely to accomplish its goals given the financial and human resources available?
- What option is the most cost-effective in financial terms?
- What are the environmental costs and benefits?
- Is the project feasible given administrative capabilities?
- Is the practice appropriate in the current social and cultural environment?
- What sectors of society are likely to be impacted and in what way are these impacts consistent with overall societal goals?

Source: Zerbock (2003).

The answers to these questions are critical and will contribute immensely towards the understanding of the existing problems and societal framework and will allow the researcher to derive appropriate solutions in the given setting.

2.3.1 Reduction in Waste Generation

“Prevention is better than cure”, so goes an old adage, and it is one of the best method to deal with the problem of solid waste. By preventing (or reducing) the generation of waste itself, we can minimize other problems (namely, disposal) related to waste to a great extent. In order to reduce waste generation several methods or tool can be applied, some of which may be:

- Enacting public policies that discourage the production, sale and consumption of products containing unnecessary packaging material. Places where flow of products cannot be controlled, appropriate policy measures (extended producers responsibility, taxes, economic incentives etc.) should be put in place to discourage unnecessary waste generation. Policies should also look into the aspect of encouraging reusable and recyclable products instead of disposable products (Medina, 2002).
- Promotion of locally grown products and less reliance on packaged food products go a long way in reducing wastes.
- Education can also play a critical role by creating awareness regarding the waste and related issues among the public.

In a developing country framework, reduction in waste generation should be targeted towards producers; because of excessive packaging, more waste is created. From the consumers side, reduction in waste can be generated by educating the consumers on ways to prevent waste; for instance asking the consumers to use a reusable bag for shopping rather than rely on goods being bagged in numerous poly bags, can significantly reduce the use of poly bags which are the main source of waste in numerous developing countries (Pradhan, 2008).

2.3.2 Reuse and Repair

Reusing relates to the recovery of items to be used again. Reusing ensures reduction in raw material consumption, saves energy and water, reduces pollution and prevents the generation of waste. Medina (2002) regards reuse of materials and products as more socially desirable than recycling the same materials. For instance, in India, soft-drinks (Coke, Pepsi etc.) are sold in glass bottles and a deposit-refund system operates. A person deposits some amount of money on purchase of the soft drink, which he/she gets back on depositing the bottle, thus enabling the producer to regulate his supply of container without having to produce new ones. Products, such as office furniture and appliances, can also be reused. For instance Manitoba Hydro donated their old office furniture and building waste to Manitoba eco-network, which was used to build a new office for the network; thus saving both time and valuable resources for both Manitoba Hydro and Eco-network. A reuse program not only saves money, it also can be a source of revenue for the companies/households that implement it. The best example would be interface, which reuses old carpets to produce new ones, thus saving valuable resources and promoting sustainability at the same time. Public policies that provide incentives for businesses and individuals to engage in reuse can have a significant and positive economic and environmental impact (Piccinini *et al.*, 1996; Medina, 2002 and Zerbock, 2003). In a developing country framework, it is to be noted that due to poor economic conditions, repairing and reusing of materials and products is a standard practice, and generally people in the developing countries reuse much more than people living in the developed countries (Medina, 2002).

2.3.3 Recycle

Although recycling is one of the most important aspects of waste management in the developed nations, due to the composition of waste and other factors, recycling may not be much of an option in terms of developing country. Separation of waste materials at the household level is perhaps a universal phenomenon; more so in developing countries where separation of anything valuable is undertaken with care, which prevents valuables and reusable materials from being discarded. The existence of waste pickers, scavengers etc., recover other valuable materials from entering the waste stream. Especially in developing countries, itinerant buyers play a vital role in recovering materials for recycling; they buy every material that has some monetary value, newspapers, plastic bottles, old shoes etc. (Zerbock, 2003). It is however, evident that some improvement in these traditional systems can be brought about. A formalized waste recycling or recovery system supported by local municipality can go a long way in ensuring health safety for the workers, chances of better income for the rag pickers, scavengers and small time merchants dealing with waste (Zerbock, 2003). Recycling waste can be a viable economic option even for some urban cities, where the nature and characteristics of waste is quite similar to the developed nations. In case of waste composition not favoring recycling, other options (recovery, diversion etc.) should be seriously considered. In the event that local municipal governments are unable to provide recycling facility due to lack of funds, private partnerships need to be encouraged and looked into as a viable option (Piccinini *et al.*, 1996; Medina, 2002 and Zerbock, 2003).

2.3.4 Incineration

Incineration is the process of burning of wastes under controlled conditions, usually carried out in an enclosed structure. The main stages of incineration process are:

- Drying and degassing – here, volatile content is evolved (e.g. hydrocarbons and water) at temperatures generally between 100 and 300 °C. The drying and degassing process do not require any oxidizing agent and are only dependent on the supplied heat.
- Pyrolysis and gasification - pyrolysis is the further decomposition of organic substances in the absence of an oxidizing agent at approx. 250 – 700 °C. Gasification of the carbonaceous residues is the reaction of the residues with water vapour and Carbon dioxide at temperatures, typically between 500 and 1000 °C, but can occur at temperatures up to 1600 °C. Thus, solid organic matter is transferred to the gaseous phase. In addition to the temperature, water, steam and oxygen support this reaction (Nelson *et al.*, 2006).
- Oxidation - the combustible gases created in the previous stages are oxidized, depending on the selected incineration method, at flue-gas temperatures generally between 800 and 1450 °C (Nelson *et al.*, 2006).

These individual stages generally overlap, meaning that spatial and temporal separation of these stages during waste incineration may only be possible to a limited extent. Indeed the processes partly occur in parallel and influence each other. Nevertheless it is possible, using in-furnace technical measures, to influence these processes so as to reduce polluting emissions. Such measures include furnace design, air distribution and control engineering (Nelson *et al.*, 2006).

Although incineration has high rate of waste reduction (80-95%), there are many issues that make incineration not so viable an option in developing countries (World Bank,

1999). Solid waste incineration plants tend to be among the most expensive solid waste management options, being highly capital-intensive and require high maintenance costs they may be beyond the reach of many of the lesser developing countries (Medina, 2002). As compared to other solid waste management options, incineration requires comparatively higher technically trained operators, and careful maintenance (World Bank, 1999); which may not be practical or feasible for the developing countries. Besides this, there is a huge environmental hazard component of incineration; generally most of the developing countries are densely populated and any incineration operation near human habitat can pose a great threat to human life and environment because of emissions. Use of scrubbers in incineration can reduce the threat greatly. However, it requires huge financial contribution, which may not be possible for developing countries to bear (Medina, 2002). Another major hurdle towards proper functioning of incinerators in developing countries is the nature and composition of waste, due to high moisture content in waste, the incinerators do not function as efficiently as in developed countries, thus posing extra burden on the exchequer (Zerbock, 2003). According to Medina (2002), in Lagos, Nigeria, incinerators were built at a cost of U.S. \$ 10 million, but because of high moisture content of the wastes, extra fuel had to be added in order to maintain combustion, which significantly increased the cost of incineration process. The result was that the incinerators never operated normally. One was abandoned and the other turned into a community center. Similar experiences have been observed in India, Mexico, the Philippines, Indonesia, and Turkey. Medina (2002) concludes that because of all these reasons, incineration of municipal solid waste is likely to fail in many developing countries.

2.3.5 Sanitary Landfills

A sanitary landfill is a facility designed specifically for the final disposal of wastes, which is marginally better than open dumping; the main difference between a sanitary landfill and open dumping is the amount of engineering, planning and administration involved (Zerbock, 2003). Sanitary landfills minimize the risks to human health and the environment associated with solid wastes (Zerbock, 2003). According to Cointreau (1982), for a landfill to be considered as sanitary four basic premises needs to be fulfilled:

- Full or partial hydro geological isolation through the use of liners to prevent leachate infiltration into the soil and groundwater; collection and treatment infrastructure should be used where leachate is expected to be generated
- Formal engineering preparations with an examination of geological and hydrological features and related environmental impact analysis, waste tipping plan and final site restoration plan
- Permanent control, with trained and equipped staff to supervise construction and use.
- Planned waste emplacement and covering, with waste and soil placed in compacted layers as well as daily and final soil cover to reduce water infiltration and reduce odors and pests.

Sanitary landfills also prevent the underground absorption of methane and may also include other pollution control measures, such as collection and treatment of leachate, and venting or flaring of methane. Production of electricity by burning methane generated from the landfill gases are being undertaken in many developing countries. Currently, over 82 Mega Watts of electricity is generated from landfill gas in Canada (Jackson, 2003), but developing countries still lack the finances to trap the energy source from landfill gases. Sanitary landfills are necessary; for safely disposing wastes that

cannot be prevented, reused, recycled or composted. They mark a dramatic improvement over disposal of wastes in open dumps. Sanitary landfills reduce the threat of environmental pollution and risks to human health as compared to open dumping. However, disposing of all municipal wastes collected at landfills is not desirable from a social, economic, and environmental point of view (Medina, 2002). Sanitary landfills require municipal governments to make significant investments and finding a proper location for a landfill may be a problem. They cannot be constructed near places that are near human residences. However, landfills can help in creating new jobs, reduce pollution and conserve natural resources; hence, diverting the waste from landfills, by reusing, recycling, composting can not only help in extending the life of the landfill, but can also help in generating economic benefits (Medina, 2002 and Zerbock, 2003).

2.3.6 Composting

For a developing country, looking into the waste composition and other socio-economic factors, the best form of waste reduction would be composting. It is a basic low-technology approach. Theoretically the waste of many developing nations would be ideal for reduction through composting, since it contains higher composition of organic material than industrialized countries. Hoornweg *et al.*, (1999) calculated that on an average, urban centers in developing countries have 50% organic content in their waste stream. Early studies conducted by Cointreau (1982), found 78-81% compostable materials in the household waste generated in major cities of Indonesia and Sri Lanka (Bandung and Colombo respectively). In a more recent study conducted by Zurbrugg (2003) found that major Asian cities like, Hanoi, Karachi, Katmandu and many Indian

cities has 68-82% compostable waste content. However, Zerbock (2003) finds it ironic that composting is not widely practiced in the developing countries.

The advantages of composting are numerous; it reduces the amount of waste significantly. It can be used as fertilizer and natural manure for agricultural uses, it also reduces the release of landfill gas emissions considerably and since it is a natural process, it reduces the damage to environment. Besides this, the foul stench covering any waste dump site is basically generated due to the rotting of organic waste, which will be controlled to a great extent if we go for composting instead of allowing the waste to rot (Piccinini *et al.*, 1996; Medina, 2002 and Zerbock, 2003). Zerbock (2003) noted that composting can be undertaken in three levels: Household, community and large scale centralized level (throughout the municipality). Unfortunately, large scale operations have been a dismal failure; owing to huge capital investment required, the need to keep the equipment in working conditions among other reasons. In India, 9 large scale composting plants constructed during 1975-1985 had been shut off by 1996 (Zerbock, 2003; Drescher and Zurbrugg, 2006), the same was true in Brazil where only 18 of the original 54 facilities were in operation (Zerbock 2003). According to Zerbock (2003); Drescher and Zurbrugg (2006), some problems associated with the failure of large scale composting operations may be briefly summarized as:

- Lack of proper technical knowledge regarding composting.
- Lack of market and marketing initiatives.
- Lack of cooperation between composting operations and local municipal government.
- Lack of institutional support.

Generally, composting has been most successful when done at household or community level. Drescher and Zurbrugg (2006) point out the advantages of household or community level (decentralized) composting as follows:

- Small-scale composting can function as a compliment to primary collection process, thus improving the overall performance of the municipal services and has the potential to significantly improve the hygienic conditions within the service area.
- Small-scale composting helps in diverting major proportion of waste generated close to the source of generation; thereby, significantly reducing transportation costs and prolonging the life span of landfills; besides enhancing the recycling activities and final disposal.
- Small-scale composting does not require large investment, and capital requirements can be distributed over long periods of time. This facilitates a stepwise approach towards integrated solid waste management.
- Due to their smaller size and location, small-scale composting projects are more flexible in management and operation.
- As composting is mainly labor intensive; composting schemes can be a source of employment particularly for poor and underprivileged people in the neighbourhood/community.
- Finally, decentralized composting activities and the interaction between residents in issues of waste handling, hygiene, cleanliness and environment can significantly enhance environmental awareness in a community.

In a developing country framework household-level composting has the greatest potential for success, as most of the urban centers are surrounded by small/large scale agriculture in abundance (Drescher and Zurbrugg, 2006). Selection of site for composting can be a key factor in determining the success or failure of the project. The role of education cannot be ignored, as education is the key to promoting awareness regarding the advantages of composting at household or local level (Medina, 2002). Many people do not indulge in composting due to their concern for possible disease, odors, and pest problems. Hence, the role of education should be focused towards spreading awareness regarding the possibilities of composting and how it can be done properly (Medina, 2002).

2.4 Co-Composting as a Waste Management Option

Waste management is all about how to dispose of all the things you don't want on the farm. Composting is a sustainable waste management practice among all the waste management practices discussed above that converts any volume of accumulated organic waste into a usable product. When organic wastes are broken down by microorganisms in a heat-generating environment, waste volume is reduced, many harmful organisms are destroyed, and a useful, potentially marketable, product is produced (Rodale, 1971). Organic waste may include manure from livestock operations, animal bedding, and yard wastes, such as leaves and grass clippings, and even kitchen scraps.

2.4.1 What is Composting?

Composting is the art and science of mixing various organic materials in a pile, monitoring the resultant biological activity and controlling conditions so that the original raw substances are transformed into stable humus. This process of humification is a combination of biochemical degradation and microbial synthesis. Composting is a form of aerobic digestion or controlled fermentation and differs markedly from anaerobic breakdown or putrefaction (Gershuny, 2011). The compost produced is a microbe-laden substance that inoculates the soil with diverse beneficial organisms (Haug, 1994). It is a source of organic matter as well as carrying a modest mineral fertilizer value. Composting offers the following advantages in addition to other benefits:

- It stabilizes the volatile nitrogen fraction by fixing it into organic forms (usually the bodies of microbes).
- It allows the use of materials that may be toxic to soil organisms such as cannery wastes or that will steal nitrogen if applied raw such as sawdust.
- It permits an even distribution of trace minerals, avoiding the problems of spot imbalances.
- It eliminates most objectionable odors created by bacterial action on sulphur and nitrogen compounds.
- It reduces volume of wastes and therefore the number of trips over the landfill.
- It eliminates most pathogens, weed seeds thermally and reduces the presence of human pathogens.
- The final product is easy to store and handle, and is versatile in its applications.
- Composts have shown to offer significant anti-fungal disease benefits. (Gershuny,2011)

2.4.2 Anaerobic Composting

The local landfill offers a prime example of anaerobic composting. This type of compost generally takes two to three years to produce a usable product. Anaerobic composting requires that you put your compost material in a pile and let it stand (Basnayake, 2001). This type of composting results in a foul-smelling odour because the organic materials get broken down into carbon dioxide and methane, according to the United States Environmental Protection Agency (1995).

2.4.3 Aerobic Composting

Aerobic composting requires more physical work than anaerobic composting but does not produce the same foul stench (Rynk *et al.*, 1992). This type of composting requires keeping the ratio of high-carbon and high-nitrogen material levels equal and turning the pile on a daily basis. Turning the pile daily will result in usable compost in about four weeks, while turning the pile weekly or biweekly will result in usable compost in one to three months, according to the Natural Resources Conservation Service. When turning an aerobic compost pile you will notice hot temperatures coming from the compost pile. These temperatures can reach up to 71 degrees Celsius (Cambardella *et al.*, 2003).

Under aerobic composting we can have windrow and aerated static pile as well as in-vessel composting. The windrow system of composting involves turned windrows and passively aerated windrows. With turned windrows, the materials for composting are arranged in long rows called windrows, with a width of about 3 to 6 meters and a height of 1.5 meters. The windrows are aerated by turning periodically (NRAES, 1992). With

the passively aerated windrows, the need for turning is eliminated by supplying air to the composting material with the aid of perforated pipes embedded in the windrows. Here the composting material is mixed thoroughly because the windrows are not turned after being formed (Strauss *et al.*, 2003).

The aerated static pile method takes the piped aeration system a step further, using a blower to supply air to the composting materials. The blower provides direct control of the process and allows larger piles. No turning or agitation of the materials occurs once the pile is formed. When the pile has been formed properly and where the air supply is sufficient and the distribution uniform, the active composting period is completed in about three to five weeks. With the aerated static pile technique, the raw material mixture is piled over a base of wood chips, chopped straw or other very porous material. The porous base material contains a perforated aeration pipe. The pipe is connected to a blower, which either pulls or pushes air through the pile (NRAES, 1992).

In-vessel composting refers to a group of methods that confine the composting materials within a building, container or vessel (NRAES, 1992). In-vessel methods rely on a variety of forced aeration and mechanical turning techniques to accelerate the composting process. Many methods combine techniques from the windrow and aerated pile methods in an attempt to overcome the deficiencies and exploit the attributes of each method (Bardos *et al.*, 1996).

2.4.4 Vermicomposting

Vermicomposting requires placing red worms into a compost pile. This type of composting is ideal for smaller composting arrangements. Vermicomposting's optimal temperatures are between 13 and 25 degrees Celsius, according to the Environmental Protection Agency, making this type of composting indoor friendly. Vermicomposting takes less work than aerobic composting, but you must prepare worm bedding and monitor the conditions of the compost to keep your worms alive and working. (US EPA, 1995).

2.5 Limiting Factors of Composting

The composting period is governed by a number of factors including, temperature, moisture, oxygen, particle size, the carbon-to-nitrogen ratio and the degree of turning involved. Generally, effective management of these factors will accelerate the composting process. These factors contribute to the success of the composting process. Understanding the processes involved is necessary for making informed decisions when developing and operating a composting program. These processes are biological, chemical and physical (O'Leary, 1999).

2.5.1 The Biological Processes

Peak performance by microorganisms requires that their biological, chemical and physical needs are maintained at ideal levels throughout all stages of composting. Microorganisms such as bacteria, fungi and actinomycetes play an important or active role in decomposing the organic materials (Rodale, 1960). Larger organisms such as

insects and earthworms are also involved in the composting process, but they play a less significant role compared to the microorganisms (Rynk, 1992).

As microorganisms begin to decompose the organic materials, the carbon in it is converted to by-products like carbon dioxide and water and humic end product, compost. Some of the carbon is consumed by the microorganisms to form new microbial cells as they increase in their population (O'Leary, 1999). Heat is released during the decomposition process.

Microorganisms have preferences for the type of organic materials they consume. When the organic materials they require are not available, they may become dormant or die. In this process, the humic end products resulting from their metabolic activity of one generation or type of microorganism may be used as a food or energy source by another generation or type of microorganism (O'Leary, 1999). This chain of succession of different types of microbes continues until there is little decomposable organic material remaining. At this point the organic material remaining is termed compost. It is made up largely of microbial cells, microbial skeletons and by-products of microbial decomposition and under composed particles of organic and inorganic origin (Alen, 2001).

Microorganisms are key in the composting process (O' Leary, 1999). If all conditions are ideal for a given microbial population to perform to its maximum potential, composting will occur rapidly. Thus the number and kind of microorganism are generally not a limiting environmental factor in composting non-toxic agricultural materials, yard

trimmings or municipal solid wastes, all of which usually contain an adequate diversity of microorganism (Bajsa *et al.*, 2004). However, a lack of microbial populations could be a limiting factor if the feed stock is generated in a sterile environment or is unique in chemical composition and lacks a diversity of microorganism (Buyuksonmez *et al.*, 1999).

2.5.2 The Chemical Properties

The chemical environment is largely determined by the composition of material to be composted. Several factors determine the chemical environment for composting especially: the presence of an adequate carbon (food)/energy source, adequate oxygen, a balance amount of nutrients, the correct amount of water, appropriate pH and the absence of toxic constituents that could inhibit microbial activity (Bertoldi, 1983).

Carbon (Energy Source)/ Nitrogen

Microorganisms in the compost process are like microscopic plants; they have more or less the same nutritional needs (nitrogen, phosphorus, potassium and other trace element). There is one important exception however; compost microorganisms rely on the carbon in organic materials as their carbon/ energy source instead of carbon dioxide and sunlight, which is used by higher plants (O'Leary, 1999).

Nitrogen is another important element during composting. While microorganisms require carbon for energy, nitrogen is required for protein synthesis for building structure in order to facilitate effective microbial decomposition during composting (Nelson *et al.*, 2006). Thus carbon to nitrogen ratio in a compost material is a critical factor in composting. A

ratio of 20:1 or less is acceptable for matured compost and the initial carbon to nitrogen ratio determines the quality of the compost and the end of the composting period (Hadas and Portnoy, 1994). Decomposition takes longer, however, when the initial Carbon to Nitrogen ratio is much above 30 (Nattipong and Alissara, 2006).

The carbon contained in natural or human-made organic materials may or may not be bio-degradable. The relative ease with which a material is biodegraded depends on the genetic makeup of the microorganism present and the makeup of the organic molecule that the organism decomposes (Edriss *et al.*, 2006). For example many types of microorganisms can decompose the carbon in sugar but far fewer types can decompose the carbon in lignins (wood fibers) and the carbon in plastics may not be biodegradable by any microorganism (De Bertoldi *et al.*, 1982). But most municipal and agricultural organic and yard trimmings contain adequate amounts of biodegradable forms of carbon and carbon is typically not a limiting factor in the composting process (Sinha, 2009).

Table 2.1: Some organic materials used for composting and their corresponding Nitrogen content and Carbon-to-Nitrogen (C/N) ratios

Material	Nitrogen (% of Total Weight)	Ratio of Carbon to Nitrogen (C:N)
Blood	10-14	3:1
Bone Meal		3.5:1
Cabbage	3.6	12:1
Carrot	1.6	27:1
Fish scrap	6.5-10	5.1:1
Lawn clippings (young)	4	12:1
Manure (farmyard)	2.15	14:1
Manure (poultry)	6.3	15:1
Meat scrap	5.1	
Newspaper	0.05	812:1
Pepper	2.6	15:1
Seaweed	1.9	19:1
Sewage (fresh)		11:1
Slaughterhouse waste	7-10	2:1
Sawdust (raw)	0.11	511:1
Soybean meal		5:1
Tomato	3.3	12:1
Urine	15-18	0.8:1
Vegetables (non-legume)	2.54	11-19:1
Wheat straw	0.3	128:1

Source: (Rodale and staff, 1960).

Nutrients

Among the plant nutrients (nitrogen, phosphorus and potassium), nitrogen is of greatest concern because it is lacking in some materials (O’Leary, 1999). The other nutrients are usually not a limiting factor in municipal solid waste or yard trimmings feed stocks. The ratio of carbon to nitrogen is considered critical in determining the rate of decomposition (Nattinpong and Alissara, 2006). Carbon to nitrogen ratios however can often be

misleading. The ratio must be established on the basis of available carbon rather than total carbon. In general, an initial ratio of 30:1 carbon to nitrogen is considered ideal. Higher ratios tend to retard the process of decomposition while ratios below 25: 1 may result in odour problems. Typically, carbon to nitrogen ratios for yard trimmings range from 20-80:1, wood chips 400 – 700: 1, manure 15 – 20:1 and municipal solid waste 40-100: 1 (Gershuny, 2011). As the composting process proceeds and carbon is lost to the atmosphere, this ratio narrows. Finished compost should have ratios of 15-20: 1.

To lower the carbon to nitrogen ratios, nitrogen-rich materials such yard trimmings, animal manures or biosolids are often added. Adding partially decomposed or composted materials (with a lower carbon to nitrogen ratio) as inoculums may also lower the ratio (Atagana *et al.*, 2003)

Moisture

Moisture content of the composting pile is an important environmental variable as it provides a medium for the transport of dissolved nutrients required for the metabolic and physiological activities of micro-organisms (Richard and Woodbury, 2002). Water is an essential part of all forms of life and the microorganism living in compost pile is no exception (Rynk, 1992). Because most compostable materials have a lower- than- ideal water content, the composting process may be slower than desired if water is not added (Bertoldi *et al.*, 1983). A moisture content of 50 to 70 percent of total weight is considered ideal (Chongrak, 2007).

Too high moisture content will cause leaching of nutrients and pathogens from the compost pile. Too high moisture content creates a potential liquid management problem and potential water pollution and odour problems (Haug, 1994) and this will also prolong the composting period (Anderson, 1991). An average of 60% moisture content is suitable for composting (Chongrak, 2007). Properly wetted compost has the consistency of a wet sponge. Systems that facilitate the uniform addition of water at any point in the composting process are performable (Richard and Woodbury, 2002). Very low moisture content would cause early dryness of the pile during composting, which will arrest the biological process, thus giving physically stable but biologically unstable composts (Bertoldi *et al.*, 1983).

The degree of wetness of the compost pile could be estimated using the moisture meter or a fist full of compost can be taken with the hand and squeezed tightly. If moisture but not free water appears between the fingers, the moisture is ideal; if however, water flows out of the tightly clenched fist, it is too wet (Bokx, 2002). If the material is too dry, water must be sprinkled over the compost pile.

Oxygen

Composting is considered an aerobic process, that is, one requiring oxygen. Anaerobic condition can produce offensive odours (Basnayake, 2001). While decomposition will occur under both conditions (aerobic and anaerobic), aerobic decomposition occurs at much faster rate (Dominguez *et al.*, 2000).

The compost pile should have enough void space to allow free air movement so that oxygen from the atmosphere can enter the pile and the carbon dioxide and other gases emitted can be exhausted to the atmosphere (Epstein, 1998). This is accomplished through some non-mechanical means such as periodic turning of the compost pile, insertion of perforated bamboo piles into the compost piles or dropping of compost heaps from floor to floor (Chongrak, 2007). Too much aeration is wasteful and can cause a loss of heat from the piles, while too little aeration would lead to the occurrence of anaerobic condition inside the compost pile (Finstein *et al.*, 1986). A 10 to 15 percent oxygen concentration is considered adequate, although a concentration as low as 5 percent may be sufficient for leaves (O'Leary, 1999). Excess air removes heat, which cools the compost pile. Too much air can also promote excess evaporation, which slows the rate of composting. Excess aeration is also an added expense that increases production cost (O'Leary, 1999).

pH

A pH between 6 and 8 is considered optimum. pH affects the amount of nutrients available to the microorganism, the solubility of heavy metals and the metabolic activity of the microorganisms. While the pH can be adjusted upward by addition of lime or downward with sulphur, such additions are not normally necessary (Wen *et al.*, 1997). This is because, as the composting progresses, the carbon dioxide produced combines with water to produce carbonic acid. The carbonic acid could lower the pH of the compost. As the composting process progresses, the final pH varies depending on the specific type of feed stocks used and operating conditions (Barrett and Lawlor, 1995). Wide swings in pH

are unusual because organic materials are naturally well-buffered with respect to pH changes (Ball *et al.*, 2003). According to Rodale (1971), pH generally falls below the neutral from the beginning due to the formation of organic acids and later rises above the neutral because the acids are consumed while ammonium is produced. A pH close to the neutral is preferred for an efficient microbial activity to take place during composting (Edriss *et al.*, 2006).

2.5.3 The Physical Properties

The physical environment in the compost process includes such factors as temperature, particle size, mixing and pile size. Each of these is essential for composting process to proceed in an efficient manner (Haug, 1994).

Particle size

The particle size of a material being composted is crucial. Because smaller particles usually have more surface area per unit of weight, they facilitate more microbial activity on their surfaces, which lead to rapid decomposition. However if particles are ground up, they pack closely together and allow few open spaces for air to circulate (Fraser-Quick, 2002). Typical particle size should be close to 1cm for forced aeration and about 5cm for passive aeration and windrow composting (Obeng and Wright, 1987).

The optimum particle sizes do not only have enough surface area for rapid microbial activity, but also enough void space to allow air to circulate for microbial respiration.

Temperature

Microorganisms all have an optimum temperature (Strom, 1985). For composting, this range is between 32⁰C and 60⁰C (O'Leary, 1999). Although compositing can occur at a range of temperatures, the optimum temperature range for thermophilic microorganism is preferred for two reasons: to promote rapid composting and destroy pathogens and weed seeds. Large piles build up and conserve heat better than smaller piles (O'Leary, 1999). Temperatures above 65⁰C are not ideal for composting (Bertoldi *et al.*, 1983). The longer duration and increased turning are necessary to achieve uniform pathogen destruction throughout the entire piles. Compost containing municipal waste water treatment plant biosolids must meet USEPA (1975) standards applicable to biosolids pathogen destruction.

According to Nelson *et al.*, (2006), temperature increases after some hours of forming a compost pile is due to the release of energy from biochemical reaction of microorganisms in the pile as easily degradables are consumed. The temperature rises from the beginning rapidly to a range of 50 to 60⁰C which is maintained for several days to weeks (Nelson *etal.*, 2006). This is the active composting stage. From this stage, the temperature gradually drops to 40⁰C as the active stage slows down and curing stage begins (Nelson et al, 2006). This drop will continue until it eventually approaches the ambient temperature. Thus composting is efficient when the temperatures of composting material are within the mesophilic (30-40⁰C) and thermophilic (50-60⁰C) ranges (Haug, 1994).

The thermophilic temperatures are required to kill plant seeds and parasitic organisms (Garcia-Gomez *et al.*, 2003). This (temperatures above 55°C) will sanitize the final compost (Watanabe *et al.*, 1997).

The compost material is considered matured when the compost temperature reaches ambient temperature.

Mixing

Mixing feed stocks, water and inoculants (if used) is important (Hickman and Lanier, 1999). Piles can be turned or mixed after composting has begun. Mixing and agitation distribute moisture and air evenly and promote the breakdown of compost clumps (Epstein, 2011). Turning and mixing are often cited as the mechanisms for aeration and temperature control during windrow composting. However, excessive agitation could also cool smaller piles or open vessels and retard microbial activity which will affect the rate of composting and the final compost quality (Bezdicek *et al.*, 2000).

2.5.4 Others

Odour and the presence of heavy metals in compost are of great concern. Odour in municipal solid waste compost is as a result of the release of sulphur compound such as hydrogen sulphide, methyl sulphide and methylmercaptan at the early stage of composting (Hue *et al.*, 1994). High levels of Nitrogen in a compost mix allows rapid microbial growth and this accelerates composting but has a problem of releasing odour as oxygen quickly depletes creating anaerobic condition (Strauss *et al.*, 2003).

Heavy metals are non-biodegradable and become toxic at some concentrations in compost amended soils. They accumulate along the food chain with human beings as the final link (Ball and Novella, 2003). Sewage sludge compost used for soil amendment in agriculture is a major concern in many countries due to the high potential heavy metal contamination, (Zorpas *et al.*, 2000). In general, metal concentrations increase during composting which is due to volume reduction in compost material as a result of loss of matter (decomposition) (Strauss *et al.*, 2003). According to Hammadi *et al.*, (2007), lower levels of copper and cadmium were recorded in matured sludge compost as compared to their respective concentrations in the sludge material used for the composting. This was achieved by the addition of large quantities of green waste which diluted the metal content in the compost. Separation of municipal solid waste at the source before composting is vital to enhance low levels of heavy metals in the final compost (Beyer *et al.*, 1982).

2.6 Compost Quality

Compost quality guidelines are relatively new, dating to the mid-1980. With regard to organic soil amendments, perhaps the only comparable standard similar to what has emerged for compost in some countries is the system of classification of peats (Allen, 2001). Compost has been widely used for decades in organic farming, but issues concerning composition and quality have only recently emerged largely by external pressure (OMRI, 1998). In determining the quality of compost, the pathogenic levels, concentration of heavy metals and the nutritional level of the matured compost (Bezdicsek *et al.*, 2000) are very essential. Of all potential quality standards, heavy metals have been

the focus of most attention. The data (Table 2.2) of permissible metal ranges reveal significant variation within Europe. However, United States numbers diverge dramatically with regard to allowed Cd, Cr, Cu, Hg and Ni.

Heavy metals limit compared: EC states versus U.S.A. - mg/kg

Table 2.2: Permissible metal ranges in compost for EC states and USA

Metal/Symbol	EU- Range	USA bio solids
Cadmium Cd	0.7 - 10	39
Chromium Cr	70 - 200	1,200
Copper Cu	70 – 600	1,500
Mercury Hg	0.7 - 10	17
Nickel Ni	20 - 200	420
Lead Pb	70 - 1,000	300
Zinc Zn	210 - 4,000	2,800

(Source: Kraus and Wilke, 1997)

Compost is considered good for handling by humans if the faecal coliform level is less than 1000 MPN/g (US EPA, 1995).

The main constituents of the nutrient in matured compost according to Straus *et al.* (2003) are Carbon, Nitrogen, Phosphorus as P_2O_5 , Potassium as K_2O , Organic matter, Ash content and Calcium as CaO . And their concentrations by percentage by weight are as shown in table 2.3 below.

Table 2.3: The main constituents of nutrients in a matured compost

Nutrient	Percentage by weight
Carbon	8—50
Nitrogen	0.4—3.5
Phosphorus (P ₂ O ₅)	0.3—3.5
Potassium (K ₂ O)	0.5—1.8
Organic matter	25—50
Ash content	20—65
Calcium (CaO)	1.5—7

Source: (Straus *et al.*, 2003)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The Chirano Gold Mine is located in southwestern Ghana, approximately 100 kilometres southwest of Kumasi, Ghana's second largest city.

Chirano was explored and developed from 1996 by Red Back Mining NL, an Australian company that moved to a Canadian listing in April 2004. Chirano began production in October 2005. Kinross Gold acquired the mine on 17 September 2010 through a US\$7.1 billion takeover of Red Back Mining, through which it also acquired the Tasiast Gold Mine in Mauritania. The mine comprises the Akwaaba, Suraw, Akoti South, Akoti North, Akoti Extended, Paboase, Tano, Obra South, Obra, Sariehu and Mamnao open pits and the Akwaaba and Paboase underground mines. The project was undertaken on the premises of the mines.

Figure 3.1 below shows the location of Chirano Gold Mines on the Southern portion of the map of Ghana



Figure 3.1: Location Map of project in Ghana

3.2 Waste Collection and Characterisation

Chirano Gold Mines Ltd has a waste dump site where all manner of wastes are disposed. The project site was close to the dumping site where random samples of the dumped waste were taken. Plastics, cans, bottles and other non-decomposable objects were taken out manually.

The biodegradable fraction was mainly food wastes, paper, fruit wastes and dry leaves. This was shredded into smaller sizes and well mixed to obtain a uniform mixture. This process was done manually using a cutlass and a shovel.

The other feedstock, dewatered sewage sludge was obtained from the company's sewage treatment plant. This was collected over a period of five (5) days and all sanitary pads

removed. The moisture, carbon and nitrogen contents of both the solid waste and dewatered sewage sludge were determined before the ratios were formulated.

3.3 Feedstock Formulation for Composting

A wide variety of raw materials (feedstock) may be used for composting. Some studies have shown that rarely will an organic material have all the characteristics needed for efficient composting so other materials (amendment or bulking agents) must be blended to achieve the desired characteristics (Tester, 1990). In this case the primary raw materials to be composted are organic solid waste and dewatered sewage sludge. Based on the preliminary analysis of moisture content and C/N ratio of the raw materials, formulations of composting ratios were made balancing moisture (50 to 70%) and C/N ratios (between 20 and 30) of the different feedstock materials.

Five (5) different formulations of co-compost open piles (heaps) were prepared (Table 3.1).

Table 3.1: Material Formulation for Composting

Feedstock ratio by volume to volume	Organic Solid Waste	Dewatered Sewage Sludge
Pile (1:0)	1	0
Pile (1:1)	1	1
Pile (2:1)	2	1
Pile (3:1)	3	1
Pile (0:1)	0	1

Each formulation was replicated, giving a total of ten (10) piles. Each formulation had an initial volume between 175 and 189cm³ and was turned every week.

A shaded structure was constructed as shown in figure 3.1 below to house the formulations to prevent rain and animals and other extreme environmental conditions from disturbing the piles. Piles that were observed to have low moisture content were watered after turning.



Plate 3.1 Shed for Housing of Compost Piles

3.4 Sampling and Monitoring of Compost Piles

3.4.1 Sampling and Analysis

Samples were collected from the stratified locations to form a representative sample. Samples for physicochemical and heavy metal analysis were air-dried and milled into powder for analysis. Samples for Total Coliforms, Faecal Coliforms and *Escherichia coli* were transported in a cold chain to maintain sample condition.

3.4.2 Monitoring Temperature (T)

Daily temperature of each compost pile was measured at different depth. This was done by inserting mercury-in-glass thermometer tied to a long rod which had graduation from 0°C to 100°C at about 30cm and 20cm from the base of the compost pile and a stable reading was obtained. The average of the two was recorded. The ambient temperature was measured daily and recorded. This was done in the mornings and evenings and the average found for the entire composting period.

3.4.3 Determination of moisture content (MC) and Total Solids (TS)

To calculate the moisture content (%) of compost weekly:

An empty crucible was weighed, W_{EC} . 10g of composting material was put into the empty crucible and weighed, W_{CM} . The sample was dried for 24hours at 105°C in an oven. The sample was reweighed, W_{DS} and the weight of the empty container, W_{EC} subtracted from it and moisture content (MC) determined using the following equation:

$$MC = ((W_{DS} - W_{EC}) / (W_{CM} - W_{EC})) \times 100\% \quad \text{Equation 1}$$

MC = moisture content (%) of composting sample

W_{CM} = wet weight of the sample, and

W_{DS} = weight of the sample after drying.

Also on a daily basis, the moisture content (MC) was determined with the squeeze test to figure out how much water could be added during composting. With the squeeze test, a sample of compost material was squeezed to the size of a golf ball with the palms of the hand, if it glistened and formed small droplets, the moisture content was ok. There is too much moisture if water drips from the sample, and if the material does not form a ball in your hand, it is too dry (Bertoldi *et al.*, 1983). And moisture is related with total solids (TS) in the following equation:

$$\text{Total Solid (TS)} = (100 - \text{MC}) \% \quad \text{Equation 2}$$

3.4.4 Determination of Total Organic Matter (OM) and Ash Content

The Ignition Method

10 g of composting material was put a well dried porcelain crucible (ashing vessel). This was dried for 4 hours at 105°C in an oven. The ashing vessel was removed from the oven and placed in a dry atmosphere. When cooled, it was weighed to the nearest 0.01 g. The content with ashing vessel was placed into a muffle furnace and the temperature gradually increased to 400°C and maintained for a period of 4 hours. A greyish-white ash produced was removed and cooled in a desiccator and weighed to the nearest 0.01 g. The percentage of the OM is calculated according to Miroslav and Vladimir (1998) as follows:

$$\text{Percent organic matter (OM)} = (W_1 - W_2) / W_1 \times 100 \quad \text{Equation 3}$$

Where:

W_1 is the weight of composting materials (sample) at 105 °C;

W_2 is the weight of composting materials (sample) at 400 °C.

$$\text{Organic Matter (OM)} = (100 - \text{Ash content}) \% \quad \text{Equation 4}$$

$$\text{The percent of Organic Carbon is given by: } \% \text{ OM} \times 0.58. \quad \text{Equation 5}$$

3.4.5 Determination of Total Nitrogen

The Kjeldahl Method

10 g air dried compost sample of each pile was weighed into 500ml long-necked kjeldahl flask and 10ml distilled water added to moisten the sample. One spatula full of kjeldahl catalyst (mixture of 1 part selenium + 10 parts CuSO_4 + 100 parts Na_2SO_4) was added, followed by 20ml conc. H_2SO_4 . This was digested until a clear colourless solution was obtained. The flask was allowed to cool, and the fluid decanted into a 100ml volumetric flask and make up to the mark with distilled water.

An aliquot of 10ml fluid from the digested sample by means of a pipette was transferred into kjeldahl distillation flask. 90ml of distilled water was added to make it up to 100ml in the distillation flask. 20ml of 40% NaOH was added to the content of the distillation flask. Distillate was collected over 10ml of 4% boric acid and 3 drops of mixed indicator in a 200ml conical flask. The presence of nitrogen gave a light blue colour. Collected distillate (about 100ml) was titrated against 0.1N HCl till the blue colour changes to grey and then suddenly flashes to pink.

A blank determination was carried out without a sample.

CALCULATION

Weight of sample used, considering the dilution and the aliquot taken for distillation

$$\%N = 14X (A-B) \times N \times 100 / (1000 \times 0.2) \quad \text{Equation 6}$$

Where,

A=volume of standard HCl used in sample titration

B= volume of standard HCl used in blank titration

N=normality of standard HCl (AOAC, 2005)

3.4.6 Monitoring of volumetric Change of Compost Piles

The Shape of the Cone Method

The rate of degradation of compost materials was determined by measuring the material lost (reduction of pile volume) using a measuring tape and a calibrated rod to measure the height (h) of the pile(heap), the circumference (c) from which the radius (r) was calculated as shown in the following equations:

$$\text{Volume of Pile (heap)} = \frac{1}{3} \pi r^2 h \quad \text{Equation 7}$$

Where $r = c/2\pi$

r = radius of pile

h = height of pile

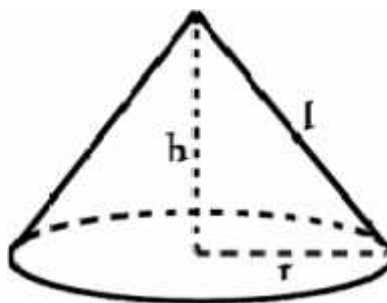


Figure 3.2 The shape of the compost heap indicating parameters measured for pile volume calculation

The volume of each pile was determined every week. This was done by measuring the heights and circumference of the pile before turning. **Equation (7)** was then used to calculate the volume of each pile.

3.4.7 Determination of pH

10 g of composting material was measured into a 50 ml beaker. 25 ml of distilled water was added. The mixture was stirred vigorously for 15 minutes allowed to stand for 30 minutes. A calibrated pH meter was inserted into the supernatant and the pH was recorded after a stable reading was observed. Calibration of the meter was done after every four (4) readings using pH 4 and pH 7 buffers. And readings were taken at room temperature making sure that the electrode was not in contact with the settled particles (Miroslav and Vladimir, 1998).

3.4.8 Electrical Conductivity (EC) Determination

The electrical conductivity of the composting materials was determined at the beginning of the composting process and the final compost. The EC of each pile was determined as follows:

A solution of 0.005 N KCl which has an electrical conductivity of 720 ± 1 dS/m at 25°C was used as the standard (reference solution).

Sample Handling and Preparation:

Each sample was air-dried, ground and passed through a 2-mm sieve.

Procedure:

25g of sample was placed in a 100 ml plastic beaker. 40 ml of distilled water added and stirred. The suspension was allowed to stand for 4 hours. Without stirring the sample, the solution was filtered through a Whatman No. 41 (11 cm) filter paper. This was done to remove the particulates and other debris from the solution.

The Conductivity meter was standardized using a 0.005N KCl solution. The probe was moved up and down in the solution several times to dislodge any bubbles on the electrode surfaces. The electrical conductivity (EC) of the extract contained in the funnel tube was measured.

The interior and exterior of the probe was rinsed with distilled water between samples. Any excess water from the exterior of the probe was removed by blotting with a tissue.

All meter readings were recorded as displayed (Miroslav and Vladimir, 1998).

3.4.9 Determination of Potassium

1.907g of potassium chloride previously dried for 2 hours at 105°C was accurately weighed. This was dissolved in 1 litre of distilled water. 100 ml of the solution was transferred in a 1 litre volumetric flask to give 100 µg K / ml. This served as the stock solution. 5, 10, 15 and 20 ml of the stock solution was transferred into 100 ml volumetric flasks and distilled water added to make up the volume giving 5, 10, 15 and 20 µg K / ml respectively. Well air-dried and ground of each sample was passed through a 2mm sieve. 0.25 g of each sample was placed into a 100 ml digestion flask and 2.5 ml of an acid

mixture (HNO_3 , H_2SO_4 and HClO_4 in the ratio 9:4:1) was added and content swirled to mix. The flask with its content was heated on a hot plate under a fume chamber until the production of red NO_2 fumes ceased and the mixture turned colourless. The volume was made up to 100 ml by adding distill water.

A blank was prepared the same without the sample. 5 ml of the aliquot was taken for estimation and made up to 100 ml. Samples were atomized on a calibrated Atomic Absorption Spectrophotometer (AAS) on which a Potassium standard solution graph had been prepared. The absorbance was recorded for each sample. Thus the concentration of Potassium (K) for absorbance obtained for each sample was used to calculate the Potassium (K) content as shown below:

K content (μg) in 1 g sample = $C \times \text{df}$

Thus potassium content (g) in 100g sample (%) = $C \times \text{df} \times 100 / 1000000$

Equation 8

Where:

C = concentration of K ($\mu\text{g}/\text{ml}$) as read from the standard curve

df = dilution factor, which is $400 \times 20 = 8000$ (because 0.25 g of sample made up to 100 ml; that is 400 times and 5 ml of sample solution made to 100 ml; that is 20 times).

Factor for converting μg to g = 1000000

3.4.10 Determination of Phosphorus

A standard Phosphate solution was prepared by dissolving 0.2195 g of analytical grade KH_2PO_4 in 1 litre of distilled water with the resultant concentration of $50 \mu\text{g P / ml}$. This was used to prepare a standard curve using 0, 1, 2, 3, 4, 5 and 10 ml of the standard solution ($50 \mu\text{g P / ml}$) in 50 ml volumetric flasks. 10 ml of vanadomolybdate reagent was added to each flask and topped up to the volume to obtain Phosphorus concentrations of 0, 1, 2, 3, 4, 5 and $10 \mu\text{g P / ml}$ respectively. The standard curve was prepared by measuring these concentrations on a spectrophotometer (at 420 nm) and recording the corresponding absorbances.

Using a di-acid digestion method, 0.25 g of each compost samples placed in 100 ml digestion flask and 2.5 ml of the acid mixture (HNO_3 and HClO_4 in the ratio 9:4) was added and the contents swirled to mix. The flask with its content was heated on a hot plate under a fume chamber until the production of red NO_2 fumes ceased and the mixture turned colourless. The volume was made up to 100 ml by adding distilled water. 5 ml of each digest was placed in a 50 ml volumetric flask containing 10 ml of vanadomolybdate (Ammonium molybdate). Distilled water was added to make up the volume. The mixture was shaken thoroughly and left to stand for 30 minutes undisturbed. A yellow supernatant solution was read at 420 nm on an Atomic Absorption Spectrophotometer (AAS). Absorbance observed was used to determine the Phosphorus, P, content as in Potassium above.

Thus, Phosphorus, P, content (μg) in 1 g of sample = $C \times df$

Hence P content (g) in 100g sample (%) = $C \times df \times 100 / 1000000$

Equation 9

Where:

C = concentration of P ($\mu\text{g/ml}$) as read from the standard curve

df = dilution factor, which is $400 \times 20 = 8000$ (because 0.25 g of sample made up to 100 ml; that is 400 times and 5 ml of sample solution made to 100 ml; that is 20 times).

Factor for converting μg to g = 1000000.

3.4.11 Calcium Determination

A standard Calcium, Ca, solution was prepared by adding 5 ml of distilled water to 0.2247 g of primary CaCO_3 . 10 ml of HCl was added to this solution to ensure complete dissolution of CaCO_3 . The mixture was diluted to 1 litre with distilled water with resultant calcium, Ca, concentration of $100 \mu\text{g Ca / ml}$. 10 ml of solution was diluted to 100 ml to give $10 \mu\text{g Ca/ ml}$.

Using a di-acid digestion method, 0.25 g of each compost samples placed in 100 ml digestion flask and 2.5 ml of the acid mixture (HNO_3 and HClO_4 in the ratio 9:4) was added and the contents swirled to mix. After the digestion, the volume was made up to 100 ml by adding distill water. The sample solution was estimated from the standard curve prepared from the standard solutions of different concentrations of Calcium, Ca, atomized in AAS and the Absorbance from the respective concentrations of Ca.

5 ml of the sample solution was placed in a 100 ml volumetric flask and distilled added to make up the volume. This was atomized and the absorbance observed. The corresponding concentration for the absorbance observed and recorded representing Ca content in solution.

Thus the Calcium content is calculated as follows:

$$\text{Calcium, Ca (\%)} = C \times df \times 100 / 1000000 \quad \text{Equation 10}$$

Where:

df = dilution factor, which is $400 \times 20 = 8000$ (because 0.25 g of sample made up to 100 ml; that is 400 times and 5 ml of sample solution made to 100 ml; that is 20 times).

Factor for converting μg to g = 1000000.

3.4.12 Determination of Magnesium

A standard solution of Magnesium was prepared by dissolving 10.141 g of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ in 250 ml of distilled water and the volume made up to 1 litre to give 1000 μg Mg / ml solution. After the standard curve was prepared from the standard solution, the calculation of Magnesium content in each sample was the same as Calcium as seen above.

3.4.13 Total and Faecal Coliform determination

The Most Probable Number Method

The Most Probable Number (MPN) method was used to determine the total and faecal coliforms in the compost samples. Serial dilutions of 10^{-1} to 10^{-10} were prepared by picking 1g of sample into 9ml sterile distilled water. 1 ml aliquots from each of the dilutions were inoculated into 5 ml of MacConkey Broth with inverted Durham tubes and incubated at 35°C for total coliforms and 44°C for faecal coliform for 24 hours. Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24 hours were identified as presumptively positive coliforms bacteria. Counts per 100 ml

were calculated by reference to Most Probable Number (MPN) statistical tables and expressed as MPN/ g (Anon, 1994). Samples were analyzed at the beginning and end of composting period.

3.4.14 *E. coli* (Thermotolerant Coliforms) determination

The Most Probable Number Method

From each of the positive tubes identified, a drop was transferred into a 5 ml test tube of trypton water and incubated at 44°C for 24 hours. A drop of Kovacs' reagent was then added to the tube of trypton water. All tubes showing a red ring colour development after gentle agitation denoted the presence of indole and recorded as presumptive positive for thermotolerant coliforms (*E. coli*). Counts per 100 ml were calculated from Most Probable Number (MPN) tables (Obiri-Danso *et al.*, 2005).

3.4.15 Heavy metals determination

A 2g of a ground compost sample was weighed and placed into 300 ml volumetric flask and 10 ml of di – acid mixture of HNO₃ and HClO₄ with ratio 9: 4 was added and the contents well mixed by swirling thoroughly. The flask with contents was then placed on a hot plate in the fume chamber and heated, starting at 85°C and then temperature raised to 150°C. Heating continued until the production of red NO₂ fumes ceased. The contents were further heated until volume was reduced to 3 – 4 ml and became colorless or yellowish, but not dried. This was done to reduce interference by organic matter and to convert metal associated particulate to a form (the free metal) that can be determined by the Spectrophotometer (AAS). Contents were cooled and volume made up with distilled

water and filtered through acid-washed Whatman No. 1 filter paper. The resulting solution was preserved at 4°C, ready for Spectrophotometric determination of the metal analysis. A blank was similarly prepared but without the compost sample. A standard solution for atomic absorption spectrophotometry was prepared from commercial stock metal standards of Lead (Pb), Cadmium (Cd), Copper (Cu), Zinc (Zn) and Chromium (Cr). Their concentrations in the final solutions were determined by Atomic Absorption Spectrophotometer model 220 (AAS).

3.5 Statistical Analysis

A single-factor randomized analysis of variance (ANOVA) was used for testing variance between variable. The data were tested at 95% confidence level.

CHAPTER FOUR

4.0 RESULTS

4.1 Waste Characterization

An initial characterization of the site revealed that organic solid wastes had moisture content (MC) of 61.3%, Carbon (C) content of 54.23% and a Nitrogen (N) content of 1.44 while dewatered sewage sludge moisture content (MC) of 70.12%, Carbon (C) content of 41.89% and Nitrogen (N) content of 2.87% as shown in table 4.1.

4.2 Physicochemical Properties, Heavy Metal Content and Biological Properties of piles before Composting

As shown in table 4.1 before composting began, with respect to the ratio of Organic Solid Waste/ Dewatered Sewage Sludge, pile 1:0 recorded the highest pH of 8.5 while pile 0:1 recorded the least pH of 6.7. The Electrical conductivity of pile 2:1 was 1.65 dS/m which happened to be the highest followed by 1.64 dS/m for pile 1:0. The least electrical conductivity of 0.51 dS/m was recorded by pile 0:1. The Moisture content recorded was highest for pile 0:1 (70.12%) and the lowest for pile 3:1 (58.21%). Total solids ranged from 29.88% (pile 0:1) and 41.79% (pile 3:1). The highest Ash content of 33.3% was recorded by pile 0:1 and the least was 21.14% for pile 1:0. The organic matter for each pile was between 78.86% (pile 1:0) and 66.7% (pile 0:1). Total carbon ranged between 54.23 (pile 1:0) and 41.89% (pile 0:1). Pile 0:1 recorded the highest Total nitrogen of 2.87% followed by pile 1:1 which recorded 2.45%. The least Total nitrogen of 1.44% was recorded by pile 1:0. Carbon-to-nitrogen was highest in pile 1:0 (37.66) and least in pile 0:1 (14.6). Phosphorus was highest in pile 0:1 (0.91%) and least in pile 1:0 (0.18%). Piles

1:0 and 0:1 recorded 0.9% and 0.94% of Potassium respectively. The least potassium was recorded in pile 2:1 (0.18%). Magnesium was highest in pile 1:1 (1.55%) and least in pile 1:0 (0.4%). Again Calcium was highest in pile 1:1 (3.04%) and least in pile 1:0 (0.88%).

Table 4.1: Mean results of initial physicochemical parameters in each pile before composting.

Parameter	Unit	Pile A (1:0)± SD	Pile B (1:1)± SD	Pile C (2:1)± SD	Pile D (3:1)± SD	Pile E (0:1)± SD
pH	-	8.5±0.28	7.1±0.21	7.7±0.85	7.4±0.00	6.7±0.42
Electrical Conductivity (EC)	dS/m	1.64±0.04	1.08±0.11	1.65±0.01	1.5±0.42	0.51±0.06
Moisture Content (MC)	%	61.3±1.13	63.55±0.78	59.88±1.24	58.21±0.03	70.12±1.58
Total Solids (TS)	%	38.7±1.13	36.45±0.78	40.21±1.24	41.79±0.03	29.88±1.58
Ash Content	%	21.14±0.35	27.12±0.64	23.18±0.57	22.1±0.14	33.3±0.99
Organic Matter (OM)	%	78.86±0.35	72.88±0.64	76.82±0.57	77.9±0.14	66.7±0.99
Total Carbon (C)	%	54.23±0.02	51.46±0.32	50.43±0.89	46.31±0.98	41.89±0.13
Total Nitrogen (N)	%	1.44±0.06	2.45±0.08	1.47±0.03	2.03±0.20	2.87±0.03
Carbon/Nitrogen ratio (C/N)	-	37.66±1.45	21±0.60	34.31±1.27	22.81±2.72	14.6±0.10
Phosphorus (P)	%	0.18±0.01	0.43±0.00	0.35±0.03	0.35±0.01	0.91±0.13
Potassium (K)	%	0.9±0.03	0.43±0.03	0.18±0.1	0.25±0.01	0.94±0.06
Magnesium (Mg)	%	0.4±0.14	1.55±0.07	0.61±0.00	0.89±0.01	0.99±0.11
Calcium (Ca)	%	0.88±0.01	3.04±0.07	2.03±0.00	2.44±0.17	1.11±0.01

Ratios are in Organic Solid Wastes/ Dewatered Sewage Sludge

Results of Initial metal content in each compost pile before composting began is shown in table 4.2. Table 4.2 as shown below indicates that Cadmium, Chromium and Lead content in the piles before composting began were between 0.01 and 0.03 mg/kg. Copper and Zinc content were also between 0.01 and 0.66 mg/kg. Pile 2:1 recorded the highest Copper content of 0.56 mg/kg while pile 0:1 recorded the highest Zinc content of 0.66 mg/kg.

Table 4.2: Mean results of initial Metal content in each pile before composting.

Parameter	Unit	Pile A (1:0)±SD	Pile B (1:1)±SD	Pile C (2:1)±SD	Pile D (3:1)±SD	Pile E (0:1)±SD
Cadmium (Cd)	mg/kg	0.01±0.00	0.01±0.00	0.02±0.00	0.01±0.00	0.02±0.00
Chromium (Cr)	mg/kg	0.01±0.00	0.02±0.01	0.01±0.00	0.02±0.00	0.03±0.00
Copper (Cu)	mg/kg	0.01±0.00	0.17±0.00	0.56±0.34	0.07±0.00	0.18±0.01
Lead (Pb)	mg/kg	0.01±0.01	0.01±0.00	0.01±0.00	0.02±0.01	0.03±0.00
Zinc (Zn)	mg/kg	0.03±0.01	0.07±0.01	0.22±0.01	0.24±0.01	0.66±0.01

Ratios are in Organic Solid Wastes/ Dewatered Sewage Sludge.

Results of Initial Biological Properties (Coliforms and *E. coli*) in each compost pile before composting started is shown in table 4.3. As shown in table 4.3 below, pile 0:1 recorded the highest total coliform of 4.15×10^{13} CFU/g while pile 3:1 recorded the least of 4.15×10^8 CFU/g; Faecal coliform for each of the piles before composting was between 9.15×10^7 (pile 1:0) and 4.15×10^{12} CFU/g (pile 0:1) and Pile 1:0 recorded the highest number of *E. coli* (9.15×10^5) and pile 3:1 recorded the least number of *E. coli* (1.50×10^5).

Table 4.3: Mean results of initial content of biological parameters (Coliforms and *E. coli*) in each pile before composting.

Parameter	Unit	Pile A (1:0)±SD	Pile B (1:1)±SD	Pile C (2:1±SD	Pile D (3:1)±SD	Pile E (0:1)±SD
Total coliform	CFU/g	2.35×10 ⁹ ± 7.07×10 ⁷	9.15×10 ¹¹ ± 2.12×10 ¹⁰	9.15×10 ¹⁰ ±2 .12×10 ⁹	4.15×10 ⁸ ± 2.12×10 ⁹	4.15×10 ¹³ ± 2.12×10 ¹²
Faecal coliform	CFU/g	9.15×10 ⁷ ± 2.12×10 ⁶	4.15×10 ¹⁰ ± 2.12×10 ⁶	9.15×10 ⁸ ±2. 12×10 ⁶	2.35×10 ⁸ ± 7.07×10 ⁶	4.15×10 ¹² ± 2.12×10 ¹¹
<i>E. coli</i>	CFU/g	9.15×10 ⁵ ± 2.12×10 ⁴	2.30×10 ⁵ ±0 .00	2.10×10 ⁵ ±0. 00	1.50×10 ⁵ ± 0.00	2.30×10 ⁵ ±0 .00

Ratios are in Organic Solid Wastes/ Dewatered Sewage Sludge.

4.3 Physicochemical Properties, Heavy Metal Content and Biological Properties of piles after Composting

Results of the Physicochemical Properties of each of the compost piles after composting is shown in table 4.4. The final pH in almost all the pile decreased at the end of composting are shown in tables 4.1 and 4.4. pH in Pile 1:0 decreased from 8.5 to 7.5; Pile 1:1 increased from 7.1 to 7.3; Pile 2:1 decreased from 7.7 to 7.4; Pile 3:1 decreased from 7.4 to 7.3 and Pile 0:1 decreased from 6.7 to 5.7.

There was a general decline in pH in all the piles from week zero (0) up to the third week which was probably due to mineralization of organic matter as shown in figure 4.1. After four weeks of composting, there was increase in pH in all the piles except pile E (0:1; organic solid waste/ sewage sludge) as shown in figure 4.1 below. This increase could be due to metabolic degradation of organic acid.

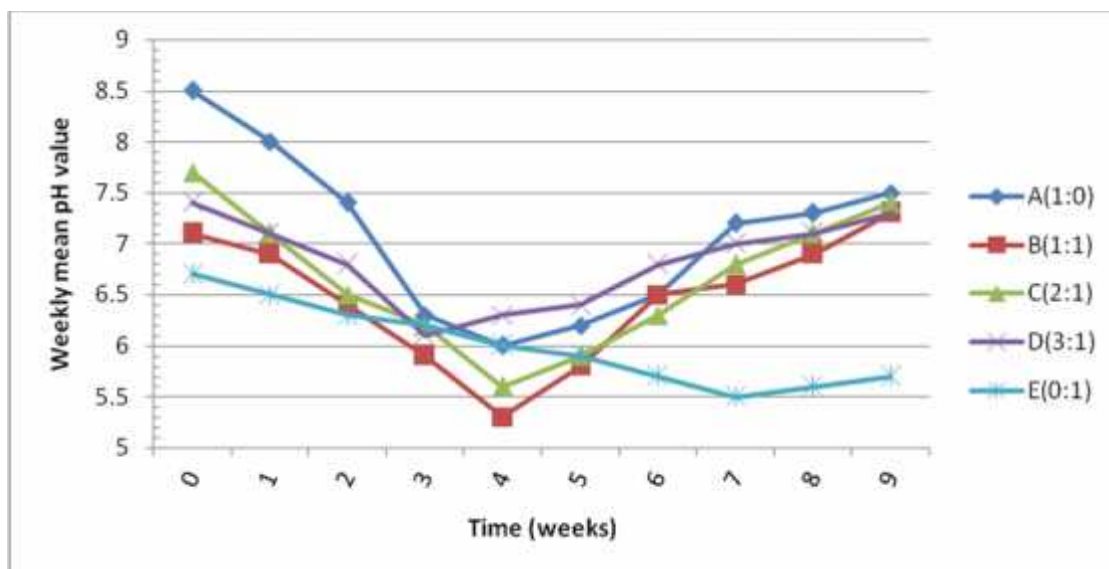


Figure 4.1: Weekly mean pH in the different compost piles of Organic Solid Waste/ Dewatered Sludge

The electrical conductivity decreased amongst all the piles except in pile 0:1 which began with 0.51 dS/m and ended with 0.65 dS/m as shown in tables 4.1 and 4.4. The moisture content decreased amongst all the piles at the end of the composting period. This is shown in Figure 4.2 below. Moisture content in Pile 1:0 decreased from 61.3% to 30.2%; Pile 1:1 from 63.55 to 41.42%; Pile 2:1 from 59.88% to 35.6%; Pile 3:1 from 58.21% to 29.43% and Pile 0:1 from 70.12% to 51.92%.

Generally, the moisture content in all the piles declined right from the beginning to the end of composting. This is observed in figure 4.2 below.

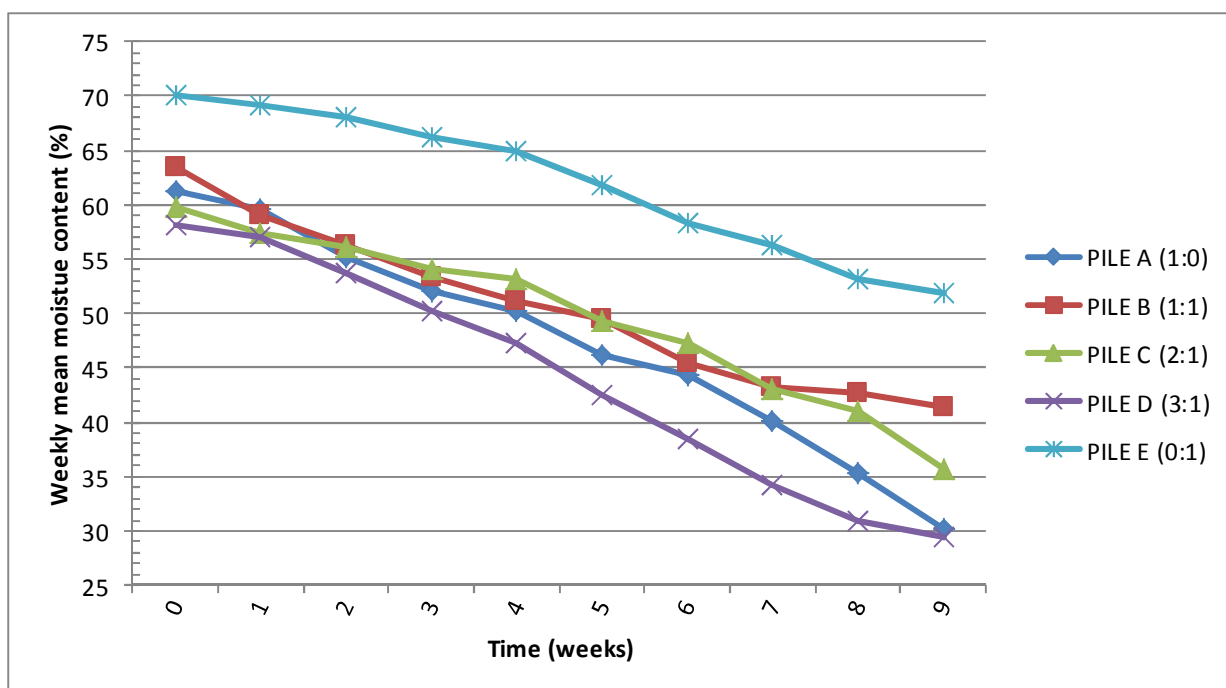


Figure 4.2: Weekly mean Moisture content (%) in the different compost piles of Organic Solid Waste/ Dewatered Sludge

Total Solids in Pile 1:0 increased from 38.7% to 69.8%; Pile 1:1 from 36.45 to 58.58%; Pile 2:1 from 40.12% to 64.4%; Pile 3:1 from 41.79% to 70.57% and Pile E from 29.88% to 48.08% as shown in tables 4.1 and 4.4.

As shown in figure 4.3, Total Solids among all the piles increased from the beginning to the end. Thus, total solids shows an inverse relationship with moisture content as shown in figures 4.2 and 4.3.

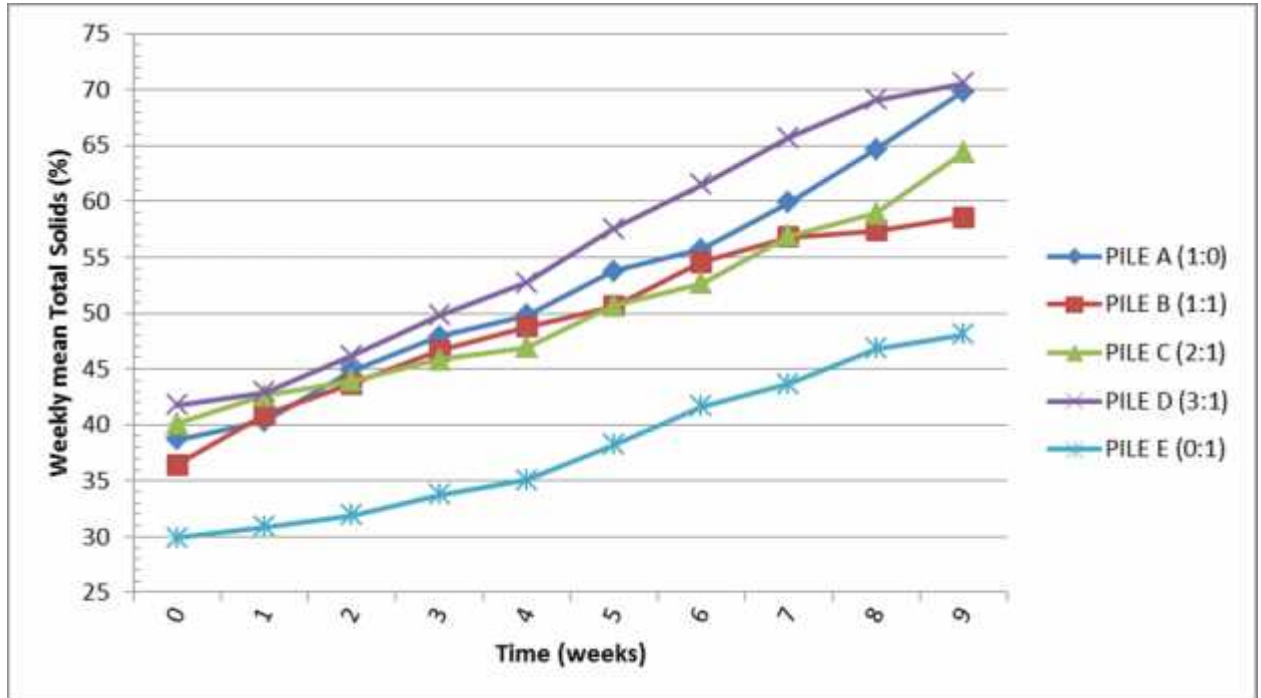


Figure 4.3: Weekly mean Total Solids (%) in the different compost piles of Organic Solid Waste/ Dewatered Sludge

Ash content in Pile 1:0 increased from 21.14% to 60.04%; Pile 1:1 from 27.12% to 55.16%; Pile 2:1 from 23.18% to 56.91%; Pile 3:1 from 22.1% to 58.06% and Pile 0:1 from 33.3% to 45.69%. Figure 4.4 gives a graphical presentation of the Ash content from beginning to end which shows an increase throughout among all the piles.

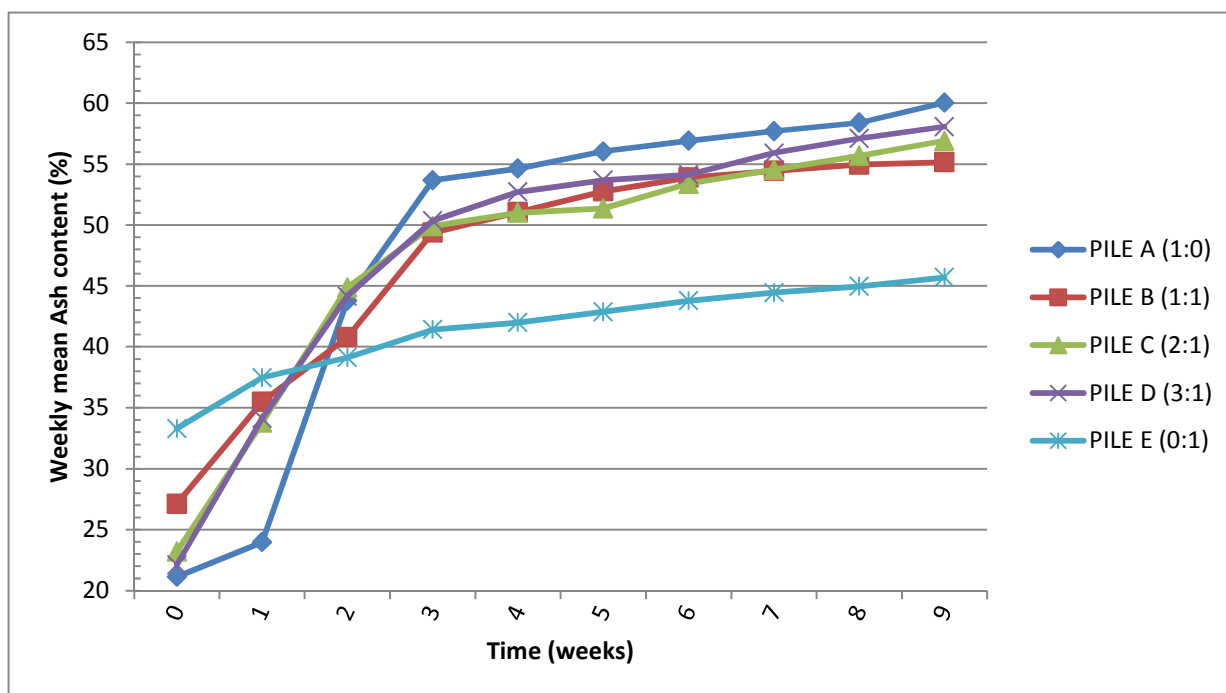


Figure 4.4: Weekly mean Ash content (%) in the different compost piles of Organic Solid Waste/ Dewatered Sludge

Organic Matter in pile 1:0 decreased from 78.86% to 39.96%; pile 1:1 from 72.88% to 44.84%; pile 2:1 from 76.82% to 43.09%; pile 3:1 from 77.9% to 41.94% and pile 0:1 from 66.7% to 54.31% as indicated in both tables 4.1 and 4.4. This is graphically presented below in Figure 4.5 that shows a general decline in organic matter as composting progressed till the 7th week. The decline was sharp in the first three weeks as shown in the figure (fig. 4.5).

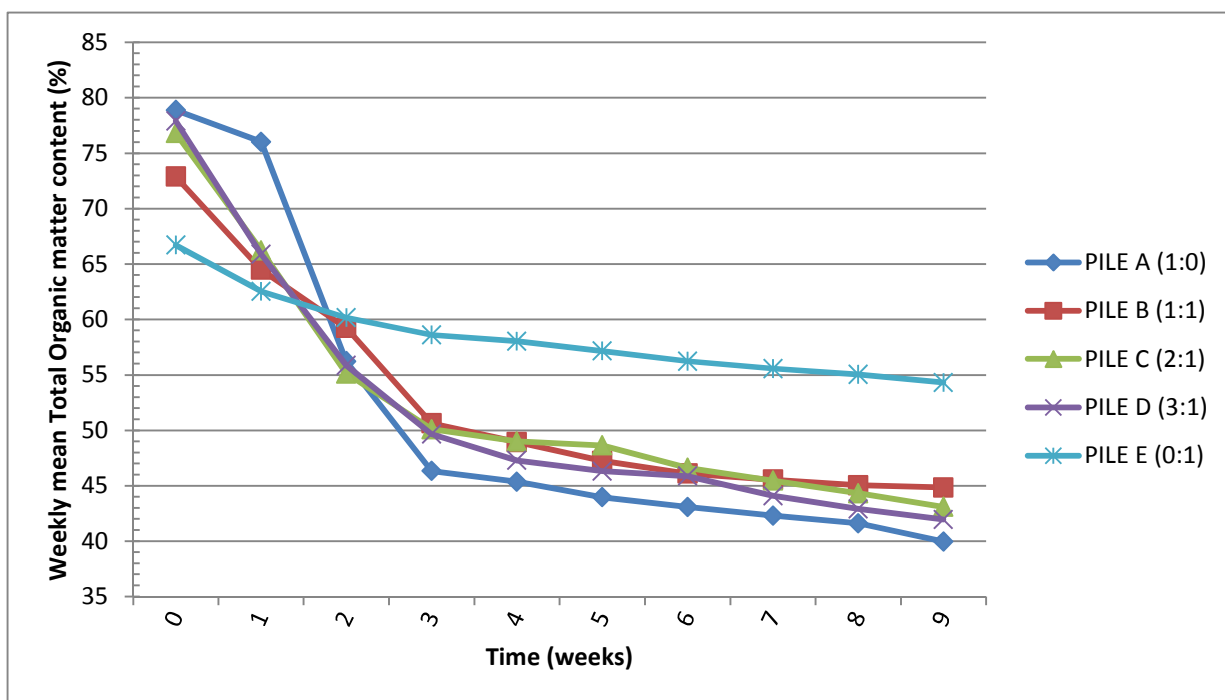


Figure 4.5: Weekly mean Organic Matter content (%) in the different compost piles of Organic Solid Waste/ Dewatered Sludge

Carbon content in Pile 1:0 decreased from 54.23% to 27.44%; Pile 1:1 from 51.46% to 29.91%; Pile 2:1 from 50.43% to 29.91%; Pile 3:1 from 46.31% to 28.33% and Pile 0:1 from 41.89% to 33.99%. This is shown graphically in Figure 4.6 below. This shows general decline in organic carbon in all the piles. The decline was sharp in the first three weeks all the piles except pile 0:1; the pile which contained only sewage sludge. As shown in the figure (fig. 4.6) below, the organic carbon stabilized after the 7th week indicating maturity of the compost.

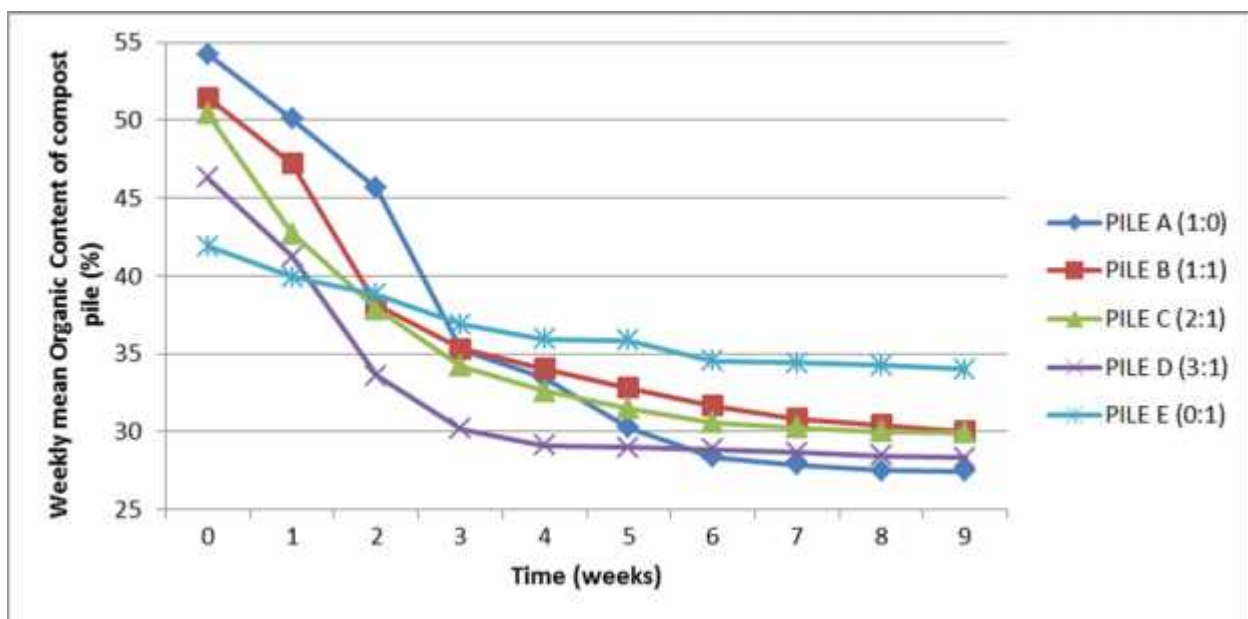


Figure 4.6: Weekly mean Organic Carbon content (%) in the different compost piles of Organic Solid Waste/ Dewatered Sludge

Nitrogen content in Pile 1:0 increased from 1.44% to 1.61%; Pile 1:1 from 2.45% to 2.59%; Pile 2:1 from 1.47% to 2.03%; Pile 3:1 from 2.03% to 2.94% and Pile 0:1 from 2.87% to 3.08% as shown in Tables 4.1 and 4.4.

Carbon-to-Nitrogen ratio in pile 1:0 decreased from 37.66 to 17.04; Pile 1:1 from 21.0 to 11.6; Pile 2:1 from 34.31 to 14.73; Pile 3:1 from 22.81 to 9.64 and Pile 0:1 from 14.6 to 11.04. This is represented graphically below in Figure 4.8 which shows a general decrease in the mean carbon-to-nitrogen ratio (C/N). The figure also shows a general increase in the C/N after the 5th week with the exception of pile 0:1.

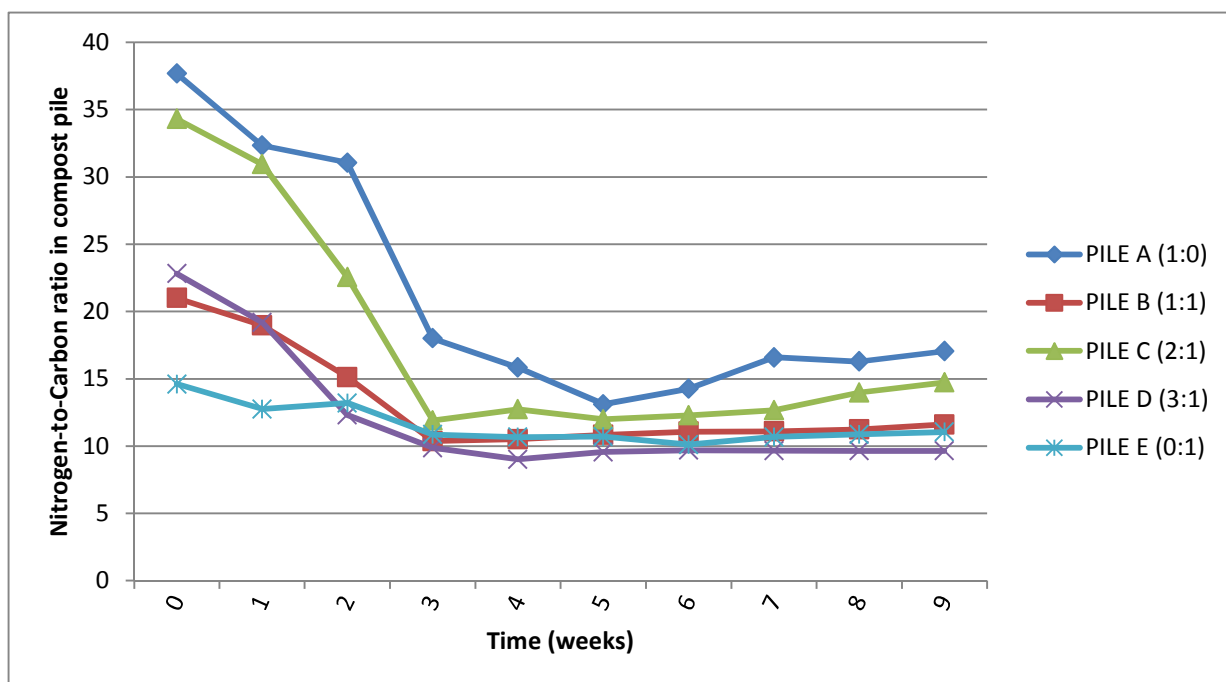


Figure 4.7: Weekly mean Carbon- to-Nitrogen ratio (C/N) in the different compost piles of Organic Solid Waste/ Dewatered Sludge

Phosphorus content in Pile 1:0 increased from 0.18% to 0.50%; Pile 1:1 from 0.43% to 0.93%, Pile 2:1 from 0.35% to 1.08%; Pile 3:1 from 0.35% to 0.70% and Pile 0:1 from 0.91% to 1.31% as shown in tables 4.1 and 4.4.

Potassium content in Pile 1:0 increased from 0.90% to 1.21%; Pile B from 0.43% to 0.59%; Pile 2:1 from 0.18% to 0.81%; Pile 3:1 from 0.25% to 0.77% while Pile 0:1 decreased from 0.94% to 0.14% as shown in tables 4.1 and 4.4.

Magnesium content in Pile 1:0 decreased from 0.4% to 0.3%; Pile 1:1 from 1.55% to 0.58%; Pile 2:1 from 0.61% to 0.18%; Pile 3:1 from 0.89% to 0.39% and Pile 0:1 from 0.99% to 0.19% as shown in Tables 4.1 and 4.4. Figure 4.8 below shows a general increase in Magnesium content among all the piles from the beginning of composting up

to the middle of the 3rd week. From there saw a rapid decline up to the middle of the 4th week of composting after which a general stability in Magnesium content among all the piles was observed as figure 4.8 shows.

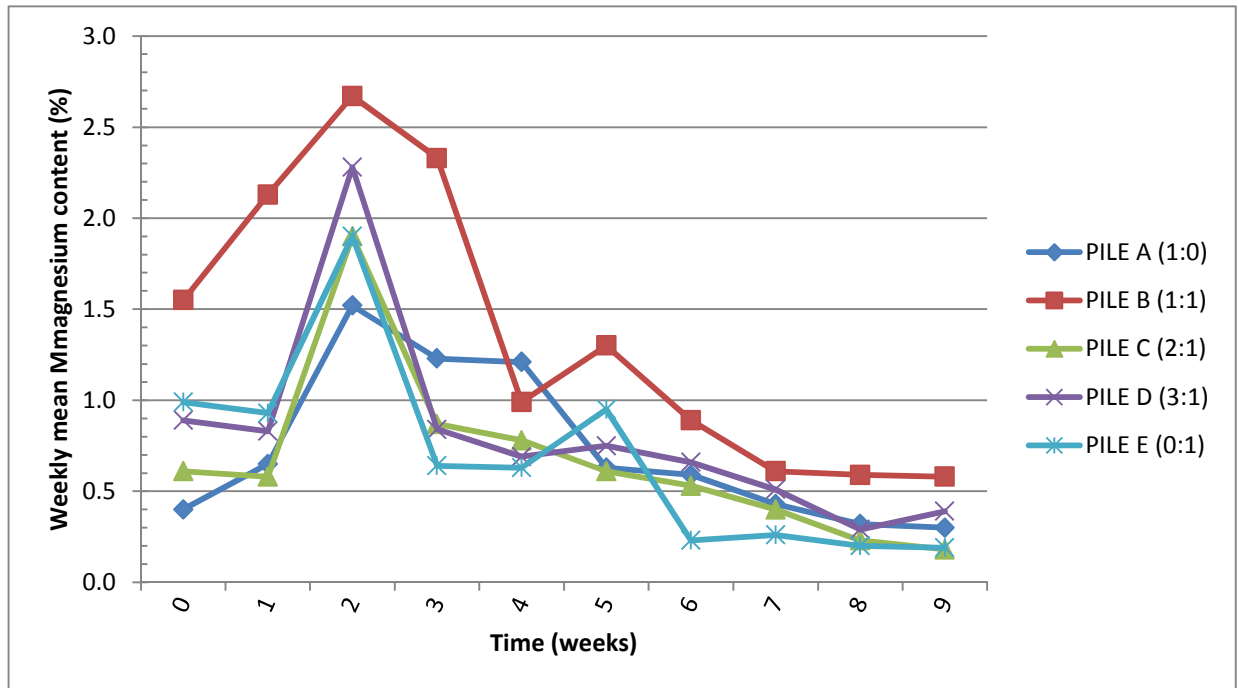


Figure 4.8: Weekly mean Magnesium (Mg) content (%) in the different compost piles of Organic Solid Waste/ Dewatered Sludge.

Calcium content in Pile 1:0 increased from 0.88% to 1.28%; Pile 1:1 from 3.04% to 3.44%; Pile 2:1 from 2.03% to 3.12%; Pile 3:1 from 2.44% to 2.72% and Pile 0:1 from 1.11% to 2.56% as shown in Tables 4.1 and 4.4.

Volume in Pile 1:0 decreased from 188.57cm³ to 70.53 cm³; Pile 1:1 from 175.04 cm³ to 90.67 cm³; Pile 2:1 from 184.8 cm³ to 83.9 cm³; Pile 3:1 from 181.03 cm³ to 69.15 cm³ and Pile 0:1 from 178.69 cm³ to 126.69 cm³. Figure 4.9 shows a rapid decline in the volumes all the piles from the first day of composting down to the 4th week except pile

0:1 (organic solid waste/ dewatered sewage sludge). Volumes of each pile stabilized after the 7th week of composting. As shown in figure 4.9, pile 0:1 had the least decrease in volume and piles 1:0 and 3:1 (piles with high organic solid waste) had the highest decline in volume after the composting period.

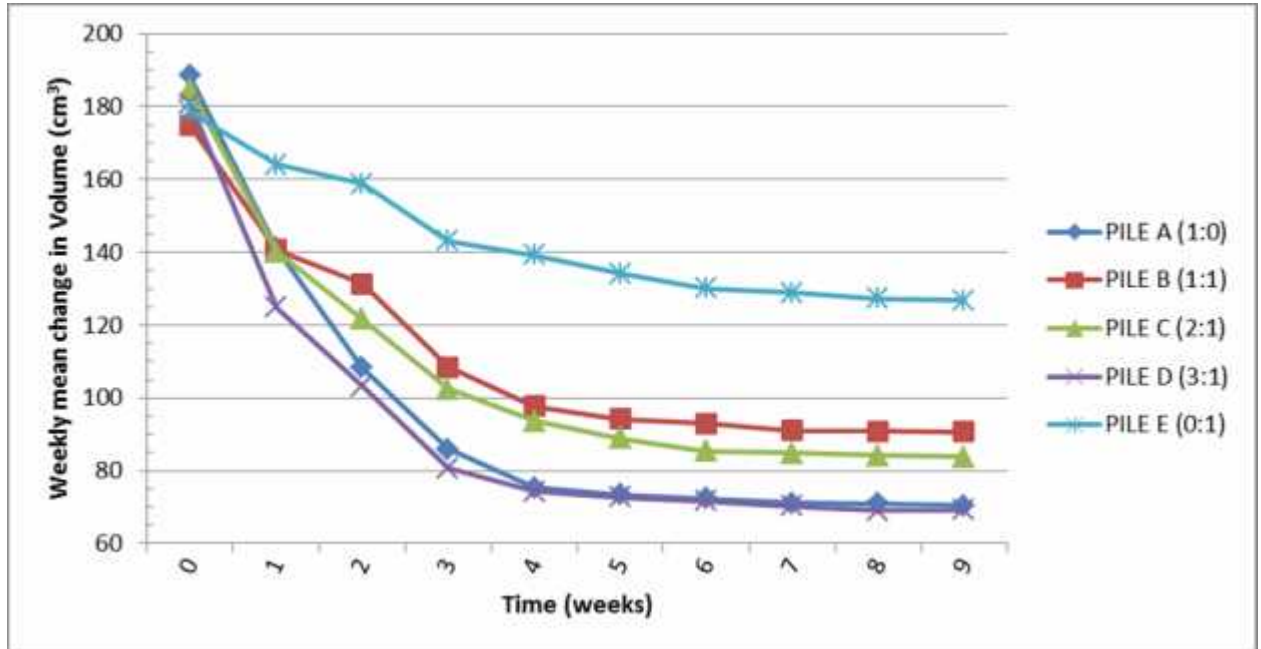


Figure 4.9: Weekly mean Changes in Volume in the different compost piles of Organic Solid Waste/ Dewatered Sludge.

Table 4.4: Mean results of physicochemical parameters in each pile at the end of the composting period

Parameter	Unit	Pile A (1:0)±SD	Pile B (1:1)±SD	Pile C (2:1)±SD	Pile D (3:1)±SD	Pile E (0:1)±SD
pH	-	7.5±0.28	7.3±0.57	7.4±0.14	7.3±0.28	5.7±0.28
Electrical Conductivity (EC)	dS/m	1.38±0.01	1.060±0.00	1.6±0.07	1.17±0.01	0.65±0.03
Moisture Content (MC)	%	30.20±1.13	41.42±2.15	35.60±0.85	29.43±0.47	51.92±1.57
Total Solids (TS)	%	69.80±1.13	58.58±2.15	64.40±0.85	70.57±0.47	48.08±1.57
Ash Content	%	60.04±2.31	55.16±0.34	56.91±0.28	58.06±0.91	45.69±0.20
Organic Matter (OM)	%	39.96±2.31	44.84±0.34	43.09±0.28	41.94±0.91	54.31±0.20
Total Carbon (C)	%	27.44±0.48	30.03±0.52	29.91±0.72	28.33±0.04	33.99±0.08
Total Nitrogen (N)	%	1.61±0.07	2.59±0.13	2.03±0.24	2.94±0.45	3.08±0.16
Carbon/Nitrogen ratio (C/N)	-	17.04±1.05	11.6±0.37	14.73±2.11	9.64±1.51	11.04±0.53
Phosphorus (P)	%	0.50±0.04	0.93±0.04	1.08±0.03	0.7±0.03	1.31±0.01
Potassium (K)	%	1.21±0.03	0.59±0.00	0.81±0.00	0.77±0.01	0.14±0.01
Magnesium (Mg)	%	0.30±0.04	0.58±0.03	0.18±0.03	0.39±0.08	0.19±0.01
Calcium (Ca)	%	1.28±0.01	3.44±0.08	3.12±0.14	2.72±0.10	2.56±0.04

Ratios are in Organic Solid Wastes/ Dewatered Sewage Sludge

Results of initial metal content in each compost pile after composting as shown in table 4.5. All the piles recorded metal content between 0.001 and 0.29 mg/kg at the end of composting as shown in table 4.5. Each pile had its metal content reduced at the end of composting as shown in tables 4.2 and 4.5. Pile 1:1 recorded the highest Zinc content of 0.29 mg/kg and the least Zinc content of 0.01 mg/kg was recorded by pile 1:0 at the end of the composting period as shown in table 4.5.

Table 4.5: Mean results of Metal content in each pile at the end of the composting period

Parameter	Unit	Pile A (1:0)±SD	Pile B (1:1)±SD	Pile C (2:1)±SD	Pile D (3:1)±SD	Pile E (0:1)±SD
Cadmium (Cd)	mg/kg	0.001±0.00	0.003±0.00	0.001±0.00	0.004±0.00	0.002±0.00
Chromium (Cr)	mg/kg	0.005±0.00	0.001±0.00	0.003±0.00	0.01±0.00	0.093±0.00
Copper (Cu)	mg/kg	0.09±0.00	0.11±0.01	0.04±0.01	0.05±0.00	0.12±0.01
Lead (Pb)	mg/kg	0.001±0.00	0.003±0.00	0.003±0.00	0.003±0.00	0.02±0.00
Zinc (Zn)	mg/kg	0.01±0.00	0.29±0.03	0.16±0.07	0.12±0.03	0.15±0.06

Ratios are in Organic Solid Wastes/ Dewatered Sewage Sludge.

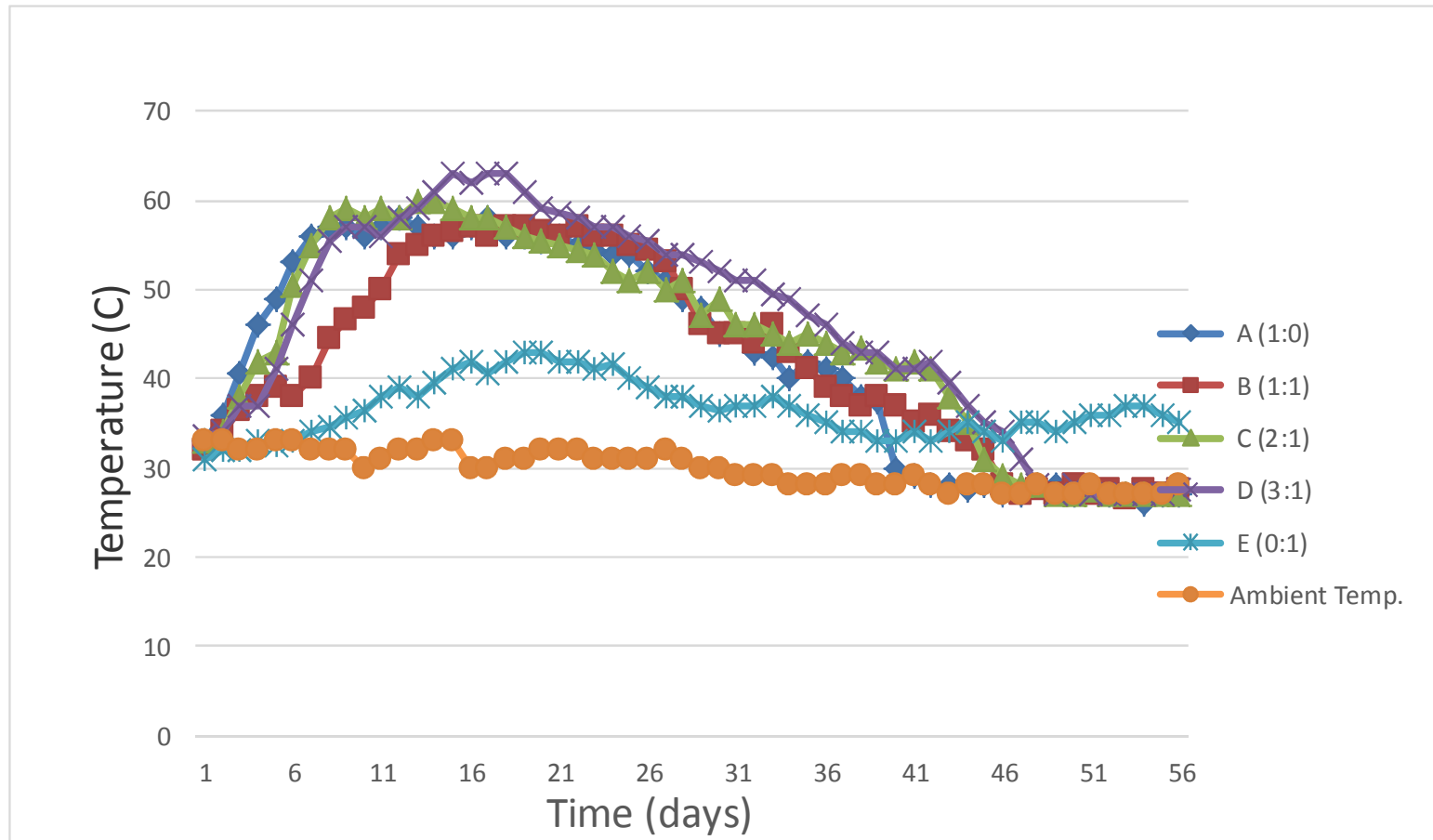
Results of Initial Biological Properties (Coliforms and *E. coli*) in each compost pile after composting is shown in table 4.6. Pile 0:1 ended with the highest number of total coliform of 9.15×10^8 CFU/g while pile 3:1 recorded the least number of total coliform of 2.35×10^3 CFU /g at the end of composting as shown in table 4.6. Again pile 3:1 recorded the least number of *E. coli* (9.15×10 CFU /g) as well as Faecal coliform (2.15×10^2 CFU /g) at end of composting. Each pile experienced more than a 99 percent reduction in Total coliforms and Faecal coliforms as shown in table 4.6 below. There was an 80.43 percent increase in the number of *E. coli* in pile 0:1. All the other piles had a more than 96 percent reduction in *E. coli* as shown in table 4.6 below.

Table 4.6: Mean results of content of biological parameters (Coliforms and *E.coli*) in each pile before and after the composting period with percentage reduction (-) or increase (+).

Parameter	Unit	Piles	Before Composting	After Composting	Percentage Reduction or Increase (%)
Total Coliforms	CFU/g	(1:0)±SD	$2.35 \times 10^9 \pm 7.07 \times 10^7$	$2.40 \times 10^3 \pm 0.00$	-99.90
		(1:1)±SD	$9.15 \times 10^{11} \pm 2.12 \times 10^{10}$	$9.15 \times 10^4 \pm 2.12 \times 10^3$	-99.99
		(2:1)±SD	$9.15 \times 10^{10} \pm 2.12 \times 10^9$	$4.15 \times 10^4 \pm 2.12 \times 10^3$	-99.99
		(3:1)±SD	$4.15 \times 10^8 \pm 2.12 \times 10^9$	$2.35 \times 10^3 \pm 7.07 \times 10$	-99.99
		(0:1)±SD	$4.15 \times 10^{13} \pm 2.12 \times 10^{12}$	$9.15 \times 10^8 \pm 2.12 \times 10^7$	-99.99
Faecal Coliforms	CFU/g	(1:0)±SD	$9.15 \times 10^7 \pm 2.12 \times 10^6$	$2.30 \times 10^2 \pm 0.00$	-99.99
		(1:1)±SD	$4.15 \times 10^{10} \pm 2.12 \times 10^6$	$2.15 \times 10^3 \pm 2.12 \times 10^2$	-99.99
		(2:1)±SD	$9.15 \times 10^8 \pm 2.12 \times 10^6$	$4.15 \times 10^2 \pm 2.12 \times 10$	-99.99
		(3:1)±SD	$2.35 \times 10^8 \pm 7.07 \times 10^6$	$2.15 \times 10^2 \pm 2.12 \times 10$	-99.99
		(0:1)±SD	$4.15 \times 10^{12} \pm 2.12 \times 10^{11}$	$9.15 \times 10^6 \pm 2.12 \times 10^5$	-99.99
<i>E. coli</i>	CFU/g	(1:0)±SD	$9.15 \times 10^5 \pm 2.12 \times 10^4$	$4.15 \times 10^2 \pm 2.12 \times 10$	-99.95
		(1:1)±SD	$2.30 \times 10^5 \pm 0.00$	$9.15 \times 10^3 \pm 2.12 \times 10^2$	-96.02
		(2:1)±SD	$2.10 \times 10^5 \pm 0.00$	$4.15 \times 10^2 \pm 2.12 \times 10$	-99.80
		(3:1)±SD	$1.50 \times 10^5 \pm 0.00$	$9.15 \times 10 \pm 2.12$	-99.94
		(0:1)±SD	$2.30 \times 10^5 \pm 0.00$	$4.15 \times 10^5 \pm 2.12 \times 10^4$	+80.43

Ratios are in Organic Solid Wastes/ Dewatered Sewage Sludge.

Figure 4.10 shows typical temperature variations experienced during the composting. All the piles had their temperatures increased to a point before declining. Pile 3:1 attained the maximum temperature of 63°C on the 15th, 17th and 18th days; pile 2:1 peaked temperature was 60°C on the 13th and 14th days; pile 1:0 had a peak temperature of 58°C on the 12th and 17th days; pile 1:1 recorded a maximum temperature of 57°C on the 16th, 18th, 19th and 22nd days and pile 0:1 recorded a maximum temperature of 43°C on the 19th and 20th days of composting. Each of the piles stabilized at the end of composting except pile 0:1 as shown in the figure (fig. 10).



Ratios are in Organic Solid Wastes/ Dewatered Sewage Sludge.

Figure 4.10: Temperature profile of each pile with respect to time (days)

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Physicochemical Parameters

5.1.1 Temperature

Temperature which is as a result of microbial activity is an important factor in a composting process. High temperatures destroy pathogenic bacteria and protozoa and weed seeds, which are detrimental to health and agriculture when final compost is used on the land.

By the standard of best practice for temperature of a formulated compost pile, it is recommended to manage pile to achieve an average temperature greater than or equal to 65°C (65°C) for at least 3-7 days or 55°C for at least 14 days if the system of composting is an out-door (with or without a shed) windrow system (Bertoldi, 1983). In the early stages of composting, there was rapid decomposition of readily available biodegradable organic matter as observed in the first 4 weeks amongst the piles. This process was associated with heat generation as a result of biochemical reaction of microorganisms. This saw all the piles temperature, except pile E (0:1); (organic solid wastes/ dewatered sewage sludge) move from the mesophilic temperatures (30 to 45°C) to thermophilic temperatures (temperatures higher than 45°C).

An average initial temperature of each pile was 32°C with an ambient temperature of 33°C. Just after one week, thermophilic temperatures (temperatures higher than 45°C) were recorded for piles 1:0, 2:1 and 3:1. Pile 1:1 begun to record thermophilic

temperatures (temperatures higher than 45°C) after the 8th day of composting. This could be attributed to the high amount of organic carbon at the initial stage of composting and adequate aeration (Bajsa *et al.*, 2004). Pile 0:1 could not attain the thermophilic phase (a phase with temperatures higher than 45°C) of composting which could be due to a relatively low amount of readily biodegradable carbon and inadequate aeration (Janda and Falkowski, 2003).

Pile A (1:0; organic solid wastes/ dewatered sewage sludge) maintained a thermophilic phase (a phase with temperatures higher than 45°C) for a period of 28 days and temperatures of 55 to 58°C for 16 days which was essential for sanitizing the final compost in terms of pathogens. Pile C (2:1; organic solid wastes/ dewatered sewage sludge) maintained a thermophilic phase (a phase with temperatures higher than 45°C) for 27 days and temperatures of 55 to 60°C for 16 days while Pile D (3:1; organic solid wastes/ dewatered sewage sludge) for a period of 19 days maintained a thermophilic phase as well as temperatures from 55 to 63°C for 19 days. All of these conform with the United States Environmental Protection Authority standards (USEPA, 1995) and (Bertoldi, 1983) for out-door pile for maximum pathogenic destruction.

Pile E (0:1; organic solid wastes/ dewatered sewage sludge) could not maintain a temperature above 43°C which could be due to relatively low amount of readily degradable carbon and less aeration. Due to this, there was an 80.43% increase in *E. coli* at the end of composting in this pile.

After the 40th day, each of the pile temperature begun to approach the ambient temperature with the exception of the pile with the ratio of 0:1 (organic solid wastes/ dewatered sewage sludge). This was sustained rather than the previous reheating after turning that was observed which was an indication that decomposition had slowed down which agrees with Nelson *et al.* (2006). Thus, the piles were maturing. After 48 days, all the piles, except pile E, had cooled down to the ambient temperature. This was a signal that the piles were cured.

5.1.2 pH

pH is a measure of active acidity in the feedstock or compost. Most compost have a pH between 6 and 8 (Strom, 1985). There was a gradual decrease in all piles at the initial stages which agree with the findings of Brinton, (2000). This could be attributed to mineralization of organic matter by bacteria that form acids and anoxic fermentation due to large oxygen consumption by oxic bacteria. This rapid metabolic degradation of the acid liberated alkaline ammonia compounds. After 4 weeks, there was a gradual increase in pH in all piles except Pile E which continued to decrease. This could be attributed to slow metabolic activity at this stage of the composting.

Most finished composts will have pH values in the range of 5.0 to 8.5 (Brinton, 2000). And it is observed that this pH range was recorded throughout the composting period which would have enhanced microbial activity. By the end of the composting period, all but Pile E recorded pH within 7.3 and 7.5. Pile E (0:1; organic solid wastes/ dewatered sewage sludge) a pH of 5.7 (acidic) after the 9th week. Ideal pH depends on compost use.

A lower pH is preferred for certain ornamental plants while a neutral pH is suitable for most applications. pH is not a measure of the total acidity or alkalinity and cannot be used to predict the compost effect on soil pH (Brinton, 2000).

5.1.3 Moisture content and Total Solids

The ideal moisture content for composting will depend on the water holding capacity of the materials being composted. And moisture content in a compost blend is an important variable as it provides a medium for transport of dissolved nutrient required for metabolic and physiological activities of microorganisms according to McCartney and Tingley (1998). In general, high organic matter materials have higher water holding capacity and a higher ideal moisture content. A typical starting compost mix will have an ideal % solids content of 35-55 % (65- 45 % moisture). Finished compost should have a percentage solids content of 50-60 % (50-40 % moisture) according to Butler *et al.* (2001).

Initially Pile E (0:1) recorded 70.12% moisture content, Pile B (1:1) 63.55%, Pile A (1:0), Pile C (2:1) 59.88% and Pile D (3:1) 58.21% all in the ratio of Organic solid waste/Dewatered sewage sludge. With time, moisture content dropped gradually. This was due to the release of moisture from the piles through water evaporation as heat was generated from microbial action. The normal range was sustained by the addition of water throughout the composting to prevent drying and too much moisture. The moisture content of Pile E was relatively high throughout.

As moisture content decreased, total solids increased as they share an inverse relationship. Pile D (3:1) recorded the highest total solids (70.57%) at the end of composting followed by Pile A (1:0) 69.8%, Pile C (2:1) 64.4%, Pile B (1:1) 58.58% and Pile E (0:1) 48.08. Analysis of variance between the final moisture content and total solids was significant ($p < 0.05$).

5.1.4 Organic Matter and Ash content

During composting, there is conversion of biodegradable organic matter into volatile Carbon dioxide (CO_2) and H_2O and this is removed from the compost material into the atmosphere (Edriss *et al.*, 2006).

Organic matter (OM) was high in each of the piles at the initial stage. Pile A (1:0; organic solid wastes/ dewatered sewage sludge) had the highest of 78.86% organic matter on day one of constituting the piles. The organic matter decreased gradually with time after a rapid initial decrease in the first three (3) weeks. The initial rapid decrease could be attributed to high rate of degradation of organic materials as a result of higher microbial activity as the composting process moved from a mesophilic phase to a thermophilic phase. However, Pile E (0:1; organic solid wastes/ dewatered sewage sludge) rate of decomposition was slower as it was difficult to reach a thermophilic phase. There is no ideal organic matter level for feedstock (initial ingredients) or finished compost (Brinton, 2000). The general decrease recorded over time was an indication of gradual stabilization of the organic matter forming humic material.

According to Brinton (2000), the organic matter content (dry weight basis) of typical feedstocks and starting mixes will be greater than 60 % while that of finished compost will be in the range of 30-70 %. Organic matter content (dry weight basis) of 50-60 % is desirable for most compost uses.

Pile A (1:0) begun with 78.86% organic matter and 39.96% after composting; Pile B (1:1) begun with 72.88% and ended with 44.84%; Pile C (2:1) started with 76.82% and ended with 43.09%; Pile D (3:1) with 77.90% and ended with 41.94% while Pile E (0:1) begun with 66.7 and ended with 54.31% all in the ratio of Organic solid waste/ Dewatered sewage sludge. Statistically, the difference in the organic matter content after composting in the piles was significant ($p < 0.05$).

Ash content is a measure of the inorganic residual material left after burning the oven-dried compost sample or material $500 \pm 50^\circ\text{C}$. It has an inverse relationship with the organic matter content. Thus as the organic matter decreased during composting, Ash content increased over the same period. Pile A (1:0) ended with 60.04% Ash content having begun with 21.14%; Pile B (1:1) from 27.12% to 55.16%; Pile C (2:1) from 23.18 to 56.91%; Pile D (3:1) from 22.1% to 58.06% and Pile E (0:1) from 33.30% to 45.69%. The amount of ash in compost or composting material reflects the microbial level of decomposition of organic matter and stabilization during composting (Masciandaro *et al.*, 2000).

5.1.5 Carbon, Nitrogen and Carbon-to-Nitrogen ratio (C/N)

It is known that a large proportion of the initial organic matter is mineralized during the composting process, leading to a faster decrease in total organic carbon at the beginning of the process because of the degradation of the most easily biodegradable organic matter fractions (Nattinpong and Alissara, 2006).

Apart from Pile E (0:1; organic solid waste/ dewatered sewage sludge) that maintained a relatively slow reduction in carbon during the entire composting period, from 41.89% to 33.99% (an 18.86% carbon loss); Piles A (1:0), B (1:1), C (2:1) and D (3:1) recorded a high rate of degradation of carbon in the first three (3) weeks of composting. Pile A (1:0; organic solid waste/ dewatered sewage sludge) ended with 27.44% carbon content haven begun with 54.23%, a 49.4% carbon loss; Pile B (1:1 organic solid waste/ dewatered sewage sludge) ended with 30.03% carbon from 51.46%, a 41.6 loss; Pile C (2:1 organic solid waste/ dewatered sewage sludge) haven begun with 50.43% ended with 29.91%, a 40.69% carbon loss and Pile D (3:1, organic solid waste/ dewatered sewage sludge) started with 46.31% to 28.33%, a 38.83% carbon loss.

In all the Piles, total nitrogen increased slightly over the entire composting period even though there was a slight decrease after the second week due to peak microbial activity during that period as microorganisms required nitrogen for protein formation. And as the compost mass decreased, total nitrogen began to rise again due to loss of dry mass in terms of carbon dioxide, water loss by evaporation and activities of nitrogen fixing bacteria. Thus as carbon content decreased as a result of CO₂ loss, total nitrogen increased according to Rodale, (1960) which also agrees with Ajay and Kazmi (2007)

report which noticed an increase in total nitrogen content after 20 days of composting which indicated it might have been due to net loss of dry mass in terms of carbon dioxide and water loss by evaporation caused by heat evolved during oxidation of organic carbon.

Generally, composts that have carbon/nitrogen ratios greater than 30:1 will require additional nitrogen when mixed with the soil for the purpose of growing plants. The larger the ratio, the greater the amount of nitrogen that will be needed. The extra nitrogen allows the soil microorganisms to multiply rapidly, without taking nitrogen from the soil and causing nitrogen deficiency in the plant. C/N ratio is thus a measure of the maturation of compost. Compost with C/N ratio 20:1 or less could be considered as matured (Nattipong and Alissara, 2006). C/N ratio generally decreased because carbon was lost from the piles as a result of microbial activity releasing volatile carbon dioxide and water. All the piles ended with a C/N ratio less than 18:1. Pile A (1:1) ended with C/N ratio of 17.04 from 37.66; Pile B (1:1) 11.6 from 21; Pile C (2:1) 14.73 from 34.31; Pile D (3:1) 9.64 from 22.81 and 11.04 from 14.6 for Pile E (0:1). Due to Pile E's poor decomposition rate, it witnessed the lowest decline in the C/N ratio over the composting period.

5.1.6 Volume of Piles

The entire period of composting registered considerable reduction in compost volume for all the compost setup. Volumetric reduction is an indication of pile settling or extent of degradation (better determined using the compost organic matter). Hence, from the graph above (fig. 4.10) Piles A (1:0, organic solid waste/ dewatered sewage sludge) and D (3:1, organic solid waste/ dewatered sewage sludge) showed the highest change in volume

by the end of the composting process. This is an indication that these piles had high amount of organic matter which facilitate high rate of degradation. Pile A (1:0) initial volume of 188.57 cm³ was reduced to 70.53 cm³ (a 62.59% volume loss); Pile B (1:1) from 175.05 cm³ to 90.67 cm³ (a 48.20% loss); Pile C (2:1) from 184.8 cm³ to 83.9 cm³ (a 54.6% loss); Pile D (3:1) from 181.03 cm³ to 69.15 cm³ (a 61.8% loss) and Pile E (0:1) from 178.69 cm³ to 126.69 cm³ (a 29.1% loss). This indicates that piles that had high amount of organic solid waste experienced high volume reduction which also depicts high rate of degradation leading to loss of organic carbon in the form of carbon dioxide and water. This was in agreement with Hartenstein and Hartenstein (1981) who reported 50% loss in volume when composting manure.

The rate of volume reduction was observed to be faster at the initial stage of composting but getting to the end of the process which presupposes that readily decomposable organic materials had been exhausted with time leaving materials that could not be readily decomposed. The final volumes between all the piles were statistically significant ($p < 0.05$).

5.1.7 Electrical Conductivity

The Electrical conductivity (EC) was within range for each of the formulations (piles). According to Strom (1985) EC is related to the total soluble salts dissolved in the slurry and is measured in dS/m. The highest EC values were observed in Pile A (1:0, organic solid waste/ dewatered sewage sludge), recording an initial average EC of 1.64 dS/m and 1.38 dS/m in the final compost because of the high amount of food waste in the organic solid waste which agrees with Epstein (1998). Composts typically have EC ranging from

1 to 10 dS/m Brinton (2000) asserts. High salinity may be toxic to plants. Ideal soluble salt levels will depend on the end use of the compost. Final compost blends with soil or container media/potting mixes should be less than 4 dS/m and testing prior to use is recommended.

5.1.8 Macronutrients

Nitrogen (N), Phosphorus (P, usually expressed as P_2O_5), and Potassium (K, usually expressed as K_2O) are the three nutrients utilized by plants in the greatest quantities, and therefore, are the nutrients most often contained in commercial and retail fertilizers (Brinton, 2000). And generally, changes in these and other macronutrients during composting were mainly due to mineralization as a result of microbial activities. Phosphorus content increased significantly in all the piles over the composting period. This could be due to organic matter decomposition which led to the net loss of dry mass which must have generally concentrated phosphorus which agrees with Nattipong and Alissara (2006). Pile A (1:0), one composed of only organic solid waste ended with the highest Potassium. This was an indication that the organic solid waste was a rich source of potassium. Although concentrations of nutrients found in compost are typically not high, in comparison to most fertilizer products, compost is usually applied at much greater rates, and therefore, can represent a significant cumulative quantity. In general, nutrients found in compost are in an 'organic' form thus released slowly as the compost decomposes. Aside from N, P and K, Calcium (Ca) and Magnesium (Mg) were also monitored. Calcium content in all the piles increased significantly over the composting period which could be attributed to calcium mineralization during decomposition as well

as reduction in compost volume. However Magnesium content decreased amongst all the piles over the composting period even though it was not that significant in Pile A (1:0) relative to the other piles.

5.1.9 Heavy Metals

There was general reduction in metal content in all the piles. This reduction may have resulted from the complexing action of the humic compounds formed (Wilson *et al.*, 1983). Heavy metal levels were generally lower than the recommended limit by the USA EPA as shown in Table 2.2 above.

5.2 Biological Properties

Generally, the high rate of pathogenic level reduction could be attributed to the thermophilic phase of the composting process. And coliforms and other pathogens are key indicators for the overall compost sanitary quality. The percentage reductions in total coliforms in the various formulations after composting were above 99% of the initial value. Even though Pile E (0:1; organic solid waste/ dewatered sewage sludge) which began with 4.15×10^{13} CFU/g and ended with 9.15×10^8 CFU/g, a 99.99% reduction (Table 4.6), it still did not meet international standards for a well sanitized compost. This was an indication that coliforms were very high in the sewage sludge.

By the US EPA standard (1995), faecal coliform in final compost must not be more than 1000 CFU/g (or must not be more than 3 in terms of \log_{10}). Again, it was observed that the final composts of Piles A (1:0), at the end of composting; C (2:1) and D (3:1) were well sanitized. While Pile B (1:1; organic solid waste/ dewatered sewage sludge) was a

little above the US EPA standard (1995), Pile E (0:1; organic solid waste/ dewatered sewage sludge) value at the end of composting was way above the standard value for a well sanitized compost in terms of faecal coliforms. Pile E (0:1) recorded a faecal coliform value of 9.15×10^6 CFU/g at the end of composting. This was an indication of high pathogenic conditions in Pile E (0:1) and the fact that it could not attain a thermophilic condition during the composting period. The highest reduction was achieved in Pile D (3:1) because it achieved temperatures greater than 55°C for period of 19 days which is good for pathogenic destruction (McKinley and Vestal, 1984). Like the total coliform, turning frequency influences faecal coliform level reduction positively. As expressed by US EPA (1995), the thermophilic temperature of 45°C or more contributed to the various pathogen reduction levels.

Piles A (1:0), C (2:1), and D (3:1) conformed with that of Brinton (2000) of <3 *E. coli*/g. Pile A (1:0; organic solid waste/ dewatered sewage sludge) recorded 2.62 *E. coli*/g in the final compost; Pile B (1:1; organic solid waste/ dewatered sewage sludge) 3.96 *E. coli*/g; Pile C (2:1; organic solid waste/ dewatered sewage sludge) 2.62 *E. coli*/g; Pile D (3:1; organic solid waste/ dewatered sewage sludge) 1.96 *E. coli*/g and Pile E (0:1 organic solid waste/ dewatered sewage sludge) 5.62 *E. coli*/g. Bertoldi *et al.*, (1983) demonstrated that composting animal manure for 40 days during which a temperature of >60 °C (140 °F) is maintained for at least 5 days is effective at removing *E. coli*. This was not the case as this kind of temperature was not attained in Pile E (0:1). The highest temperature attained in Pile E (0:1) was 43°C.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The ideal formulation feedstock of co-composting organic solid waste and dewatered sewage sludge at the Chirano Gold Mines site was successful. Thus, as per the quality of the compost produced from the different piles examined showed that the quality of compost produced were within an acceptable range of the United States EPA (1995). The best formulation was 3:1 (organic solid waste/ dewatered sewage sludge) followed by 2:1 (organic solid waste/ dewatered sewage sludge) as well as 1:0 (organic solid waste/ dewatered sewage sludge) and 1:1 (organic solid waste/ dewatered sewage sludge) in that order.

Formulations (piles) A (1:0; organic solid waste/ dewatered sewage sludge), B (1:1; organic solid waste/ dewatered sewage sludge), C (2:1; organic solid waste/ dewatered sewage sludge) and D (3:1; organic solid waste/ dewatered sewage sludge) produced good composts. Each of these piles had their compost well sanitized in terms of faecal coliforms and *E. coli*. Pile E (0:1) could not also attain a thermophilic phase necessary for the destruction of pathogenic organisms. The rate of decomposition in Pile E was slow. But Pile E (0:1; organic solid waste/ dewatered sewage sludge) ended with a pH of 5.7 which is more acidic instead of close to neutral for soil amendment.

6.2 Recommendations

Since large quantities of organic waste and dewatered sewage sludge are generated on site, it is recommended that it should be used to produce compost. This will help achieve the company's aim of reducing waste to the landfill as well as use the compost for its reclamation exercise. Studies should be carried out on the effect of turning regimes on compost quality.

REFERENCES

- Ajay, S.K. and Kazmi, A.A., (2007). Rotary Drum Composting of Mixed Organic Waste based on different C/N ratios. Proceedings of the International Conference on Sustainable Solid Waste Management, Chennai, India. Pp. 258-265.
- Allen, A.R., (2001). Containment landfills: The myth of sustainability. J. Eng. Geol., 60, 3-19
- Anderson, J.G., (1991). Treatment of wastes by composting, In Senior E (ed) Microbiology of Landfill sites. CRC Press Inc., Boca Raton.
- Anon, (1994). Centre for disease control and prevention. Food borne outbreaks of enterotoxigenic *Escherichia coli*. Rhode Island and New Hampshire, MMWR, 43: 81-89.
- Association of Official Analytical Chemists (2005).
- Atagana, H.I., Haynes RJ, Wallis FM (2003). Co-composting of soil heavily contaminated with creosote with cattle manure and mixed vegetable waste. Soil and Sediment Contamination.
- Bajsa O., Nair J., Mathew, K. and Ho, G.E., (2004). Pathogen dies off in vermicomposting process. Paper presented at the International Conference on Small Water and Wastewater Treatment Systems, Perth, 2004.
- Ball, J.M. and Novella, P.H., (2003) Coastal Park Landfill: leachate plume migration and attenuation. In: Christensen, T.H., Cossu, R., Stegmann, R. (Eds.), Proceedings Sardinia 2003, Ninth International Landfill Symposium, CISA Publisher.
- Bardos, R.P., Forsythe S. and Westlake, K., (1996). The co-treatment of municipal and industrial waste. In: de Bertoldi M, Sequi P, Lemmes B, Papi T (eds) The Science of Composting. Blackie Academic and Professional, London.

- Barrett, A., Lawlor, J. (1995). The economics of waste management in Ireland. Economic and Social Research Institute, Dublin. 129pp
- Bartone, C.,(2000). Strategies for Improving Municipal Solid Waste Management: Lessons from World Bank Lending and CWG Activities. Workshop on Planning for Sustainable and Integrated Solid Waste Management, Manila, 18-22 September 2000. Washington, DC: Urban Management Division, World Bank.
- Basnayake, B. F. A., (2001). Municipal Solid Waste for Organic Agriculture. A paper presented at the annual session of the National Agricultural Society for Sri-Lanka on “Organic Agriculture”: Trends and Challenges.
- Bertoldi, M.D., Vallini G. and Pera, A. (1983). The Biology of Composting. Waste Management Resource. 1: pp. 157-176
- Beyer, W.N., Chaney, R.L. and Mulhern, B., (1982). Heavy metals concentrations in earthworms from soil amended with sewage sludge. Journal of Environmental Quality.
- Bezdicek, D., M. Fauci, D. Caldwell, and Finch, R.,(2000). Compost quality: New threats from persistent herbicides. Agrichemical and Environmental News.
- Bokx, W., (2002).Measuring Moisture by Feel. Biocycle February (2002).
- Brinton, W.F., (2000). Compost Quality Standards & Guidelines: An International View. Woods End Research Laboratory, Inc. 2nd may 2009.
<http://www.woodsend.org/pdf-files/nysar-ne.pdf>

- Butler, T.A., Sikora, L.J., Steinhilber, P.M. and Douglass, L.W., (2001). Compost age and sample storage effects on maturity indicators of biosolids compost. *Journal of Environmental Quality*, 30, 2141-2148.
- Buyuksonmez, F., Rynk, R., Hess, T. G., and Bechinski, E., (1999). Occurrence, degradation and fate of pesticides during composting. Part I: Composting, pesticides and pesticide degradation. *Compost Science and Utilization*.
- Cambardella, C.A., Richard, T.L., Russell, A., (2003). Compost mineralization in soil as a function of composting process. *European Journal of Soil Biology* V. 39, no. 3.
- Chakrabarti, Snigdha and Sarkhel, Prasenjit, (2003). *Economics of Solid Waste Management: A Survey of Existing Literature*. Economic Research Unit Indian Statistical Institute.
- Chang, Andrew C., Genxing Pan, Albert, L. Page and Takashi, Asano, (2001). *Developing Human Health-related Chemical Guidelines for Reclaimed Water and Sewage Sludge Applications in Agriculture*. Prepared for World Health Organization.
https://www.who.int/water_sanitation_health/wastewater/gwwuchemicals.pdf
- Chongrak, Polprasert, (2007). *Organic Waste Recycling: Technology and Management*.
- Cointreau, S. (1982). *Environmental Management of Urban Solid Wastes in Developing Countries [pdf]: A Project Guide*. Urban Development Technical Paper Number 5, World Bank, Washington DC.
- Cole, Victoria and Sinclair, A. John, (2002). *Measuring the Ecological Footprint of a Himalayan Tourist Center*. *Mountain Research and Development*. 22(2): 132-141, International Mountain Society and United Nations University.

- Daskalopoulos, E., Badr, O. and Probert, S.D., (1998). An Integrated Approach to Municipal Solid Waste Management. Resources, Conservation and Recycling. 24(1): 33-50.
- De Bertoldi, M., Vallini, G., Pera, A. and Zucconi, F., (1982). Comparison of three windrow composting system. BioCycle, 23, (2), 45- 50.
- Dominguez, J., Edward, C.A. and Webster, M., (2000). Vermicomposting of sewage sludge: effect of bulking materials on growth and reproduction of the earthworm *E. anderi*. Journal of Pedobiologia.
- Drescher, Silke and Zurbrügg, Chris, (2006). Decentralised composting: Lessons Learned and Future Potentials for Meeting the Millennium Development Goals. Solid waste, health and the Millennium Development Goals. CWG – WASH Workshop Paper no. 27.1 – 5 February in Kolkata, India.
- Edriss, B., Zazouli, A. M., Javad, B. and Anoushirvan, M. B., (2006). Evaluation of microbiological chemical parameters during wastewater Sludge Sawdust Co-composting. J. Appl. Sci. Environ. Mgt. Vol. 10(2) 115-119
- Edwards, C.A. and Fletcher, K.E., (1988) Interaction between earthworms and microorganisms in organic matter breakdown. Agriculture Ecosystems and Environment, 24, 235–247.
- Epstein, Eliot, (2011). Industrial Composting: Environmental Engineering and Facilities Management. CRC Press. Taylor and Francis Group. www.taylorandfrancis.com. 24 April, 2014.
- Epstein, E., (1998). Design and Operations of Composting Facilities: Public Health Aspect. <http://www.rdptech.com/tch15.htm>.

- Finstein, M.S., Miller F.C., and Strom P.F.,(1986). Waste treatment composting as a controlled system. In “Biotechnology” vol. 8, 363-398. Ed. W. Schoenborn, Publ. VCH, Weinheim, Germany.
- Fraser-Quick, G., (2002). Vermiculture – A sustainable total waste management solution. What’s New in Waste Management? Vol. 4, No. 6; pp. 13-16
- Garcia-Gomez, A, Roig, A, and Bernal M.P., (2003). Composting of the solid fraction of olive oil mill wastewater with olive leaves: organic matter degradation and biological activity. Bioresour. Technol. 86: 59-64. Garcia, C., T. Hernandez, and F. Costa, 1991. “The Influence of Composting on the Fertilizing Value of an Aerobic Sewage Sludge.” Plant and Soil, 136:269-272.
- Gershuny, G., (2011). Compost, Vermicompost and Compost Tea: Feeding the Soil on the Organic Farm; A Project of the Northeast Organic Farming Association. First Chelsea Green.
- Hadas, A. and Portnoy, R., (1994). Nitrogen and carbon mineralization rates of composted manures incubated in soil. J. of Environ. Qual. 23:1184-1189.
- Hammadi, M. A. E., Trabelsi, M., Jrad, A. and Hanchi, B., (2007). Analysis and Comparison of Toxicants between Tunisian Activated Sludge and Produced Compost. Research Journal of Environmental Sciences 1 (3): 122-126.
- Hartenstein, R. and Hartenstein, F., (1981). Physico-chemical changes affected in activated sludge by the earthworm *Eisenia fetida*. Journal of Environmental Quality, 10; 377–382.
- Haug, R. T., (1994). Composting Engineering Principles and Practices. New York, N.Y: Lewis Publisher.

- Hickman Jr. and Lanier, H. (1999). The Principles of Integrated Solid Waste Management. American Academy of Environmental Engineers, Annapolis, MD.
- Hoornweg, D., Thomas, L., et al. (1999). Composting and its Applicability in Developing Countries, Urban Waste Management, World Bank, Urban Development Division. Washington DC, USA.
- Hue, N. V., Ikawa, H., and Silva J. A., (1994). Increasing plant available phosphorus in an ultisol with a yard-waste compost.
- Inanc, B., Azni, I., Atsushi, T. and Shin-ichi, S., (2004). Development of a database of landfills and dump sites in Asian countries. J Mater Cycles Waste Management. 6: 97–103
- Jackson, D., (2003) National Office of Pollution Prevention. Inventory of Landfill Gas Recovery and Utilization in Canada.
- Janda, K. and Falkowski J., (2003). The adaption of microorganisms to high temperatures. Advances of Agricultural Sciences Problem Issues, 429, 117-122.
- Jokela, J. P., Kettunen, R. H. and Rintala, J. A., (2002): Methane and leachate pollutant emission potential from various fractions of municipal solid waste (MSW): effects of source separation and aerobic treatment. Waste Management and Research. 20(5): 424 33.
- Khawas, Vimal, (2003) Urban Management in Darjeeling Himalaya: A Case Study of Darjeeling Municipality. Mountain Forum. Accessed on August 15, 2013. <<http://web.archive.org/web/20041020031749/http://www.mtnforum.org/resources/library/khawv03e.htm>> Kruger Ralph

- Kraus, P. and Wilke, M., (1997). Schadstoffe in Bioabfallkompost. (Contaminants in bio-compost) Mull and Abfall 211-219.
- Mark, V.H., (1995). Compost Production and Utilization: A Grower's Guide, Issue 21514
- Masciandaro, G., Ceccanti, B., and Garcia, C. (2000) In-situ vermicomposting of biological sludges and impacts on soil quality. Journal of Soil Biology and Biochemistry, 32, 1015–1024.
- McCarthy J., (2002). Beneficial reuse (of sewage sludge vermicompost) in action. Water, March, 72–76.
- McCartney, D. and Tingley, J., (1998). Development of a rapid moisture content method for compost materials. Compost Science and Utilization. Vol. 6: 14-25.
- McKinley V.L. and Vestal J.R., (1984). Biokinetic analyses of adaptation and succession: microbial activity in composting municipal sewage sludge. Applied Environmental Microbiology, 47, 933-941.
- McMichael, Anthony J. 2000: The Urban Environment and Health in A World of Increasing Globalization: issues for developing countries. Bull World Health Organ. 78(9): 1117-1126.
- Medina, M.,(2002). Globalization, Development, and Municipal Solid Waste Management in Third World Cities.
- Methane to Markets Partnership (2004). Accessed online on September 15, 2013. <http://www.methanetomarkets.org/landfills/landfills-bkgrd.htm>

- Miroslav, R. and Vladimir N. B., (1998). Practical Environmental Analysis, Second Edition.
- Nattinpong, K. and Alissara, R., (2006). Effect of C/N ratio on the composting of cassava pulp with swine manure. Journal of Water and Environmental Technology. Vol. 4, No. 1.
- Nelson, V. L., Crowe, T. G., Shah, M. A. and Watson, L. G., (2006). Temperature and turning energy of composting feedlot manure at different moisture content in Southern Alberta. Canadian Biosystems Engineering.
- NRAES (1992). On-farm composting (Ed. Rynk, Robert). Natural Resource, Agricultural and Engineering Services Cooperative Extension, Cornell University.
- Obeng, L. A. and Wright, F. W., (1987). The Co-composting of Domestic Solid and Human Wastes. UNDP/ World Bank Integrated Resource Recovery Series GLO/80/004, GLO 80/0/007, Report No 7.
- Obiri-Danso, K., Weobeng, C. A. A., and Jones, K. (2005). Aspect of health-related microbiology of Subin, an urban river in Kumasi, Ghana.
- O'Leary, P. R., (1999). Decision-Maker's Guide to Solid-Waste Management
- OMRI (1998). Organic Materials Review Institute. Draft Standards, Compost Quality. Manuscript. Eugene Oregon
- Piccinini S, Rossi, L, Bonazzi G. and Dall'Orso, G., (1996). The Emilia- Romagna Experiment in animal manure composting, In: de Bertoldi M, Sequi P, Lemmes B, Papi T (eds) The Science of Composting.

- Pradhan, U. M., (2008). Sustainable Solid Waste Management in a mountain ecosystem: Darjeeling, West Bengal, India, November, 2008.
- Richard, T. and Woodbury, P.,(2002). The impact of separation of heavy metal contaminants in MSW composts. *Biomass& Bioenergy* Vol3-pp195-211
- Rodale, Jerome Irving, (1971). *The complete book of composting*
- Rodale, J.I., editor in chief. (1960). *The Complete Book of Composting*. Rodale Press, Emmaus, PA.
- Rynk, R., van de Kamp, M., Willson, G.G., Singley, M.E., Richard, T.L., Kolega, J.J., Gouin, F.R., Laliberty Jr. L., Kay, D., Murphy, D., Hoitink, H.A.J. and Brinton, W.F., (1992). *On-Farm Composting Handbook*. R. Rynk (Ed.) NRAES-54. 186p. Natural Resource, Agriculture, and Engineering Service. Ithaca, NY.
- Sinha, R.K. (2009). Earthworms: the miracle of nature and Charles Darwin's Unheralded Soldiers of Mankind & Farmer's Friends' (editorial) *The Environmentalist*, In press.
- Strauss, M., Montangero, A., Zurbrugg, C., Drescher, S., Olufunke, C. and Drechel, P., (2003) *Composting of faecal sludge and solid waste. A literature and State-of-Knowledge Review*. EAWAG-SANDEC/IWNI (Ghana) / French Ministry of Foreign Affairs Project report. P. O. Box 611, CN-8600 Duebendorf, Switzerland.
- Strom, P.F.,(1985). Effect temperature on bacterial species diversity in thermophilic solid-waste composting. *Applied and Environmental Microbiology*, 50, 899-905.
- Tester, C. F., (1990). Organic amendment effects on physical and chemical properties of a sandy soil. *Soil Sci. Soc. Am. J.* 65:1284-1292.

- Thorneloe, S. A., Keith, A. W., Subba, R. Nishtala, Sherry, Yarkosky and Maria Zannes (2002). The Impact of Municipal Solid Waste Management on Greenhouse Gas Emissions in the United States. Journal of the Air & Waste Management Association. 52: 1000-1011
- Tiquia, S. M., Wan, J. H. C. and Tam, N. F. Y., (2002). Microbial population dynamics and enzyme activity during composting. Compost science and utilization vol. 10: 150-161.
- UNECA (1996). Ninth conference of African Planners, Statisticians, and population and Information Scientists, Addis Ababa, 11-16 March 1996. http://www.uneca.org/eca_resources/Publications/DISD/old/planning%20conf/o stat.txt
- United States Composting Council, (2000). Field Guide to Compost Use. U.S. Composting Council, Hauppauge, New York.
- US EPA (1975), Office of Solid Waste Management Programs. Third Report to Congress: Resource Recovery and Source Reduction (SW-161).
- US EPA, (1995).A Guide to the Biosolids Risk Assessments for the EPA Part 503 Rule, United States Environmental Protection Agency, Office of Wastewater Management, EPA/832-B-93-005, 144 p.
- Venkateshwaran, Sandhya, (1994). Ecological, Economic and Social Dimensions, Economic and Political Weekly, November 5-12.
- Watanabe H., Kitamura T., Ochi S., and Ozaki M.,(1997). Inactivation of pathogenic bacteria under mesophilic and thermophilic condition. Water Science and Technology, 36, 25-32.

- Wen, G., Bates, T. E., Voroney, R. P., Winter, J. P. and Schellenbert, M. P., (1997). Comparison of phosphorus availability with application of sewage sludge, sludge compost, and manure compost. *Comm. Soil Sci. Plant Anal.* 28:1481-1497.
- Wilson G.B., Sikora L, and Parr, J.F., (1983). Composting of chemical industrial wastes prior to land application, In: Parr JF, Marsh PB, Kla, JM (eds) *Treatment of hazardous wastes*. Noyes Data Corporation, New Jersey, pp. 263-273
- World Bank (1999). *Decision Makers' Guide to Municipal Solid Waste Incineration*. Washington D.C
- Zerbock, O., (2003). *Urban Solid Waste Management: Waste Reduction in Developing Nations*. Michigan Technological University.
http://www.cee.mtu.edu/peacecorps/documents_july03/Waste_reduction_and_incineration_FINAL.pdf> (Accessed on 6th September, 2013)
- Zorpas, A., Constantinides, T., Vlyssides, A. G. and Haralambous, I., (2000). Heavy metal uptake by natural zeolite and metal partitioning in sewage sludge compost. *Biores Technol.*, 72: 113-119.
- Zurbrugg, C., 2003: *Solid Waste Management in Developing Countries*. SANDEC/EAWAG available on line Accessed on 6th September, 2013.
http://www.sandec.ch/SolidWaste/Documents/04-SWManagement/Basics_of_SWM.pdf

APPENDICES

APPENDIX A

Weekly mean Organic Carbon content (%) in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	54.21	50.13	46.6	35.26	33.51	30.25	28.15	27.96	28.35	27.1
PILE A2 (1:0)	54.25	50.09	46.7	35.2	33.1	30.25	28.61	27.78	26.67	27.78
MEAN±SD	54.23±0.03	50.11±0.03	45.65±0.07	35.23±0.04	33.41±0.29	30.25±0	28.38±0.33	27.87±0.13	27.51±1.19	27.44±0.48
PILE B1 (1:1)	51.69	47.52	38	36	33.87	31.9	31.22	30.6	30.14	29.66
PILE B2 (1:1)	51.23	46.92	38.26	34.68	34.21	33.72	32.1	31.04	30.74	30.4
MEAN±SD	51.46±0.33	47.22±0.42	38.13±0.18	35.34±0.93	34.04±0.24	32.81±1.29	31.66±	30.82±	30.44±	30.03±0.52
PILE C1 (2:1)	49.8	41.7	37.43	34.1	31.6	31.2	30.28	29.95	29.56	29.4
PILE C2 (2:1)	51.06	43.72	38.33	34.3	33.6	31.82	30.88	30.55	30.5	30.42
MEAN±SD	50.43±0.89	42.71±1.43	37.88±0.64	34.2±0.14	32.6±1.41	31.51±0.44	30.58±0.42	30.25±0.42	30.03±0.66	29.91±00.72
PILE D1 (3:1)	47	41.56	34	30.39	29.1	29	28.9	28.68	28.5	28.36
PILE D2 (3:1)	45.62	41	33.22	29.93	29.1	28.96	28.84	28.64	28.4	28.3
MEAN±SD	46.31±0.98	41.23±0.4	33.61±0.55	30.16±0.32	29.1±0	28.98±0.03	28.87±0.04	28.66±0.03	28.45±0.07	28.33±0.04
PILE E1 (0:1)	41.8	39.82	38.4	36.5	35.88	35.82	34.5	34.4	34.22	33.93
PILE E2 (0:1)	41.98	40	39.2	37.3	35.98	35.86	34.6	34.4	34.28	34.05
MEAN±SD	41.98±0.13	39.91±0.13	38.8±0.57	36.9±0.57	35.93±0.07	35.84±0.03	34.55±0.07	34.4±0	34.25±0.04	33.99±0.08

APPENDIX B

Weekly mean Nitrogen content (%) in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	1.4	1.45	1.49	2.02	2.23	2.41	2.06	1.98	1.74	1.66
PILE A2 (1:0)	1.48	1.65	1.45	1.9	1.99	2.21	1.92	1.38	1.64	1.56
MEAN±SD	1.44±0.06	1.55±0.14	1.47±0.03	1.96±0.08	2.11±0.17	2.31±0.14	1.99±0.1	1.68±0.42	1.69±0.07	1.61±0.07
PILE B1 (1:1)	2.51	2.53	2.5	3.33	3.22	3	2.8	2.67	2.65	2.5
PILE B2 (1:1)	2.39	2.45	2.54	3.49	3.26	3.06	2.92	2.89	2.77	2.68
MEAN±SD	2.45±0.08	2.49±0.06	2.52±0.03	3.41±0.11	3.24±0.03	3.03±0.04	2.86±0.08	2.78±0.16	2.71±0.08	2.59±0.13
PILE C1 (2:1)	1.49	1.4	1.73	3	2.88	2.71	2.53	2.49	2.29	2.2
PILE C2 (2:1)	1.45	1.36	1.63	2.76	2.24	2.55	2.45	2.29	2.01	1.86
MEAN±SD	1.47±0.03	1.38±0.03	1.68±0.07	2.88±0.17	2.56±0.45	2.63±0.11	2.49±0.06	2.39±0.14	2.15±0.2	2.03±0.24
PILE D1 (3:1)	1.89	1.97	2.46	2.9	3.1	2.73	2.66	2.66	2.63	2.62
PILE D2 (3:1)	2.17	2.33	3	3.22	3.36	3.33	3.3	3.28	3.28	3.26
MEAN±SD	2.03±0.2	2.15±0.25	2.73±0.38	3.06±0.23	3.23±0.18	3.03±0.42	2.98±0.45	2.97±0.44	2.95±0.46	2.94±0.45
PILE E1 (0:1)	2.85	3.06	2.87	3.33	3.35	3.15	3.27	3.17	2.98	2.97
PILE E2 (0:1)	2.89	3.2	3.01	3.47	3.39	3.55	3.59	3.25	3.32	3.19
MEAN±SD	2.87±0.03	3.13±0.1	2.94±0.1	3.4±0.1	3.37±0.03	3.35±0.28	3.43±0.23	3.22±0.06	3.15±0.24	3.08±0.16

APPENDIX C

Weekly mean Carbon-to-Nitrogen ratio (C/N) in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	38.72	34.57	31.28	17.46	15.03	12.55	13.67	14.12	16.29	16.33
PILE A2 (1:0)	36.66	30.36	32.21	18.53	16.74	13.69	14.9	20.13	16.26	17.81
MEAN±SD	37.66±1.46	32.33±2.98	31.05±0.66	18±0.76	15.83±1.21	13.1±0.8	14.26±0.87	16.58±4.25	16.28±0.02	17.04±1.05
PILE B1 (1:1)	20.59	18.78	15.2	10.81	10.52	10.63	11.15	11.26	11.37	11.86
PILE B2 (1:1)	21.44	19.15	15.06	9.94	10.49	11.02	10.99	10.74	11.1	11.34
MEAN±SD	21±0.6	18.96±0.26	15.13±0.1	10.36±0.62	10.51±0.02	10.83±0.28	11.07±0.11	11.09±0.37	11.23±0.19	11.6±0.37
PILE C1 (2:1)	33.42	29.79	21.64	11.37	10.97	11.51	11.97	12.03	12.91	13.36
PILE C2 (2:1)	35.21	32.15	23.52	12.43	15	12.48	12.6	13.34	15.17	16.35
MEAN±SD	34.31±1.27	30.95±1.67	22.55±1.33	11.9±0.75	12.73±2.85	11.98±0.69	12.28±0.45	12.66±0.93	13.97±1.6	14.73±2.11
PILE D1 (3:1)	24.87	21.1	13.82	10.48	9.39	10.62	10.86	10.78	10.84	10.82
PILE D2 (3:1)	21.02	17.6	11.07	9.3	8.66	8.7	8.74	8.73	8.66	8.68
MEAN±SD	22.81±2.72	19.18±2.47	12.31±1.94	9.86±0.83	9.01±0.52	9.56±1.36	9.69±1.5	9.65±1.45	9.64±1.54	9.64±1.51
PILE E1 (0:1)	14.67	13.01	13.38	10.96	10.71	11.37	10.55	10.85	11.48	11.42
PILE E2 (0:1)	14.53	12.5	13.02	10.75	10.61	10.1	9.64	10.58	10.32	10.67
MEAN±SD	14.6±0.1	12.75±0.36	13.2±0.25	10.85±0.15	10.66±0.07	10.7±0.9	10.1±0.64	10.68±0.19	10.87±0.82	11.04±0.53

APPENDIX D

Weekly mean Ash content (%) in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	20.89	24.75	46.34	58.78	59.66	60	60.9	61.13	61.51	61.67
PILE A2 (1:0)	21.39	23.21	41.24	48.56	48.62	52.08	52.94	54.27	55.29	58.41
MEAN±SD	21.14±0.35	23.98±1.09	43.79±3.6	53.67±7.23	54.64±7.81	56.04±5.6	56.92±5.63	57.7±4.85	58.4±4.4	60.04±2.31
PILE B1 (1:1)	26.67	34.6	40.3	48.64	50.12	52.55	53.61	54.34	54.84	54.92
PILE B2 (1:1)	27.57	36.42	41.24	50.1	52	52.99	54.19	54.56	55.08	55.4
MEAN±SD	27.12±0.64	35.51±1.29	40.77±0.66	49.37±1.03	51.06±1.33	52.77±0.31	53.9±0.41	54.45±0.16	54.96±0.17	55.16±0.34
PILE C1 (2:1)	22.78	33.46	44.02	49.12	50.8	51.34	52.76	54.26	55.39	56.71
PILE C2 (2:1)	23.58	34.1	45.72	50.7	51.2	51.38	54	54.82	55.97	57.11
MEAN±SD	23.18±0.57	33.78±0.45	44.87±1.2	49.91±1.12	51±0.28	51.36±0.03	53.38±0.88	54.54±0.4	55.68±0.41	56.91±0.28
PILE D1 (3:1)	22	32.93	43.2	49.7	51.66	52.49	53.04	55.62	53.37	57.42
PILE D2 (3:1)	22.2	35.33	45.1	51	53.78	54.89	55.22	56.2	57.83	58.7
MEAN±SD	22.1±0.14	34.13±1.7	44.15±1.34	50.35±0.92	52.72±1.5	53.69±1.7	54.13±1.54	55.91±0.41	57.1±3.15	58.06±0.91
PILE E1 (0:1)	34	37.99	40.1	42	42.95	43.43	44.85	44.81	45.44	45.83
PILE E2 (0:1)	32.6	36.95	38.14	40.82	41.01	42.31	42.69	44.07	44.48	45.55
MEAN±SD	33.3±0.99	37.47±0.74	39.12±1.39	41.41±0.83	41.98±1.37	42.87±0.79	43.77±1.53	44.44±0.52	44.96±0.68	45.69±0.2

APPENDIX E

Weekly mean Organic Matter (OM) content (%) in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	79.11	75.25	53.66	41.22	40.34	40	39.1	38.87	38.49	38.33
PILE A2 (1:0)	78.61	76.79	58.76	51.44	51.38	47.92	47.06	45.73	44.71	41.59
MEAN±SD	78.86±0.35	76.02±1.09	56.21±3.6	46.33±7.23	45.36±7.81	43.96±5.6	43.08±5.63	42.3±4.85	41.6±4.4	39.96±2.31
PILE B1 (1:1)	73.33	65.4	59.7	51.36	49.88	47.45	46.39	45.66	45.16	45.08
PILE B2 (1:1)	72.43	63.58	58.76	49.9	48	47.01	45.81	45.44	44.92	44.6
MEAN±SD	72.88±0.64	64.49±1.29	59.23±0.66	50.63±1.03	48.94±1.33	47.23±0.31	46.1±0.41	45.55±0.16	45.04±0.17	44.84±0.34
PILE C1 (2:1)	77.22	66.54	55.98	50.88	49.2	48.66	47.24	45.74	44.61	43.29
PILE C2 (2:1)	76.42	65.9	54.28	49.3	48.8	48.62	46	45.18	44.03	42.89
MEAN±SD	76.82±0.57	66.22±0.45	55.13±1.2	50.09±1.11	49±0.28	48.64±0.03	46.62±0.88	45.46±0.4	44.32±0.41	43.09±0.28
PILE D1 (3:1)	78	67.07	56.8	50.3	48.34	47.51	46.96	44.38	43.63	42.58
PILE D2 (3:1)	77.8	64.67	54.9	49	46.22	45.11	44.78	43.8	42.17	41.3
MEAN±SD	77.9±0.14	65.87±1.7	55.85±1.34	49.65±0.92	47.28±1.5	46.31±1.7	45.87±1.54	44.09±0.41	42.9±1.03	41.94±0.91
PILE E1 (0:1)	66	62.01	59.6	58	57.05	56.57	55.15	55.19	54.56	54.17
PILE E2 (0:1)	67.4	63.05	60.72	59.18	58.99	57.69	57.31	55.93	55.52	54.45
MEAN±SD	66.7±1	62.53±0.74	60.16±0.79	58.59±0.83	58.02±1.37	57.13±0.79	56.23±1.53	55.56±0.52	55.04±0.68	54.31±0.2

APPENDIX F

Weekly mean Magnesium (Mg) content (%) in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	0.5	0.7	1.94	1.55	1.53	0.7	0.63	0.45	0.35	0.33
PILE A2 (1:0)	0.3	0.6	1.1	0.91	0.89	0.56	0.55	0.41	0.29	0.27
MEAN±SD	0.4±0.14	0.65±0.07	1.52±0.59	1.23±0.45	1.21±0.45	0.63±0.1	0.59±0.06	0.43±0.03	0.32±0.04	0.3±0.04
PILE B1 (1:1)	1.5	2.07	2.66	2.33	1.01	1.34	1	0.7	0.63	0.6
PILE B2 (1:1)	1.6	2.19	2.68	2.33	0.97	1.26	0.78	0.52	0.54	0.56
MEAN±SD	1.55±0.07	2.13±0.08	2.67±0.01	2.33±0	0.99±0.03	1.3±0.06	0.89±0.16	0.61±0.13	0.59±0.06	0.58±0.03
PILE C1 (2:1)	0.61	0.59	2	0.9	0.8	0.62	0.53	0.41	0.25	0.2
PILE C2 (2:1)	0.61	0.57	1.8	0.84	0.76	0.6	0.53	0.39	0.21	0.16
MEAN±SD	0.61±0	0.58±0.01	1.9±0.14	0.87±0.04	0.78±0.03	0.61±0.01	0.53±0	0.4±0.01	0.23±0.03	0.18±0.03
PILE D1 (3:1)	0.88	0.84	2.35	0.9	0.75	0.79	0.69	0.53	0.33	0.45
PILE D2 (3:1)	0.9	0.82	2.21	0.78	0.63	0.71	0.63	0.49	0.25	0.33
MEAN±SD	0.89±0.01	0.83±0.01	2.28±0.1	0.84±0.08	0.69±0.08	0.75±0.06	0.66±0.04	0.51±0.03	0.29±0.06	0.39±0.08
PILE E1 (0:1)	0.91	0.89	1.8	0.58	0.61	0.89	0.19	0.23	0.2	0.18
PILE E2 (0:1)	1.07	0.97	2	0.7	0.65	1.01	0.27	0.29	0.2	0.2
MEAN±SD	0.99±0.11	0.93±0.06	1.9±0.14	0.64±0.08	0.63±0.03	0.95±0.08	0.23±0.06	0.26±0.04	0.2±0	0.19±0.01

APPENDIX G

Weekly mean Calcium (Ca) content (%) in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	0.87	1.55	1.99	1.54	1.4	1.22	1.65	1.09	1.2	1.29
PILE A2 (1:0)	0.89	1.45	1.85	1.42	1.32	1.2	1.55	0.97	1.12	1.27
MEAN±SD	0.88±0.01	1.5±0.07	1.92±0.1	1.48±0.08	1.36±0.06	1.21±0.01	1.6±0.07	1.03±0.08	1.16±0.06	1.28±0.01
PILE B1 (1:1)	2.99	3.05	3.07	2.31	2.1	2	1.98	2.5	2.97	2.5
PILE B2 (1:1)	3.09	3.17	3.33	2.41	2.1	1.3	1.88	2.52	2.95	2.38
MEAN±SD	3.04±0.07	3.11±0.08	3.2±0.18	2.36±0.07	2.1±0	1.65±0.49	1.93±0.07	2.51±0.01	2.96±0.01	3.44±0.08
PILE C1 (2:1)	2.03	2.13	1.94	1.8	2.67	2.4	2	2.97	3.1	3.22
PILE C2 (2:1)	2.03	2.09	1.9	1.72	2.5	2.26	1.82	2.91	2.98	3.02
MEAN±SD	2.03±0	2.11±0.03	1.92±0.03	1.76±0.06	2.61±0.12	2.33±0.1	1.91±0.13	2.94±0.04	3.04±0.08	3.12±0.14
PILE D1 (3:1)	2.32	2.07	2.49	2.54	1.8	1.89	1.79	1.84	2.85	2.79
PILE D2 (3:1)	2.56	2.21	2.59	2.58	1.9	1.89	1.51	1.74	1.77	2.65
MEAN±SD	2.44±0.17	2.14±0.1	2.54±0.07	2.56±0.03	1.85±0.07	1.89±0	1.65±0.2	1.79±0.07	2.81±0.76	2.72±0.1
PILE E1 (0:1)	1.12	0.99	3.02	3.2	2.84	2.16	2.09	2.03	2.23	2.53
PILE E2 (0:1)	1.1	1.05	3.4	3.32	2.88	2.3	2.21	2.15	2.39	2.59
MEAN±SD	1.11±0.01	1.02±0.04	3.21±0.27	3.26±0.08	2.86±0.03	2.23±0.1	2.15±0.08	2.09±0.08	2.31±0.11	2.56±0.04

APPENDIX H

Weekly mean Phosphorus (P) content (%) in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	0.19	0.29	0.3	0.41	0.53	0.7	0.69	0.6	0.59	0.53
PILE A2 (1:0)	0.17	0.27	0.3	0.39	0.53	0.52	0.53	0.56	0.55	0.47
MEAN±SD	0.18±0.01	0.28±0.01	0.3±0	0.4±0.01	0.53±0	0.61±0.13	0.61±0.11	0.58±0.03	0.57±0.03	0.5±0.04
PILE B1 (1:1)	0.43	0.81	1.08	1.35	1.22	1	1.06	1.01	0.98	0.9
PILE B2 (1:1)	0.43	0.79	1.07	1.33	1.21	1.12	1.12	1.05	1.04	0.96
MEAN±SD	0.43±0	0.8±0.01	1.08±0.01	1.34±0.01	1.22±0.01	1.06±0.08	1.09±0.04	1.03±0.03	1.01±0.04	0.93±0.04
PILE C1 (2:1)	0.37	0.7	1.06	1.36	1.2	1.17	1	0.99	1.02	1.1
PILE C2 (2:1)	0.33	0.62	1	1.22	1.06	1.03	0.94	0.97	1	1.06
MEAN±SD	0.35±0.03	0.66±0.06	1.03±0.04	1.29±0.1	1.13±0.1	1.1±0.1	0.97±0.04	0.98±0.01	1.01±0.01	1.08±0.03
PILE D1 (3:1)	0.35	0.8	1.1	1	1.01	0.93	0.76	0.76	0.74	0.72
PILE D2 (3:1)	0.34	0.66	1.02	0.98	1.02	0.94	0.8	0.77	0.7	0.68
MEAN±SD	0.35±0.01	0.73±0.1	1.06±0.06	0.99±0.01	1.02±0.01	0.94±0.01	0.78±0.03	0.77±0.01	0.72±0.03	0.7±0.03
PILE E1 (0:1)	1	0.9	0.88	0.97	1.04	1.11	1.13	1.29	1.24	1.31
PILE E2 (0:1)	0.82	0.82	0.82	0.89	0.98	1.06	1.09	1.17	1.24	1.3
MEAN±SD	0.91±0.13	0.86±0.06	0.85±0.04	0.93±0.06	1.01±0.04	1.09±0.04	1.11±0.03	1.23±0.08	1.24±0	1.31±0.01

APPENDIX I

Weekly mean Potassium (K) content (%) in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	0.88	0.82	0.7	0.7	0.9	0.97	1.05	1.11	1.17	1.19
PILE A2 (1:0)	0.92	0.9	0.71	0.72	0.96	1.01	1.13	1.11	1.18	1.23
MEAN±SD	0.9±0.03	0.86±0.06	0.71±0.01	0.72±0.01	0.93±0.04	0.99±0.03	1.09±0.06	1.11±0	1.18±0.01	1.21±0.03
PILE B1 (1:1)	0.45	0.41	0.5	0.49	0.52	0.61	0.62	0.65	0.61	0.59
PILE B2 (1:1)	0.41	0.41	0.44	0.45	0.53	0.62	0.63	0.69	0.69	0.59
MEAN±SD	0.43±0.03	0.41±0	0.47±0.04	0.47±0.03	0.53±0.01	0.62±0.01	0.63±0.01	0.67±0.03	0.65±0.06	0.59±0
PILE C1 (2:1)	0.19	0.3	0.47	0.46	0.5	0.59	0.68	0.9	0.88	0.81
PILE C2 (2:1)	0.17	0.28	0.46	0.45	0.48	0.55	0.67	0.92	0.87	0.81
MEAN±SD	0.18±0.01	0.29±0.01	0.47±0.01	0.46±0.01	0.49±0.01	0.57±0.03	0.68±0.01	0.91±0.01	0.88±0.01	0.81±0
PILE D1 (3:1)	0.24	0.44	0.48	0.59	0.56	0.66	0.81	0.77	0.76	0.76
PILE D2 (3:1)	0.25	0.44	0.46	0.57	0.57	0.67	0.85	0.78	0.8	0.77
MEAN±SD	0.25±0.01	0.44±0	0.47±0.01	0.58±0.01	0.57±0.01	0.67±0.01	0.83±0.03	0.78±0.01	0.78±0.03	0.77±0.01
PILE E1 (0:1)	0.9	0.79	0.34	0.26	0.22	0.14	0.14	0.15	0.17	0.13
PILE E2 (0:1)	0.98	0.87	0.33	0.24	0.23	0.15	0.14	0.16	0.17	0.14
MEAN±SD	0.94±0.06	0.83±0.06	0.34±0.01	0.25±0.01	0.23±0.01	0.15±0.01	0.14±0	0.16±0.01	0.17±0	0.14±0.01

APPENDIX J

Weekly mean Moisture content (MC) (%) in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	62.1	60.09	55.6	52.4	50.97	46.9	44.5	40.22	34.8	31
PILE A2 (1:0)	60.5	59.17	54.6	51.8	49.45	45.6	44.1	40.02	35.88	29.4
MEAN±SD	61.3±1.13	59.63±0.65	55.1±0.71	52.1±0.42	50.21±1.07	46.25±0.91	44.3±0.28	40.12±0.14	35.34±0.76	30.2±1.13
PILE B1 (1:1)	63	58.91	54.6	53	49.83	49.1	44.99	42.56	42.3	39.9
PILE B2 (1:1)	64.1	59.31	58.02	53.66	52.63	49.72	45.83	43.88	42.98	42.94
MEAN±SD	63.55±0.78	59.11±0.28	56.31±2.42	53.33±0.47	51.23±1.98	49.41±0.44	45.41±0.59	43.22±0.93	42.64±0.48	41.42±2.15
PILE C1 (2:1)	60.76	57.78	57.06	54.24	53.13	49.75	47.75	43.32	41.15	36.2
PILE C2 (2:1)	59	56.9	55	54.02	53.05	48.97	46.89	42.9	41.01	35
MEAN±SD	59.88±1.24	57.34±0.62	56.03±1.46	54.13±0.16	53.09±0.06	49.36±0.55	47.32±0.61	43.11±0.3	41.08±0.1	35.6±0.85
PILE D1 (3:1)	58.19	57	52.98	49.95	47	42.23	38.09	34.03	30.56	29.1
PILE D2 (3:1)	58.23	57.2	54.62	50.43	47.54	42.65	38.93	34.53	31.24	29.76
MEAN±SD	58.21±0.03	57.1±0.14	53.8±1.16	50.19±0.34	47.27±0.38	42.44±0.3	38.51±0.59	34.28±0.35	30.9±0.48	29.43±0.47
PILE E1 (0:1)	71.24	69.99	68.52	66.68	65.47	62.35	59	56.71	54.38	53.03
PILE E2 (0:1)	69	68.23	67.64	65.8	64.35	61.21	57.66	55.97	52	50.81
MEAN±SD	70.12±1.58	69.11±1.24	68.08±0.62	66.24±0.62	64.91±0.79	61.78±0.81	58.33±0.95	56.34±0.52	53.19±1.68	51.92±1.57

APPENDIX K

Weekly mean Total Solids (%) in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	37.9	39.91	44.4	47.6	49.03	53.1	55.5	59.78	65.2	69
PILE A2 (1:0)	39.5	40.83	45.4	48.2	50.55	54.4	55.9	59.98	64.12	70.6
MEAN±SD	38.7±1.13	40.37±0.65	44.9±0.71	47.9±0.42	49.79±1.07	53.75±0.92	55.7±0.28	59.88±0.14	64.66±0.76	69.8±1.13
PILE B1 (1:1)	37	41.09	45.4	47	50.17	50.9	55.01	57.44	57.7	60.1
PILE B2 (1:1)	35.9	40.69	41.98	46.34	47.37	50.28	54.17	56.12	57.02	57.06
MEAN±SD	36.45±0.78	40.89±0.28	43.69±2.42	46.67±0.47	48.77±1.98	50.59±0.44	54.59±0.59	56.78±0.93	57.36±0.48	58.58±2.15
PILE C1 (2:1)	39.24	42.22	42.94	45.76	46.87	50.25	52.25	56.68	58.85	63.8
PILE C2 (2:1)	41	43.1	45	45.98	46.95	51.03	53.11	57.1	58.99	65
MEAN±SD	40.12±1.24	42.66±0.62	43.97±1.46	45.87±0.16	46.91±0.06	50.64±0.55	52.68±0.61	56.89±0.3	58.92±0.1	64.4±0.85
PILE D1 (3:1)	41.81	43	47.02	50.05	53	57.77	61.91	65.97	69.44	70.9
PILE D2 (3:1)	41.77	42.8	45.38	49.57	52.46	57.35	61.07	65.47	68.76	70.24
MEAN±SD	41.79±0.03	42.9±0.14	46.2±1.16	49.81±0.34	52.73±0.38	57.56±0.3	61.49±0.59	65.72±0.35	69.1±0.48	70.57±0.46
PILE E1 (0:1)	28.76	30.01	31.48	33.32	34.53	37.65	41	43.29	45.62	46.97
PILE E2 (0:1)	31	31.77	32.36	34.2	35.65	38.79	42.34	44.03	48	49.19
MEAN±SD	29.88±1.58	30.89±1.24	31.92±0.62	33.76±0.62	35.09±0.79	38.22±0.81	41.67±0.95	43.66±0.52	46.81±1.68	48.08±1.57

APPENDIXL

Weekly mean pH in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	8.3	7.5	7.1	6.5	6.1	6.3	6.8	7.4	7.6	7.7
PILE A2 (1:0)	8.7	8.5	7.7	6.1	5.9	6.1	6.2	7	7	7.3
MEAN±SD	8.5±0.28	8±0.71	7.4±0.42	6.3±0.28	6±0.14	6.2±0.14	6.5±0.42	7.2±0.28	7.3±0.42	7.5±0.28
PILE B1 (1:1)	6.9	6.9	6.3	5.7	5	5.6	6.1	6.2	6.5	6.9
PILE B2 (1:1)	7.2	6.9	6.5	6.1	5.6	6	6.9	7	7.3	7.7
MEAN±SD	7.1±0.21	6.9±0	6.4±0.14	5.9±0.28	5.3±0.42	5.8±0.28	6.5±0.57	6.6±0.57	6.9±0.57	7.3±0.57
PILE C1 (2:1)	8.3	7.4	6.9	6.3	5.9	6.3	6.7	7	7.2	7.5
PILE C2 (2:1)	7.1	6.8	6.1	6.1	5.3	5.5	5.9	6.6	7	7.3
MEAN±SD	7.7±0.85	7.1±0.42	6.5±0.57	6.2±0.14	5.6±0.42	5.9±0.57	6.3±0.57	6.8±0.28	7.1±0.14	7.4±0.14
PILE D1 (3:1)	7.4	7.2	7	6.4	6.7	6.8	7	7.3	7.2	7.5
PILE D2 (3:1)	7.4	7	6.6	5.8	5.9	6	6.6	6.7	7	7.1
MEAN±SD	7.4±0	7.1±0.14	6.8±0.28	6.1±0.42	6.3±0.57	6.4±0.57	6.8±0.28	7±0.42	7.1±0.14	7.3±0.28
PILE E1 (0:1)	6.4	6.1	6.1	6	5.9	5.9	5.6	5.5	5.4	5.5
PILE E2 (0:1)	7	6.9	6.5	6.4	6.1	5.9	5.8	5.5	5.8	5.9
MEAN±SD	6.7±0.42	6.5±0.57	6.3±0.28	6.2±0.28	6±0.14	5.9±0	5.7±0.14	5.5±0	5.6±0.28	5.7±0.28

APPENDIX M

Weekly mean Volume Reduction in the different compost piles of Organic Solid waste/ Dewatered Sewage Sludge.

	WEEKS									
COMPOST PILES	0	1	2	3	4	5	6	7	8	9
PILE A1 (1:0)	188.03	142.15	108.8	85.29	76.4	73.1	71.43	71.2	70.93	70.37
PILE A2 (1:0)	189.11	139.95	107.8	86.69	74.46	73.78	73.37	71.2	71.07	70.69
MEAN±SD	188.57±0.76	141.05±1.56	108.3±0.71	85.99±0.99	75.43±1.37	73.44±0.48	72.4±1.37	71.2±0	71±0.1	70.53±0.23
PILE B1 (1:1)	175.1	140.13	131.07	109.51	97.78	94.51	92.57	91.1	90.77	90.56
PILE B2 (1:1)	174.98	141.33	131.49	107.53	97.56	94.01	93.43	91.16	91.03	90.78
MEAN±SD	175.04±0.08	140.73±0.85	131.28±0.3	108.52±1.4	97.67±0.16	94.26±0.35	93±0.61	91.13±0.04	90.9±0.18	90.67±0.16
PILE C1 (2:1)	184	139.81	121.21	101.99	93.44	88.84	85.28	84.63	84.04	83.71
PILE C2 (2:1)	185.6	140.35	121.99	103.13	93.94	89.16	85.38	84.99	84.24	84.09
MEAN±SD	184.8±1.13	140.08±0.38	121.6±0.55	102.56±0.81	93.69±0.35	89±0.23	85.33±0.07	84.81±0.25	84.14±0.14	83.9±0.27
PILE D1 (3:1)	180.81	124.31	103.02	80.95	74.5	72.72	71.67	70.41	69.09	69.2
PILE D2 (3:1)	181.25	125.51	103.36	80.53	74.3	72.7	71.63	70.29	68.93	69.1
MEAN±SD	181.03±0.31	124.91±0.85	103.19±0.24	80.74±0.3	74.4±0.14	72.71±0.01	71.65±0.03	70.35±0.08	69.01±0.11	69.15±0.07
PILE E1 (0:1)	178.99	164.22	159.12	143.57	139.47	134.22	130.33	128.97	127.37	126.8
PILE E2 (0:1)	178.39	163.86	158.6	142.69	138.93	134	130.05	128.63	127.31	126.58
MEAN±SD	178.69±0.42	164.04±0.25	158.86±0.37	143.13±0.62	139.2±0.38	134.11±0.16	130.19±0.2	128.8±0.24	127.34±0.04	126.69±0.16

APPENDIX N

Single Factor ANOVA for Organic Carbon with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	117.6832	4	29.42079	0.582551	0.676839	2.578739
Within Groups	2272.653	45	50.5034			
Total	2390.336	49				

APPENDIX O

Single Factor ANOVA for Nitrogen with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	12.86159	4	3.215397	24.47055	8.42E-11	2.578739
Within Groups	5.91294	45	0.131399			
Total	18.77453	49				

APPENDIX P

Single Factor ANOVA for Carbon-to-Nitrogen ratio with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	697.861132	4	174.4653	4.580737	0.00345	2.578739
Within Groups	1713.90291	45	38.08673			
Total	2411.764042	49				

APPENDIX Q

Single Factor ANOVA for Ash Content with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	163.6695	4	40.91737	0.338783	0.850358	2.578739
Within Groups	5434.995	45	120.7777			
Total	5598.664	49				

APPENDIX R

Single Factor ANOVA for Organic Matter with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	336.0055	4	84.00137	0.734804	0.573089	2.578739
Within Groups	5144.315	45	114.3181			
Total	5480.32	49				

APPENDIX S

Single Factor ANOVA for Magnesium with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	3.381228	4	0.845307	2.618372	0.047354	2.578739
Within Groups	14.52766	45	0.322837			
Total	17.90889	49				

APPENDIX T

Single Factor ANOVA for Calcium with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	9.568292	4	2.392073	8.058664	5.47E-05	2.578739
Within Groups	13.35746	45	0.296832			
Total	22.92575	49				

APPENDIX U

Single Factor ANOVA for Phosphorus with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	2.32964	4	0.58241	12.71138	5.293E-07	2.5787392
Within Groups	2.06181	45	0.045818			
Total	4.39145	49				

APPENDIX V

Single Factor ANOVA for Potassium with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	2.093972	4	0.523493	11.68917	1.36E-06	2.5787392
Within Groups	2.0153	45	0.0447844			
Total	4.109272	49				

APPENDIX W

Single Factor ANOVA for Moisture Content with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	1813.4074	4	453.35184	5.9347583	0.0006357	2.5787392
Within Groups	3437.5171	45	76.389268			
Total	5250.9244	49				

APPENDIX X

Single Factor ANOVA for Total Solids with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	1813.4074	4	453.35184	5.9347583	0.0006357	2.5787392
Within Groups	3437.5171	45	76.389268			
Total	5250.9244	49				

APPENDIX Y

Single Factor ANOVA for pH with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	6.6088	4	1.6522	4.3724418	0.0045159	2.5787392
Within Groups	17.004	45	0.3778667			
Total	23.6128	49				

APPENDIX Z

Single Factor ANOVA for Volume Decrease with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	16427.781	4	4106.9453	3.9884725	0.007463	2.5787392
Within Groups	46336.672	45	1029.7038			
Total	62764.453	49				

APPENDIX AB

Single Factor ANOVA for Temperature with respect to the composting period.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	2926.6304	4	731.65759	6.7727901	3.267E-05	2.4044701
Within Groups	29707.969	275	108.02898			
Total	32634.599	279				