MATERIAL FLOW ANALYSIS ON A LANDFILL SITE IN JOHANNESBURG

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This is a research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

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DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the Master of Science in Engineering by coursework and research report to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

.... 25th day of FEBRUARY, 2016

(Signature of Candidate) (day) (month) (year)

ABSTRACT

The purpose of this study is the demonstration of the effectiveness of material flow analysis (MFA) for decision making in waste management in achieving an integrated solid waste management system. Solid waste generation is a universal human activity. The increase in the scale of economic activities in developing areas has led to a significant increase in the volume of waste generated. The eco-system has a limited capacity for waste absorption; hence inappropriately managed solid waste tends to cause health risks to humans and is associated with ecological degradation.

This study analysed the material flows of the municipal solid waste deposited at Robinson Deep landfill situated in the City of Johannesburg (CoJ). Material flow analysis is the tool adopted in providing a holistic characterization of the municipal solid waste and also used as a means of generating optimized management solutions. MFA is based on mass balance principle which states that mass can neither be created nor destroyed. Mathematical modelling and simulations are carried out as the tool to performing the material flow analysis. A situational model (status-quo) which is the actual flow of materials through the landfill site was developed and compared to four scenarios developed in order to evaluate the performance of the waste management system regarding the waste management goals. The scenarios developed showed that they all comply much better with the waste management goals as compared to the status quo. Scenarios 4, comprising a mechanical biological treatment facility and a waste to energy technology and scenario 2 which ensures that all recyclable materials are recovered before landfilling showed to be the favourable options which significantly divert most of the hazardous and valuable materials to the appropriate sinks and recycling processes. Scenario 2 however ensures a more sustainable approach overall but it is an extensive approach. The cost implication of both scenarios are however high.

This study was able to show that with the use of MFA, the sources of waste generation, composition of waste deposited on the landfill and the ratio of recycling and total volume of waste diverted from being landfilled can be tracked. This study however recommends further research in tracking the municipal solid waste right from the point generation to the point it is landfilled or recycled using MFA for the whole City of Johannesburg.

DEDICATION

Dedicated

Firstly, to God Almighty for His steadfastness, and

To all third-world countries with municipal solid waste management issues, I hope we would phase it out permanently in the nearest future.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
CER	Certified Emission Reduction
CLR	Common Language Runtime
CO_2	Carbon dioxide
CoJ	City of Johannesburg
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DEFRA	Department for Environment, Food and Rural Affairs
DWAF	Department of Water Affairs and Forestry
ECA	Environmental Conservation Act
EU	European Union
GDP	Gross Domestic Product
GHGs	Green House Gases
ISWM	Integrated Solid Waste Management
IWMP	Integrated Waste Management Plan
IZWA	Institute for Zero Waste in Africa
MBT	Mechanical Biological Treatment
MDGs	Millennium Development Goals
MFA	Material Flow Analysis
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
NEMWA	National Environmental Management Waste Act
NO_X	Nitrogen Oxides

NWMSI	National Waste Management Strategy Implementation
PCDDs	Polychlorinated Dibenzo Dioxins
PET	Polyethylene Tetraphthalate
PS	Polystyrene
PVC	Polyvinyl Chloride
RDF	Refuse-Derived Fuel
REDISA	Recycling and Economic Development Initiative of South Africa
SA	South Africa
SO_X	Sulphur Oxides
SWANA	Solid Waste Association of North America
SWM	Solid Waste Management
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USEPA	United States Environmental Protection Agency
WTE	Waste to Energy
WWF	World Wide Fund
XOCs	Xenobiotic Organic Compound

Chapter One

1.0 INTRODUCTION

Solid waste management poses a major challenge for growing cities in developed and developing countries as a result of the increasing generation of waste associated with population expansion and economic development. Solid waste management is part of the basic vital services provided by the municipal authorities in any country to ensure a clean and healthy environment. High cost associated with waste management often poses a burden on the municipality's budget coupled with inadequate understanding of the various factors that may impact on the several levels of management of waste and linkages required to ensure that the whole handling system functions; these are often common issues with developing countries (Abarca et al., 2012).

Inappropriately managed solid waste tends to cause health risks to humans and is associated with ecological degradation. Likewise, the lack of monitoring of the dumping and improper handling of waste poses many environmental health issues ranging from pest (rodents, insects, etc) infestation, flooding caused by blockages of drains, contamination of water and in serious cases fire hazards or explosions may occur (USEPA 2002). It is widely known in waste management that the main objectives are the protection of human beings and the eco-system, as well as the conservation of resources, which are measured by the type and quantity of either harmful emissions or resource consumption (Tang and Brunner, 2013). It is therefore imperative to address solid waste management by looking at the root cause of solid waste generation and the current landfilling operations in order to proffer possible alternatives and treatment methods which would lead to a holistic and sustainable management approach.

The generation and management of solid waste is one of the contemporary world's greatest challenges. World cities generate about 1.3 billion tonnes of solid waste annually (Hoornweg and Bhada-Tata, 2012). This volume is expected to increase to 2.2 billion tonnes by 2025. The impacts of solid waste are growing exponentially. This makes solid waste management ever more important. Globally, the most common method for waste disposal is in a landfill. Approximately 95% of South Africa's solid waste ends up in a landfill (van der Linda et al., 2004).

Solid waste management in South Africa, especially with regard to domestic waste, faces many challenges (CSIR, 2011). Furthermore, waste management services are a function of local government according to the South African Constitution (Act No. 108 of 1996). Research shows that the present state of waste management in South Africa is a reflection of how well these municipalities handle their respective functions (CSIR 2011). So if the city aspires to a 'modern' waste management system, there has to be an efficient data collection on which to base this management system. Hence as stated by Wilson et al. (2012), 'if you don't measure it, you cannot manage it'. Poor data gathering and management system of solid waste makes it tricky to be accountable and transparent, or even proffer efficient and sustainable strategies and budget for them.

According to a report from Dolphin Coast Landfill Management (2014), the average amount of waste produced per person per day in South Africa is 0.7kg which appears to be closer to the situation in more developed countries like the United Kingdom (UK) and Singapore which produce 0.73kg and 0.87kg respectively. With this said, the growing population, high demands on existing resources, and emphasis on basic needs has placed significant pressure on the municipalities' waste management system.

A major reason for solid waste management problems is the "law of unintended consequences" whereby solid waste managers are often called on to deal with the negative out-comes of well intentioned policies, laws and regulations (Ross, 2014). A review of these policies, laws and regulations is discussed in chapter 3. An example cited refers to the case of municipalities in developing countries which often qualify for low-interest loans for the development of solid waste management infrastructure, but most times fall short in implementing a sufficient cost recovery structure which would help in adequately operating and maintaining the facility (Ross, 2014). In situations like this, caused by improper design, planning and management of these waste management infrastructures, it is imperative to have sufficient knowledge of the population trend of the city, a detailed account of the waste pattern and waste generated in order to be able to manage the solid waste in a sustainable way, and also help decision makers in planning and policy making.

This study attempts to apply the concept of Material Flow Analysis (MFA) to solid waste management on landfill sites as a way of understanding solid waste and proffering alternative solutions to sustainably managing the solid waste and the landfill site in order to reduce harm to human health, and the eco-system. The study also attempts to analyze possible 'air space saving' of the landfill site using MFA. To the best of the author's knowledge, MFA has not been applied in the Johannesburg context. The results from this study present graphical illustrations depicting the flow of waste materials, resulting products (those recycled) and emissions in a clear and concise manner.

1.1 CITY OF STUDY

The City of Johannesburg covers an area of 1 645km^2 and it is the largest and most populated city in South Africa with a population of 4 434 827 as at the last census (Statistics SA, 2011). The City of Johannesburg's Pikitup manages solid waste in the City, from collection to disposal and as such is responsible for ensuring that the City remains clean and the environment hygienic for inhabitants. An approximate sum of 1.4 million tonnes of domestic waste is handled by Pikitup on an annual basis (City of Johannesburg, 2014) through its various waste management depots, garden refuse sites, landfill sites and incinerator.

All the landfill sites are licensed by the Department of Water Affairs and are supposed to be managed in line with their permit requirements. According to the 2014 report by the City of Johannesburg (CoJ), littering costs the city about R74million and illegal dumping another R80million. As regards sustainable waste management options, the report states that the City of Johannesburg has successfully implemented two landfill 'gas to energy' projects which are aimed at reducing the Green House Gases (GHGs) effect of the landfills. The sites are the Robinson Deep and the Marie-Louise landfill sites. It is expected that upon successful completion of all the landfill 'gas to energy' projects on all five landfill sites situated in the City, 19 MW should be generated. This can supply approximately 12 500 middle income households. This can only be achieved with the proper management of the operations that occur on the landfill sites.

It is therefore imperative for the City to have an efficient waste management system which should contain a good data collection process and as such should be a key component in achieving its main objective to achieve zero waste to landfills by 2022 (City of Johannesburg, 2014).

1.2 SOLID WASTE CHARACTERIZATION/QUATIFICATION/CONSTITUTION

Solid waste characterization as the name implies is a means of ascertaining and analyzing the composition of various waste streams. Waste characterization is normally performed on an existing municipal solid waste stream or landfill to evaluate its suitability for other sustainable waste processing technologies (Sethi et al., 2013). According to Wang et al. (2004) and Sebola et al. (2014), waste quantification is a process used to determine the types of goods/materials being disposed of in a municipal's waste stream as well as ascertaining in what proportion they are disposed. Sebola et al. (2014) further describe waste characterization as the study of the chemical composition of the waste stream after a detailed waste quantification has been carried out. Sethi et al. (2013) classify waste characterization into three:

1) Physical Waste Characteristics;
2) Chemical Waste Characteristics, and
3) Geotechnical Waste Characteristics.

For the purpose of this study, the author would be inclined to the latter description (i.e. Sethi et al., 2013) as it is more comprehensive. Also for the purpose of this study, only the physical waste characteristics are be carried out.

Landfilling is one of the most common means of disposal of municipal solid waste in developing countries (Mor et al., 2006). It is important to have a comprehensive database of the solid waste characteristics/quantification getting into the landfill site. This knowledge would serve as a useful tool in determining the most suitable treatment option to adopt on such site.

1.3 ENVIRONMENTAL IMPACT OF SOLID WASTE LANDFILLING

Studies have shown that municipal solid waste is a considerable contributor to the greenhouse gas emissions through the life cycle activities and decomposition processes predominantly through landfilling of these solid wastes (El-Fadel et al., 1997; Lou and Nair, 2009; Manfredi and Christensen, 2009). Other significant environmental hazards caused by disposal of municipal solid waste into landfill sites are listed below (adapted from El-Fadel et al., 1997):

a) Damage to the surrounding vegetation: El-Fadel et al. (1997) suggest that damage to surrounding vegetation occurs mainly due to oxygen insufficiency in the root zone causing a direct disarticulation of the oxygen by these landfill gases. This lack of oxygen results in death of plants from asphyxia around the landfill site. Furthermore, high concentrations of CO_2 (30 – 50%) released by landfill is also harmful to the growth of surrounding vegetation. Other toxic constituents found in landfill gas are also known to inhibit the growth of vegetation.

b) Pollution to the atmosphere: Focusing on the trace amount of other constituents present in the landfill gas, literature (Young and Parker, 1983; Young and Heasman, 1985; Rettenberg, 1987; El-Fadel et al., 1997) suggests that these other constituents pose enough potential to cause health and ecological concerns to the surrounding environment.

c) Pollution to the ground water: The presence of leachate in landfill sites is a major concern as its infiltration to the ground water poses a severe health and ecological risk. According to El-Fadel et al. (1997), the infiltration of leachate has been linked to possible contamination of the aquifer underlying landfills. Other possible pollutants of the underlying aquifers/ground water include high concentration of CO_2 due to its high solubility and other trace toxic constituents of landfill gases.

d) Unpleasant Odours: This results from the life cycle activities and decomposition processes that occur on the landfill site. Odorous constituents present in the landfill such as hydrogen sulfide, esters, limonene, organosulfurs, hydrocarbons, etc are emitted into the air and hence the foul smell perceived by neighbouring inhabitants and passersby (Young and Parker, 1983; El-Fadel et al., 1997). These odorous constituents are quite toxic, but it is perceived to be more of an ecological nuisance than an imminent danger to public health.

e) Explosions and Fire Risk: Explosions and fire are common incidents on landfill sites as well as subsurface explosions (as a result of air entrainment in the landfill) brought about by the presence of the methane gas. Methane gas has often been regarded to be a liability on landfill sites due to its high flammability, its possible migration away from the landfill borders by advection and diffusion processes, and its ability to form explosive mixtures with the atmosphere (El-Fadel et al., 1997).

f) Global Warming: Methane and CO_2 emissions from landfill sites are major contributors to global warming (El-Fadel et al., 1997). According to Bogner et al. (1989) and El-Fadel et al. (1997), CO_2 and methane fluxes can be as high as 950 and 630 $kg/m^2/yr$ respectively during dry soil conditions at a semi-arid landfill site. Methane in particular possesses a more effective characteristic of trapping infra-red radiation and is normally able to persevere longer in the atmosphere (Bingemer and Crutzen, 1987; El-Fadel et al., 1997). It is therefore critical to have recovery control systems implemented in landfill sites to limit the amount of methane escaping into the atmosphere especially in areas faced with increase in population and urbanization which would experience development of more landfill sites.

All these environmental impacts of solid waste landfilling can be reduced significantly by adopting globally accepted best practice, which revolves around the concept of sustainable solid waste management system; that is, to ensure that appropriate solid waste management policies are in place, implementation of efficient strategies to reduce the generation of waste and promote re-use and recycling of materials, with innovative technologies in adopted. Figure 1.1 depicts an illustration of factors influencing gas and leachate generation in landfills which are major contributors to environmental and health pollution.

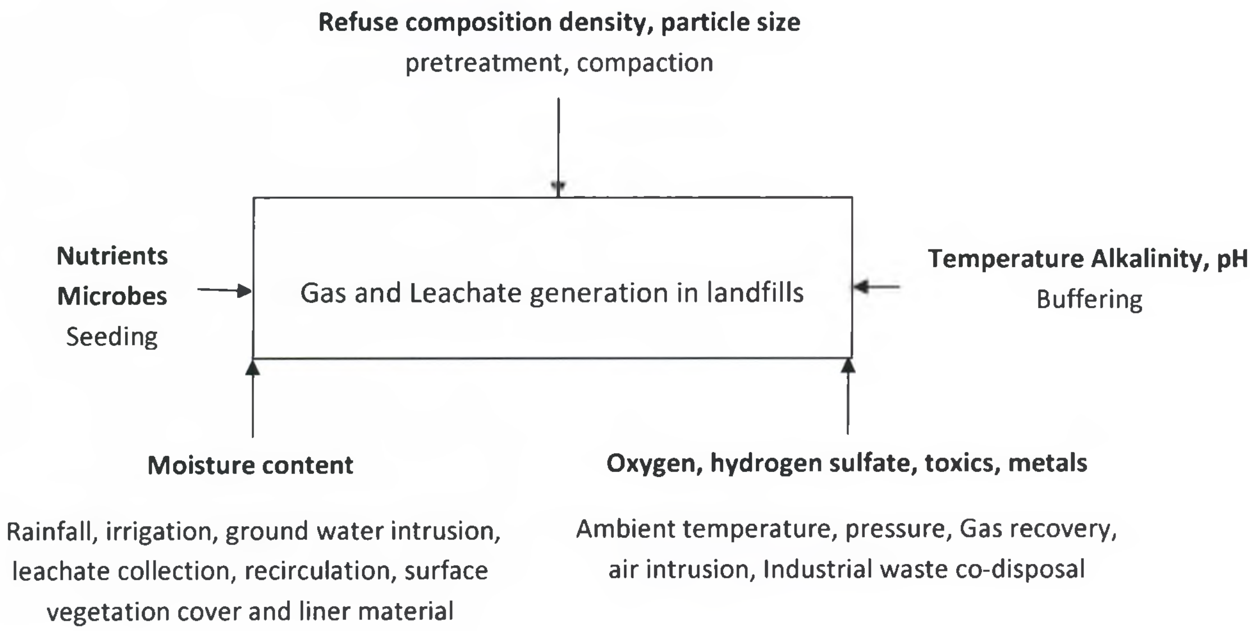


Figure 1.1: Factors influencing gas and leachate generated in landfills (After: El-Fadel et al., 1997)

1.4 RESEARCH PROBLEM STATEMENT

From the objectives of a sustainable landfill highlighted in section 1.0, which are maintaining the public health, environment and resource management, *the current situation of landfill sites around the City of Johannesburg appears to be that they only practice the minimum level of global best practice while some do not even meet up to it.* This would not be sustainable in the long haul to achieve an effective waste management system which entails a zero waste to landfill. In simple terms if there is no adequate knowledge (composition and quantity) of the waste coming into the landfill site, there is no way of effectively managing it.

1.5 RESEARCH QUESTION

What are the main sources of waste generation in the City, the composition of waste deposited on landfill sites and the ratio being recycled or recovered?

1.6 RESEARCH OBJECTIVES

This research intends to analyze the material flows of the municipal solid waste which is deposited at a selected landfill site in the City of Johannesburg. This study aimed at analyzing the impact of the current waste technology adopted on the case study site using four developed scenarios of different waste technology on the environment and health of the public; this knowledge can help facilitate future waste management practices. This study attempted to determine the reliability and accuracy of data relating to solid waste being deposited to landfill sites. It also tested the applicability of material flow analysis in providing a holistic characterization of municipal solid waste as a means to generating optimized management solutions.

1.7 RESEARCH DELINEATIONS (SCOPE)

This research focuses on one strategic landfill site that handles mainly municipal waste from the City of Johannesburg. The material flow analysis of waste from the point of generation is not covered in this study as it would be difficult to track such voluminous data given the time constraint for this study.

1.8 RESEARCH ASSUMPTIONS

Data derived from one landfill site is assumed to be similar to other landfill sites that accept waste of similar characteristics and from similar geo-political and socio-economical regions. Although in reality, the quality of data varies across landfills in Johannesburg. It is also assumed that MFA is a valid method for analyzing solid waste, although its limitations may be revealed in this study.

1.9 RESEARCH LIMITATIONS

The study site is limited to only one strategic landfill site with general characteristics common to most sites. Availability and accessibility of accurate and reliable data poses a constraint for this study. The study also only focuses on the volume and composition of waste material entering the landfill within a 3 years span, which is from June, 2012 to May, 2015.

1.10 OVERVIEW OF CHAPTERS

In this section, a brief outline of the structure of the remaining chapters of the research report is highlighted in the following bullet points:

i. Chapter 2 covers a review of the literature which investigates various topics such as solid waste generation, collection and recycling status in South Africa (SA). A look at sustainable solid waste management practices and integrated solid waste management are also reviewed in this chapter.

ii. A brief review of solid waste management policies and legislation in SA is discussed in chapter 3.

iii. Chapter 4 entails a detailed description of the area of study as well as the methodology that has been adopted. An overview on MFA and a review of methodologies that have been adopted to analyze waste flows in a specified boundary. A research design framework is also developed in this chapter.

iv. Chapter 5 comprises of analysis and discussions of the results obtained from the methodology adopted. The outcome of analysis is presented and possible limitations and errors that might be encountered are stated.

v. Conclusions and recommendations in relation to the research objective is outlined in chapter 6. Possible future research areas and topics are suggested.

Chapter Two

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter focuses on existing literature on solid waste management and related topics. Solid waste practitioners have struggled to comprehend the overriding factors affecting municipal solid waste generation in developing and the developed countries. This chapter reviews the literature on pertinent issues of waste management with specific focus on solid waste generation, sustainable practices and waste characterization.

According to several academic papers such as Mastellone et al. (2009), Wilson et al. (2012), Brunner and Rechberger (2005); there is a general agreement on the following main objectives of modern solid waste management:

i. The protection of health of humans and the eco-system,

ii. The conservation of natural resources such as materials, energy and space,

iii. The orientation to treat waste before final disposal in order to minimize the effort needed when eventually disposed at the landfill sites.

2.2 Overview on Solid Waste Management

Solid waste as an issue can be dated back to prehistoric times (Chandrappa and Das, 2012). Solid waste management (SWM) differs vastly between cultures and countries and has evolved over time. It entails an understanding of waste generation, storage, collection, transport, processing and disposal (Mihelcic and Zimmerman, 2010). Research shows that SWM is peculiar to the type and characteristics of the area in which the waste is generated and as such there is no universal solution that can be applied to different cities and circumstances. A common limitation in evaluating solid waste management system in various cities is the absence of consistence global solid waste management baselines (Rodic et al., 2010).

This section presents some definition of common terms used in solid waste management, subsequent sections explore related topics such as solid waste generation rates, sustainable solid waste management, landfilling, 'zero waste to landfill', integrated solid waste management and municipal solid waste characterization.

2.2.1 Definitions

A) Waste

The South African Department of Environmental Affairs and Tourism (DEAT) define waste as objects which are no longer useful and requires disposal. The City of Johannesburg report (2011) defines waste as any material, irrespective of its characteristics to be reduced, recycled, reused and recovered when it:

i. Is unnecessary and in abundance;

ii. Is not being required by the user for the intent of production;

iii. Falls under the materials categorized by the Minister as waste, which comprises municipal solid waste, waste water, waste generated from the mining, construction and manufacturing industries.

Waste is classified into two broad classes according to the National Environmental Management: Waste Amendment Act, 2014. They are general waste and hazardous waste. General waste refers to waste that does not pose an immediate threat to human health and the eco-system; it comprises municipal solid waste, construction and business waste and inert waste. Hazardous waste refers to waste that contains organic and inorganic elements in its composition. As a result, it is capable of impacting adversely on human health as well as the eco-system. Hazardous wastes possess characteristics such as being highly combustible, very corrosive, and chemically reactive.

B) Municipal Solid Waste

According to Mudau (2012), municipal solid waste refers to waste which is generated, collected, transported, treated and eventually disposed of within the administrative boundary of a municipal authority. A general composition of municipal solid waste comprises household garbage, garden waste, waste from street cleaning, commercial waste and construction and demolition waste.

C) Municipal Solid Waste Management

Masters and Ela (2008) define municipal solid waste management as the recovery of materials for recycling or composting, combustion with or without energy recovery, and the final disposal of the waste in landfills. The United States Environmental Protection Agency (US EPA) (2008) defines municipal solid waste management as those materials conventionally managed by municipalities by common practices such as recycling or composting, incineration and landfilling.

SWM usually consist of both the formal and informal sectors with the formal sector comprising mainly the municipal agencies while the informal sector comprises unregulated and unregistered individuals or groups and small businesses (Sembiring and Nitivattananon, 2010). This study focuses on municipal solid waste which according to Wang and Nie (2001) constitutes nearly 80% of the total main waste stream and in terms of composition, it is the most complex. Municipal solid waste is basically solid waste generated from residential, commercial, institutional, and industrial sources (Masters and Ela, 2008). Figure 2.1 presents a full description of municipal solid waste.

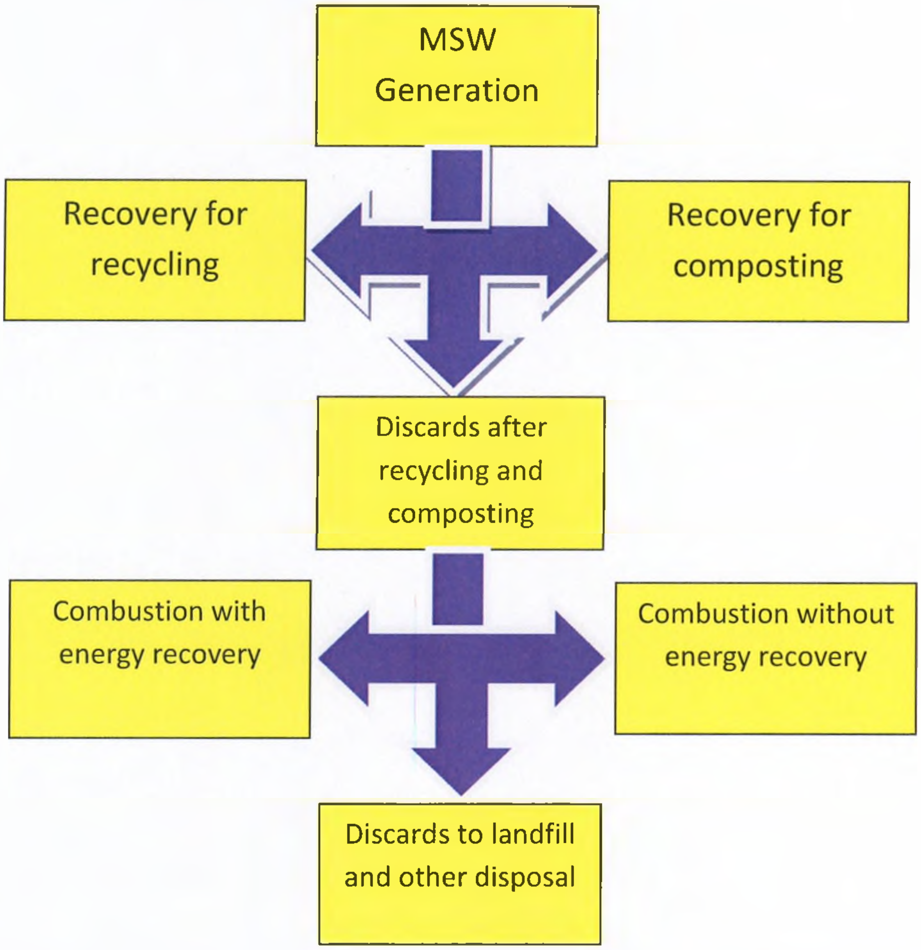


Figure 2.1: Summary of municipal solid waste management (After: Masters and Ela 2008)

2.2.2 Benefits of municipal solid waste management

The benefits of proper administration of municipal solid waste management are vast, spanning from its economic to its environmental benefits. A summary of benefits is highlighted in this section. An efficient practice of sustainable solid waste management system serves as a means of resource recovery for municipalities. Hoornweg and Bhada-Tata (2012) elaborate on the impact of improperly managed waste which usually results in down-stream costs as opposed to what it would have been if the waste had been properly managed in the first place.

Issues such as the occurrence of an epidemic could be curbed or prevented from efficient SWM systems. The prevention of infestation of rodents and vectors as well accumulation of hazardous substances are important reasons for the implementation of an efficient and effective system. A report from the United Nations Millennium Development Goals (MDG) (2005) suggests that proper solid waste management will possibly result in reducing poverty, child mortality, improving maternal health and preventing diseases, which are part of the Millennium Development Goals.

2.3 Solid waste generation rate

The generation of solid waste on a global scale is on the rise as many societies strive to attain a better quality of life (Troschinetz, 2005). According to Chandrappa and Das (2012), the human population is expected to have doubled from 1990 to the present, with most of this increase happening in the less developed countries, especially associated with rapid urbanisation. Hence, the increase in population in some parts of the world has led to an inevitable increase in the demand for efficient solid waste management practices.

Guerrero et al. (2013) present solid waste generation rates (kg/capita/day) across Africa, Asia and the Central and South America in relation to the respective city's gross domestic product (GDP). The study focuses on solid waste source from: a) households, b) offices, c) construction, d) health care, e) agriculture, f) industry, g) shops/stores. The findings are presented in Table 2.1.

Table 2.1: Waste generation rates in relation to various cities' GDP (Source: Guerrero et al., 2013)

Continent	Country	City	Year of Study	GDP (US dollars)	Waste source	Waste generation rate (kg/capita/day)
Africa	Ethiopia	Addis Ababa	2009	344	a,b,d,f,g	0.32
	Kenya	Nakuru	2009	738	a,b,c,d,e,f,g	0.50
	Malawi	Lilongwe	2009	326	a.	0.50
	South Africa	Pretoria	2009	5786	a,b,c,d,g	0.65
	Tanzania	Dar es Salam	2010	509	a,b,d,e,f,g	0.50
	Zambia	Lusaka	2010	985	a,b,c,d,f,g	0.37
Asia	Bangladesh	Gazipor	2007, 2008, 2009	551	a,d	0.25
	China	Beijing	2010	3744	a,c,d,g	0.80
	India	Dodda-ballapur	2010	9232	a,b,c,f,g	0.28
	Indonesia	Jogjakarta	2010	2349	a,b,e,g	0.90
	Nepal	Kathmandu	2007	364	a,b,f,g	0.35
	Pakistan	Lahore	1995	495	a,b,f,g	0.85
	Philippines	Quezon City	2009	1995	a,b,c,d,g	0.67
	Sri Lanka	Balangoda	2010	2068	a,b,c,d,f,g	0.83
	Thailand	Bangkok	2009, 2010	4043	a,b,c,d,f,g	1.10
Central and South America	Costa Rica	San José	2011	6386	a,b,c,d,f,g	1.10
	Ecuador	Pillaro	1995	1771	a,g	0.50
	Nicaragua	Managua	2008, 2009, 2010	1069	a,b,c,d,e,f,g	0.48
	Peru	Cañete	2008, 2009, 2010	4447	a,b,c,d,e,f,g	0.47
	Suriname	Paramaribo	2008, 2009	5888	a,g	0.47

*a) household waste, b) office waste, c) construction waste, d) health care, e) agriculture, f) industry, g) shops

From the values presented in the table, there is no direct relationship between the waste generation rate and the gross domestic product (GDP) of the country. However, Shekar (2009) suggests that there is a direct relationship between the economic status of a society and the solid waste generation rate where the study reiterates that solid waste generation in countries with low GDP is lower than countries with high GDP.

Guerrero et al. (2013) also support this perception and suggest the reason for the inconsistency is that waste generation rates were acquired from data provided in the cities by several sources such as academic institutions, municipalities, research centres and non-governmental organizations and as such, there can be insufficient data in some cities to relate it to the country's GDP which is an indicator of the economic situation at a national level. For the purpose of this study, waste generation rate is assumed to be directly related to a country's GDP as most literature suggest so.

In South Africa, Nahman et al. (2012) present data on waste generated across the country. It shows that 8.9 million tonnes of household waste were generated in SA in 2004 based on the mid-2004 population of 46.6 million. The study further breaks down the generation rates per income group, the results of which are 1.29, 0.74 and 0.41 kg/person/day for high, middle and low income households respectively. This simply shows that high-income communities generate more waste.

There are other factors that influence waste generation such as the size of the household and level of education (Sujauddin et al., 2008). Table 2.2 shows domestic waste generated across SA by income group in 2011. These figures were attained by extrapolating the waste generation rates to the mid-2011 from mid-2004 at an estimated 50.59 million population (acquired from Statistics South Africa, 2011). It shows that a likely total of 9.6 million tonnes of household waste was generated.

Table 2.2: Figures of generated household waste across South Africa by income group (2011) (Source: Nahman et al., 2012)

Income level	Waste generation rates (kg/person/day)	Percentage Population distribution (%)	Mid 2011 population distribution	Household waste generated (tonnes/annum)
High	1.29	4.59	2,322,081	1,093,352
Medium	0.74	21.44	10,846,496	2,929,639
Low	0.41	73.97	37,421,423	5,600,116
Total		100	50,590,000	9,623,106

This table aligns with most literature on waste generation rates and economic situation of the waste producers. It shows that the high income level household generates more waste per kg per person per day as compared to the two lower household income level classifications.

2.4 Sustainable Solid Waste Management

Managing solid waste in a sustainable manner is a global concern as represented by the United Nations Millennium Development Goals (UNMDGs) which constitutes of 191 member states' support (Troschinetz, 2005). Urbanization and industrialization are characterized by increase in concentration of population which inevitably results in high pressures on the eco-system and its resources due to high rate of waste generation and disposal. One of the major aims of sustainable solid waste management is to tackle long term environmental pressures through environmentally sound and economically effective processes of recycling, recovering and reuse of resources as well as the minimization of the waste streams.

According to Williams et al. (2013), sustainability in the solid waste sector comprises several aspects. The first of these is social sustainability, which involves making sure minimum social conditions are met, such as safe working conditions for the employees as well as implementing a health and safety plan for the community. The second aspect is environmental sustainability, which involves attaining a level of resource efficiency through promoting sustainable consumption and implementing waste prevention strategies. The third aspect discussed is economic sustainability, which entails the solid waste sector ensuring a cost effective means to provide a rising range of secondary materials of high quality which aids in tackling the increasing rate of resource consumption and waste generation. Sustainable waste management also contributes to a sustainable economy through the development of new enterprises and consequently more jobs.

In terms of sustainable solid waste management, developed countries are significantly more advanced in their practice of regulating and tracking their waste streams (Troschinetz, 2005). This well-developed record-keeping system provides the opportunity for waste developers to manage and design efficient and effective sustainable solid waste management treatment options. Conversely, a common issue for developing countries highlighted by Troschinetz (2005) is the adaptation of developed countries' solid waste management legislation and policies that appears seldom to work effectively in these developing countries due to lack of clear roles, responsibility and most especially data.

In the South African context, Karani and Jewasikiewitz (2007) state that solid waste management is gradually becoming a key sector for sustainable development in the country, with opportunities for improving investments in carbon credits by targeting reduction of methane from landfills and by improving moveable assets, referring to eco-friendly equipment used for efficient solid waste management. Williams et al. (2013) suggest that the waste sector is able to offer net carbon savings and a significant resource contribution to the economy by practicing sustainable solid waste management.

The South African Constitution (1996) states that local government must provide communities with affordable, equitable, and sustained basic services which includes solid waste management. The Local Government Municipal System Act (No. 32, 2000) endeavour to attain sustainability in services provided, including solid waste management. These services which are provided to local communities are expected to be accessed equitably and delivered in a financially and environmentally sustainable manner. According to Chandrappa and Das (2012), a sustainable solid waste management system consists of some or all of the following elements depicted in Figure 2.2.

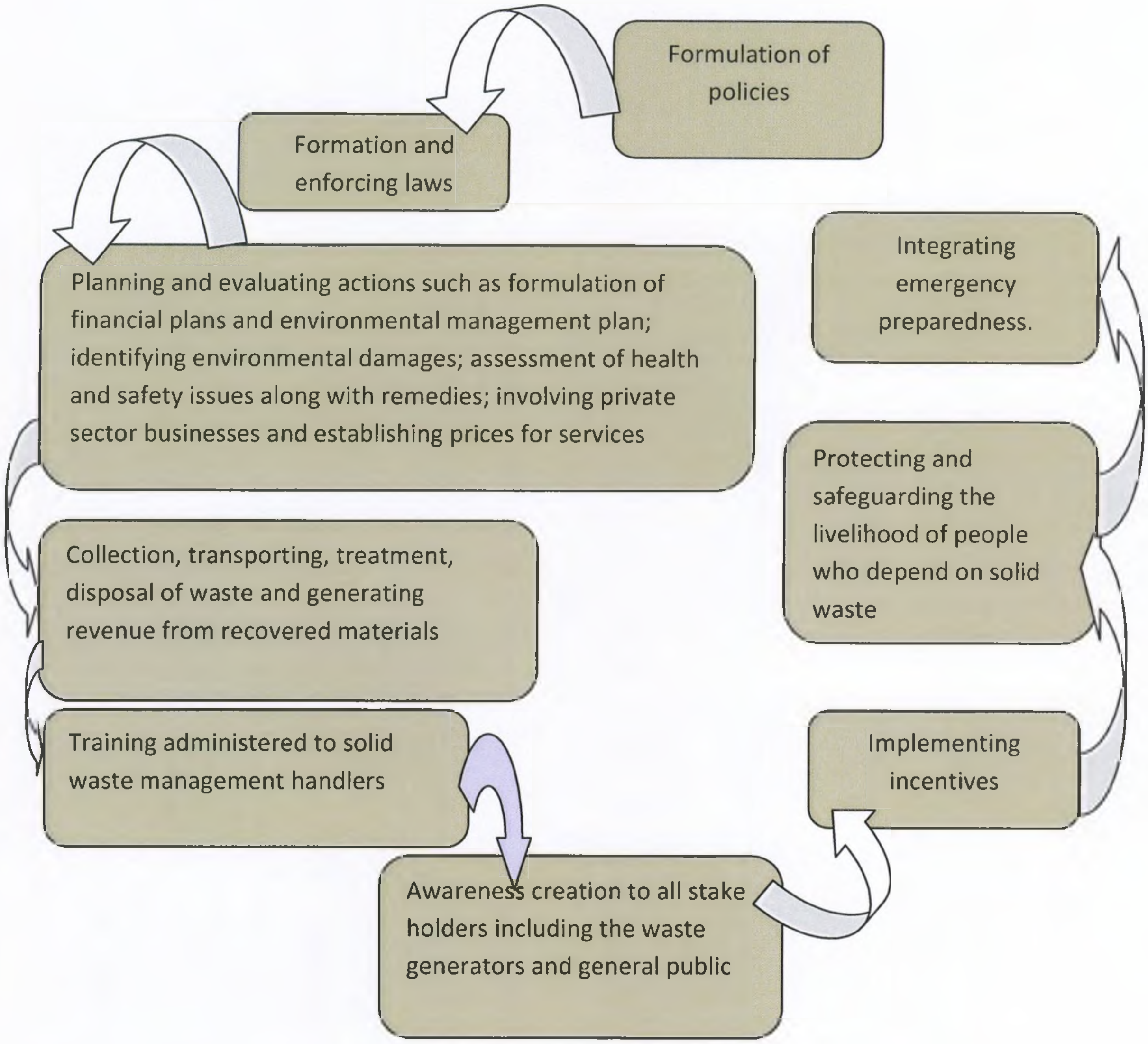


Figure 2.2: Elements of a sustainable solid waste management system (Adapted from: Chandrappa and Das, 2012)

According to Williams et al. (2013), the following activities are sustainable solid waste management practices:

1. Waste Prevention;

2. Waste Reuse;
3. Waste Recycling and Composting;
4. Waste to Energy (WTE).

These practices are discussed in detail below.

2.4.1 Waste Prevention

Waste prevention as the name implies is avoiding the generation of waste, it is the most desirable option of the waste management practices relative to environmental benefit. It also refers to activities carried out to minimize the mass, volume or toxicity of materials or products consumed and later disposed of through changes to their 'design, purchase, manufacture or use' (US EPA, 1999; Cleary, 2010). According to the European Union Waste Framework Directive, (2008), waste prevention involves avoidance, reduction, re-use; and also minimizing the use of hazardous materials.

Salhofer et al. (2008) mention two categories by which waste prevention targets are classified - quantitative and qualitative waste prevention. Quantitative waste prevention focuses on the weight of waste i.e. reducing the amount of waste generated and qualitative waste prevention focuses on the composition of the waste with the aim of reducing hazardousness of the waste generated. The authors carried out a study in Vienna, Austria, to estimate waste prevention potential of five unique prevention measures focusing on beverage packing, advertising material, food waste, diapers and big events, which was spear-headed by the service providers. It was discovered that each measure has a capacity of producing an estimated 10% reduction in the amount of the relevant waste stream. This suggests a combination of legislation and education as the 'management' activity.

2.4.2 Waste Reuse

According to the US Environmental Protection Agency, the term 'waste reuse' refers to using a material or product in its original form more than once; for example, reusing could be in the form of donating old clothes, furniture, etc to shelter homes or carrying your own personal mugs to coffee shops instead of requesting disposable cups. This involves checking, cleaning, repairing and refurbishing materials in part or as a whole. The concept of reuse is an essential part of sustainable solid waste management practice due to its environmental soundness and socio-economic potential for managing excess and disposed materials or products.

There have been attempts by some cities in the developed countries to implement and enforce policies that would support reuse of materials. An example of such city is Toronto, Canada, where there are policies offering financial incentives for citizens to carry their personal reusable shopping bags and mugs to stores and coffee shops with the aim of minimizing the generation of waste and promoting material reuse (City of Toronto, 2008; Cleary, 2010). In developing countries such as Rwanda and Bangladesh, there is a policy which prohibits the use of plastic bags around the country in order to minimize the generation of waste plastic bags which have very slow decomposition rates (Alamgir and Ahsan, 2007).

In South Africa, literature shows that approximately 8 billion plastic bags are consumed annually (Dikgang et al., 2010). The South African government in 2003 introduced the plastic bag levy which required retailers/stores charging customers for plastic bags. This was envisioned as a way of encouraging the reuse of plastic bags in possession of the customers, thus minimizing the generation of plastic bag waste as it was similarly applied in Ireland. Dikgang et al. (2010) present data which shows that the overall reduction of plastic bag consumption per R 1000 of shopping is estimated at 44%. The study also shows that reductions of 57% for high income earners and 50% reductions for low income earners were found. However, there have been occurrences that have caused the court to over-turn this levy for some stores as reported by the Herald Sun in 2013 of Target department stores which was as a result of several complaints from customers that eventually led to poor sales. This suggests a miscarriage of environmental justice as such incidents have not been recorded in other countries to the best of the author's knowledge that have similar policies on plastic bags. It shows the inadequacies and ineffectiveness of the plastic bag levy policy and as a result, the overall contribution of plastic bag levy to waste minimization is insignificant as also suggested by Dikgang et al. (2010).

2.4.3 Waste Recycling

According to Masters and Ela (2008), recovery of materials or products for recycling refers to materials that have not only been extracted from the waste stream, but are also sold on to an end-user. Recycling of solid waste is known to be an environmentally sound technology as it minimizes the cost of transportation of waste and extends the life-span of landfill sites while reducing pollution to the environment through leachate and landfill gas generation (Kaseva and Gupta, 1996). The process of recycling of waste involves the collection of recyclables, separating them and transforming them into a new material, substance or product. Composting, which is discussed in section 2.3.3.1 is a common form of waste recycling. There are many recyclable materials commonly found in the municipal waste streams, such as paper and paperboard, glass containers, plastics, yard waste, aluminium and other metal materials.

From a socio-economic perspective, expansion in recycling usually entails the development of new markets since surplus of supply over demand would lead to a drop in the value of the recovered materials which could make recycling not an economically viable venture (Mihelcic and Zimmerman, 2010). Hence, it is important to also focus on the business side of recycling to ensure a sustainable practice by constantly sourcing out for new markets. Recycling systems (such as material recovery facilities) should entail preliminary separation at the source by the generators of waste. This is further separated by the use of machinery in conjunction with trained workers at a central location. This process is evident in Curatiba in Brazil, where households do primary separation into organic, recyclable and non-recyclable waste. The recyclable waste is then sorted in the central facility (WWF, 2012). This process appears to be effective and should be adopted in many local communities in order to manage their local resources in a sustainable manner. Williams et al. (2013) emphasize the need for local economies to attain some level of resource independence given that raw materials are not evenly distributed globally. Figure 2.3 shows a sustainable recycling system.

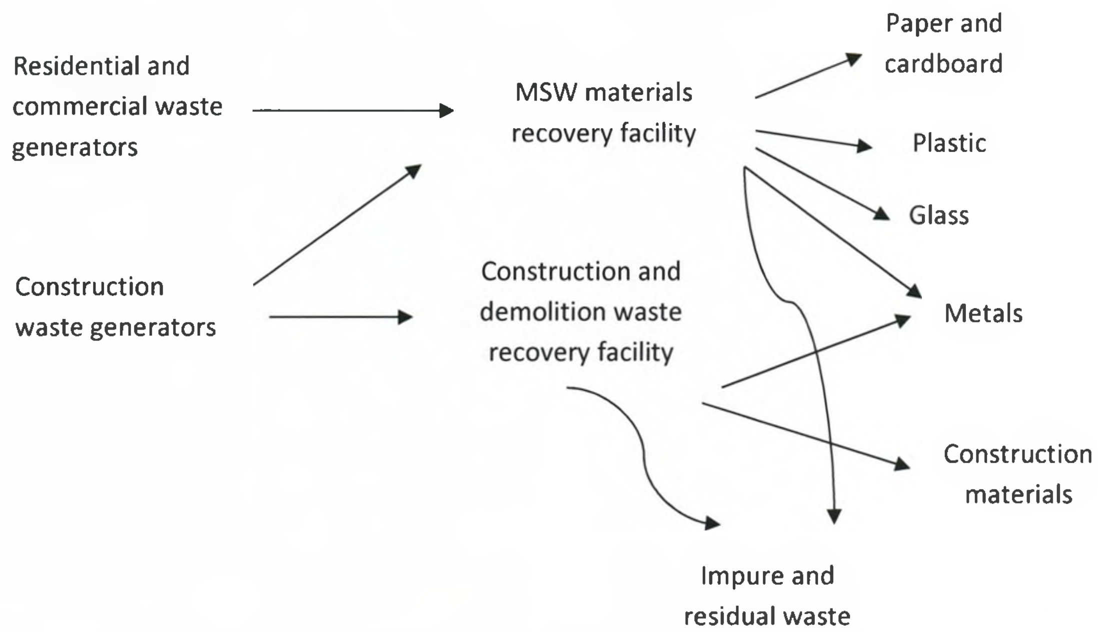


Figure 2.3: A recycling system including the waste generators, material recovery facilities, and markets for recovered material (Source: Mihelcic and Zimmerman, 2010)

In developed countries, refined recycling programs with adequate municipal solid waste databases are available and the practice of curb-side recycling programs to gather and sort waste for recycling is commonly adopted. By contrast, in developing countries, availability of an adequate and up-to-date database usually poses an issue. A social aspect of the community is the emergence of waste pickers who engage in such activities (Troschinetz and Mihelcic, 2009). An accurate account of what such a city recycles is therefore difficult to obtain. These waste pickers end up selling the accumulated solid waste materials to recycling shops, exporters or middlemen. The work conditions of these waste pickers are often unsafe due to lack of integrating these workers into the city's waste management system.

Although the work conditions may be poor, waste picking seems to be aiding a sustainable socio-economic status as discussed in a study done in Dar es Salaam. The study mentions that waste picking which was opted for due to unemployment ends up providing a monthly income exceeding the official minimum wage when the study was undertaken. This ensured gainful employment and implied lower crime rates in the city (Kaseva and Gupta, 1996). A study by

[1]According to Ross (2014), in California, USA, there is a law that was passed in 2011 which mandates an increase in the recycling rate from 50% to 75% by 2020. It is expected that this law comes with the creation of an estimated 110,000 "green jobs" in the state.

Korfmacher (1997) also mentions how recycling by waste picking helps the socio-economics of cities in South Africa, as it provides gainful employment and income.

According to Matete and Trois (2008), South Africa has a well-established recycling sector even though there are no particular policies or legislation addressing or enforcing recycling of municipal solid waste. Presently, publicly run recycling methods in South Africa include drop-off centres, organized waste picking and buy-back centres, although most of the recycling in South Africa is carried out by the packaging industry (DEAT, 1999; Matete and Trois, 2008). Table 2.3 depicts statistics acquired from several studies on waste recycling in South Africa within a 10 year time-frame, from 1991 to 2000.

Table 2.3: Recycling statistics in South Africa (Source Matete and Trois, 2008)

PRODUCT	Percentage Recycled			
	1991	**1992**	**1998**	**2000**
Paper and cardboard	28.4	29	38	89
Plastics	14.8	11	12	29
Tin plate	26.3	21	67	46
Aluminium	29.6	36	45	
Glass	22.4	14	12.6	20
Average	24.3	22.2	34.9	46.0

From the table, there appears to be a general upward trend in the percentage of materials been recycled except for glass which could be attributed to fact that the market driven nature of the recycling sector remains heavily dependent and susceptible to the availability of markets for the recyclables. Another externality that could have influenced an uneven trend for the glass material especially is that it is quite expensive to recycle glass when it is mixed with other household garbage; it would involve investing in expensive machinery to separate the glass materials (Serena, 2015).

2.4.3.1 Composting

Compost is decomposed organic materials which is useful for improving soil fertility (Mihelcic and Zimmerman, 2010). According to David (2013), typical organic materials include food waste and green (leaf and yard) waste. Composting is an environmentally sound means of managing food and green waste. In the United States of America (USA), a fifth of the solid waste generated annually comprises green waste according to the US Environmental Protection Agency (1998).

In Africa, research shows that an average of 56% of the municipal solid waste stream is of organic content which contributes significantly to greenhouse gas emissions (Couth and Trois, 2010). Diversion of the organic waste from being landfilled aids in minimizing the production rate of leachate (which pollutes surface and ground water) as well as the landfill gases such as carbon dioxide (CO_2) (Couth and Trois, 2010). Another benefit of diverting organic waste from being landfilled is the production of organic fertilizer. This aids in reducing the use of chemical fertilizer which could be harmful to the environment as a result of accumulation of heavy metals, excess nutrients such as phosphate and nitrogen, and other inorganic pollutants in the soil and plant system, and also in the ground water through drainage flows and leaching (Savci, 2012). Moreover, composting can aid in creating additional livelihood opportunities and supporting poorer farmers (Couth and Trois, 2010).

There is an increasing preference for composting over landfilling because of the associated emissions and the long-term "bury and forget it" attitude. Conversely, Ross (2014) suggests that studies have shown that biological aerosols emitted from composting process might be as problematic as the production of methane from landfills.

The process of composting of municipal solid waste is not a new practice in Africa; in South Africa for example, Johannesburg and Cape Town have been separating green waste for composting from the main waste stream (Couth and Trois, 2010). The study further describes composting process as a two-stage waste treatment process as waste accumulated should initially be sorted and the bio-waste screened to take out the metals, glass and plastics, then shredded. The separated biodegradable waste can be composted either in open windrows or closed vessels with controls on vermin, moisture and air injection. According to Richard (1996), the design of a typical municipal solid waste composting system comprises the following process: collection, contaminant separation, sizing and mixing, and biological decomposition.

Nahman et al. (2012) present some economic implications of the household food waste in South Africa. They estimate that about R21.7 billion per annum or 0.82% of South Africa's annual GDP is associated with the financial and external cost involved with landfilling. They also note that wasted food is associated with wasted resources, citing the agricultural sector which consumes 62% of all water used in South Africa. Hence, source reduction at the point of production would be a good way of reducing food waste; thereby the use of the agricultural water resources could be minimized.

2.4.4 Waste to Energy (WTE)

There have recently been investigations into alternative sources of energy, which is essential for the future global stability and sustainability. This alternative source of energy should be environmentally compatible and sustainable (Kothari et al., 2010). The use of combustion treatment on municipal solid waste with heat recovery presents a sustainable way of treating such waste whereby the solid waste ceases to be a problem, rather becoming an important alternative, partially renewable fuel (Paulas et al., 2010).

According to Al-Salem et al. (2009), WTE implies the incineration of waste to produce energy in the form of heat, steam and electricity. It is a combustion process whereby oxygen is applied at high temperatures to release the energy contained in solid waste (Mihelcic and Zimmerman, 2010). Converting municipal solid waste to energy has the potential of conserving more valuable non-renewable fuels and enhancing the eco-system by reducing the amount of waste to be landfilled, thus extending the life-span of the landfill site (Ruth, 1998).

This process also helps in reducing the transportation cost of conveying the municipal solid waste to the landfill site and it has the potential of generating energy for a community. Referring to data acquired by the United States WTE industry, an average of 1 metric ton of municipal solid waste in a modern WTE power plant can produce about 600kWh of electricity. This saves the US from mining a quarter ton of high quality coal or importing a barrel of oil for the same power generation (Psomopoulos et al., 2009).

According to Paulas et al. (2010) and Psomopoulos et al. (2009), another advantage of WTE process is the reduction of greenhouse gases and other pollutants. It also leads to source diversification, replacement of fossil fuels and security of supply. In the US, Psomopoulos et al. (2009) presents a figure of about 26 million tonnes of carbon dioxide emission reduction.

There are two common categories of WTE plants, namely the Refuse-Derived Fuel (RDF) and Mass-burn plants. In the RDF, the solid waste is initially shredded to smaller pieces with most of the metals recovered prior to the incineration process. In Mass-burn Plants, the untreated solid waste is deposited into a large furnace. In the study by Al-Salem et al. (2009), they point out that when plastics are incinerated, they result in a volume reduction of 90 – 99% and make a suitable source of energy due to the high heating value of plastics and its high calorific value considering that they are obtained from crude oil. Table 2.4 shows the calorific value of some single-polymer plastics compared to oil and municipal solid waste while Table 2.5 illustrates a comparison of air emissions generated from waste to energy and fossil fuel power plants.

Table 2.4: Comparison of calorific value of some plastics with common fuels (Source Al-Salem, et al., 2009)

Item	Calorific value (Mega Joule per Kilogram MJ Kg^{-1})
Polystyrene	41.90
Polyethylene	43.30 – 46.50
Polypropylene	46.50
Household plastic solid waste	31.80
Petroleum	42.30

Heavy oil	42.50
Gas oil	45.20
Kerosene	46.50

Table 2.5: Comparison of air emissions (Kg/MWh) from waste to energy and fossil fuel power plants (Source: O'Brien and Swana, 2006; Psomopoulos et al., 2009)

Fuel	Air Emissions (Kg/MWh)		
	Carbon dioxide	Sulphur dioxide	Nitrogen oxides
Municipal Solid Waste	379.66	0.36	2.45
Coal	1020.13	5.90	2.72
Oil	758.41	5.44	1.81
Natural gas	514.83	0.04	0.77

The table shows that a waste to energy power plant generates a relatively low volume of gases released as compared to other fossil fuels.

According to Al-Salem et al. (2009), the energy recovery process from the incineration of plastic waste results in the destruction of foams, granules and other harmful elements that are present. There are some environmental concerns from this incineration process as discussed by Shibamoto et al. (2007); in the study it is stated that the combustion of plastics such as polyvinyl chloride (PVC), polystyrene (PS), polyethylene tetraphthalate (PET) and several other plastic products gives rises to highly toxic pollutants such as polychlorinated dibenzo dioxins (PCDDs) and carcinogenic substances. These dioxins are known to have adverse effects on human health such as impeding reproductive development. The study suggests that to significantly reduce the formation of dioxins, the combustion of the plastic waste should occur at temperatures above 850°C.

Al-Salem et al. (2009) also highlight environmental issues associated with the combustion of plastic waste through the emission of air pollutants such as smoke (particulate matter), carbon dioxide (CO_2), nitrogen oxides (NO_x) and sulfur oxides (SO_x), and the generation of volatile organic compounds. The study also suggests that factors such as the temperature, and the addition of certain other types of waste, aids in the reduction of some of the air pollutants such as the sulfur and nitrogen oxides.

As regards using by-products of the waste to energy process, Haque and Sharif (2014) conducted a study whereby the use of ash from informal incineration of municipal solid waste was used as clay replacement raw material for the manufacture of bricks. It shows that the compressive strength of the bricks with about 20% ash provides a standard for severe weather conditions.

2.5 Landfilling

The disposal of solid waste in landfills has been for a long time the most economic and attractive form of disposal of a city's solid waste (El-Fadel et al., 1997). In more developed economies, there have been aggressive preventive strategies to separate the discarded materials from the environment (Shekdar, 2009). However, this is a highly expensive venture and requires an advanced level of technology (Shekdar, 2009). Landfill is the common solid waste management option that is practiced in most developing countries, South Africa inclusive.

An improved technology of operating landfill is allowing part of the leachate to re-circulate the landfill space with an adequate layer of cover materials. This acts as an anaerobic digester and enhances a faster rate of decomposition of the waste materials. A common practice on landfills is the extraction of methane gas, which is usually collected and deposited at the flaring unit, but a setback of these landfills is that some of the methane is dispersed into the atmosphere, and the biochemical process is much slower than in a biogas plant (McDougall et al., 2001; Arena et al., 2003). A brief discussion on these areas of landfill is discussed in this section.

Landfill in developing countries is a necessary component in achieving an integrated solid waste management system (Mihelcic and Zimmerman, 2010). Local authorities are charged with the duty of managing the solid waste management systems in their jurisdiction. In the South African context, there is lack of literature on how the municipalities are performing as regards solid waste management challenges and minimization initiatives, given the new waste management and regulations in the country (Bhagwandin, 2013). Landfilling in South Africa, however economical, appears to present some challenges in certain parts of the country like the Gauteng province, where there is limited space for new landfills with the existing ones gradually reaching full capacity. Table 2.6 presents a list of operational landfill sites in the Gauteng province with their respective characteristics

Table 2.6: Status of landfills in Gauteng as at 2008 (GDACE, 2008)

Municipality	Estimated Life span (Calculated from 2007)	Number of operational landfills	Number of permitted landfills	Number of landfills with weighbridges	Number of landfills with some form of recycling
Tshwane	3 – 40 years	8	5	1	3
City of Johannesburg	0 – 20 years	5	4	4	0
Ekurhuleni	20 – 60 years	6	6	6	3
Sedibeng	1 – 15 years	11	4 in process	0	2 formal 2 informal
West Rand	5 – 10 years	5	4	0	3 at tip face
Metsweding	3 – 40 years	1	1	Not operational	Informal
Total	-	36	24	12	13

From the table presented by GDACE, it can be seen that most of the landfills will attain their full capacity soon. It is therefore critical to ensure the management of each site is run in a sustainable manner where recycling and energy recovery processes are implemented. The table also shows that about 30% of the landfills do not have permit, about 20% do not have weighbridges and only about 38% engage in some form of on-site recycling (either formal or informal). These figures show that sustainable 'best landfill practice' is not yet attained in some of the landfill sites in the Gauteng province.

Landfills are engineered facilities designed and operated for the long-term control of discarded solid waste (Mihelcic and Zimmerman, 2010). The design of the landfill usually depends on the type of waste being discarded and the location of the landfill site (Mihelcic and Zimmerman, 2010).

According to Masters and Ela (2008), there are three classifications for landfills, namely:

1. Class I landfills (Secure landfills), designed to handle hazardous waste,
2. Class II landfills (Monofills), designed to handle 'designated waste' that is relatively consistent in characteristics and needs special means of handling such as incinerator ash or sewage sludge.
3. Class III landfills (Sanitary landfills), designed to handle municipal solid waste. Class III landfills are the focus of this study.

Other studies have also classified landfills into various types; Wroblewski et al. (2009), groups landfill into the following types: sanitary landfills, municipal solid waste landfills, construction and demolition waste landfills and industrial waste landfills. Most classifications are similar in terms of the type of waste materials being disposed of. A noteworthy type of landfill is the bioreactor landfill. The Solid Waste Association of North America (SWANA) describes a bioreactor landfill as a controlled landfill where liquid and gas collection are managed actively so as to enhance bio-stabilization of the waste.

Research shows that there is significant increase in the rate of decomposition of organic waste, conversion rates, and process effectiveness over the typical process in a municipal or sanitary landfill site (Mudua, 2012). US EPA, 2002 describes a bioreactor landfill as a landfill whose mode of operation is to rapidly degrade and transform organic waste. The rapid degradation and stabilization process involves the introduction of liquid and air into the landfill to enhance the microbial process. Bioreactor landfill differs from the conventional sanitary or municipal landfill mainly in terms of its design and mode of operation. Leachate generated at the bottom of a landfill is designed to recirculate back into the landfill in a controlled manner. According to Reinhart et al. (2002), there is a general reluctance to apply the bioreactor concept as the technology is not demonstrated in detail and there appear to be technical barriers, imprecise cost implications and regulatory constraints.

Pacey et al. (1999) also agrees that barriers such as limited regulatory awareness, negative perception, limited availability of project economic assessments, insufficient project sustainability experience, lack of financing experience and increased regulatory constraints and conditions have put a setback on the technology but the study advocates for the implementation of the technology as it is a key strategy for deriving short and long-term environmental, regulatory and socio-economic benefits. The study highlights a few significant benefits of the bioreactor landfill:

i. Rapid organic waste conversion/stabilization;

ii. Maximisation of landfill gas capture for energy recovery projects;

iii. Increased landfill space capacity re-use as a result of rapid settlement during the operational period;

iv. Improved treatment and storage of leachate;

v. Reduction in post-closure care, maintenance and risk.

Manfredi and Christensen (2009) argue that although bioreactor technologies practice the recirculation of leachate to increase the decomposition process, there appear to be no noticeable environmental benefits in 100 years from a life cycle assessment perspective. The study points out that a better environmental performance could be achieved if a semi-aerobic technology is adopted. This landfill technology combines two steps which are the anaerobic and aerobic metabolism processes to stabilise the waste materials. The technology comprises reduced generation of leachate as a result of the aerobic waste degradation step.

There is a general consensus in literature as to the types of landfill listed in this study especially relating to the type of solid waste materials being disposed of at these landfills. Municipal solid waste landfill and sanitary landfill are typical landfills surrounding cities as they accommodate major types of solid waste materials except for hazardous waste. Literature also shows that the conversion of these municipal and sanitary landfills to a bioreactor technology would aid the concept of sustainable solid waste management. Although there appears to be reservations in some literature in the implementation of a bioreactor technology as certain barriers listed earlier could be problematic. Manfredi and Christensen (2009) suggest a semi-aerobic technology due to the reduced leachate generation involved with the technology. However, this study suggests that more research should be carried out with particular focus on exploring the aforementioned barriers of a bioreactor technology (since there is more literature on this technology) and how they can be curbed.

Landfilling in sites in City of Johannesburg and indeed the whole Gauteng province appears to require extra efforts towards a sustainable manner of administration as most sites are attaining their full capacity coupled with limited land space. Recycling needs to be practiced extensively in order increase the life-span of these sites. Recent visited to the site of study in the City of Johannesburg shows that the weighbridge is currently not working and it was reported that some other sites experienced a similar predicament. It is not possible to manage a site sustainably if a proper record of materials getting into the landfill cannot be attained. It can also be deduced from Table 2.6 that 'best landfill practice' is not being followed in this region as anticipated in the study's problem statement.

2.5.1 Landfill Design

Legislation in South Africa and indeed in many countries globally, requires that landfill developments are designed, constructed and operated to government guided levels of sophistication (Strachan et al., 1998). The study suggests that a modern design of an engineered landfill necessitates the implementation of relatively sophisticated construction facets, which includes the following:

i. The aspects integrated into the landfill barrier system;

ii. The control of ground water and surface run-off;

iii. The leachate drainage system;

iv. Daily cover;

v. The overall geometric shaping of the final waste body.

A common practice of many landfill sites is merely storing the waste for later generations to deal with. This practice of 'dry-tomb', which is also common in South Africa, is characterized by an extremely slow decomposition of the solid waste (Fourie, 1998). The predominantly semi-arid climate in South Africa in conjunction with an effective cover system also inhibits the moisture ingress, slowing decomposition of the buried waste. The engineering design of landfills should be according to global best standards as these facilitate more anaerobic decomposition to take place.

As regards best practice, a typical landfill should comprise the following components: a composite liner; a leachate system to prevent groundwater pollution and gas collection to minimise air pollution (Masters and Ela, 2008). Figure 2.4 shows a cross-section of a typical municipal solid waste landfill.

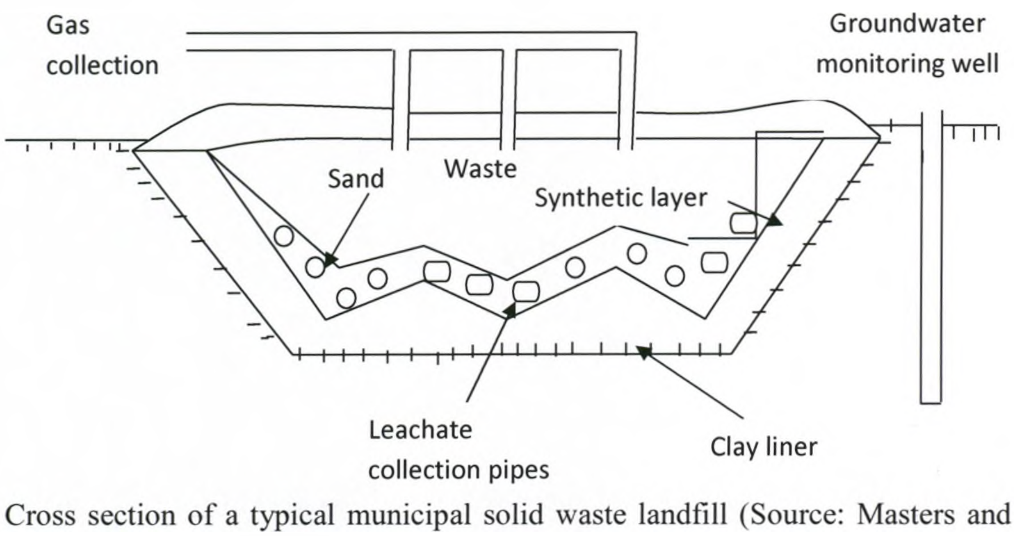


Figure 2.4: Cross section of a typical municipal solid waste landfill (Source: Masters and Ela, 2008)

In developing countries such as South Africa, some municipalities encounter financial challenges occasionally, hence the need for cost effective ways of delivering services (Rohrs et al., 1998). Sanitary landfill and modern municipal landfill designs from developed countries are extremely expensive, therefore, more attainable standards for South Africa have been offered in the Minimum Requirements for waste disposal by landfill which are discussed further in chapter three.

In the design of a bioreactor landfill, the required components are similar to a modern landfill (Pacey et al., 1999). It should have the bottom liner, gas and leachate collection and management facilities and a final cap. However, the study points out the following critical issues that must be addressed in order to establish a successfully run landfill that satisfies regulatory concerns:

a) Cell size: deep cells (or phases) are required to be completed within two to five years. The construction of these cells can easily take advantage of future technological upgrades. Upon closure of the cells, methanogenic conditions within the cell are optimized so that the generation and extraction of the landfill gas is facilitated.

b) Maximum allowable leachate-head on the bottom liner: this is facilitated by federal regulations in the USA and may be readily achieved by adopting proper design and specifications of bottom liner slopes, drainage layer flow distances, and hydraulic conductivity of the leachate drainage layer.

c) Liquid management: liquid storage, design flow rates and supplementary capacity estimations must be made in the design for the liquid management system. To ensure that the system can accommodate events such as peak leachate generation, sufficient storage would be required in its design.

d) Solid waste density considerations: the addition of liquid to solid waste will enhance its density which is a significant aspect in designing the load-bearing structural members in the landfill.

e) Landfill gas control system: due to the rapid rate of decomposition a bioreactor landfill generates landfill gas at a faster rate than the conventional drier municipal landfills. As a result, the installation of larger pipes, blowers and related equipment that is capable of efficiently controlling the gas and odour problems would be required.

f) Landfill stability: the issue of stability can be assessed and resolved with standard geotechnical analyses. Similar to solid waste density considerations, there is also addition of liquid to the solid waste however; the biological activity that occurs is of focus here. With the addition of liquid to the solid waste, this process hastens the biological activity; it will also enhance the total weight of the solid waste mass and could lead to an increase in internal pore pressure.

Figure 2.5 shows the major components of a bioreactor landfill design.

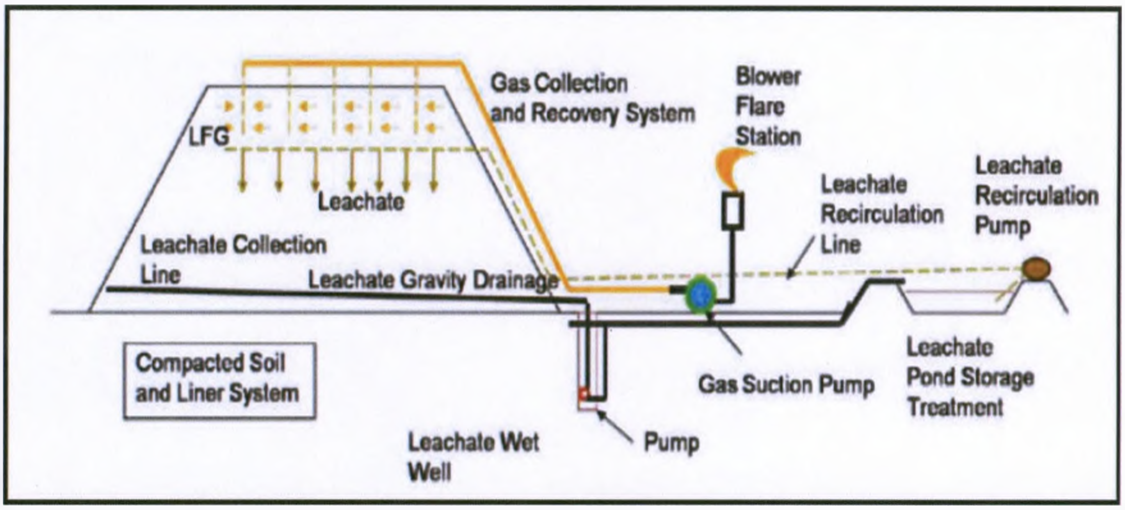


Figure 2.5: Components of a Bioreactor Landfill (Source: Mudua, 2012)

2.5.2 Landfill Gas and Leachate Generation

According to El-Fadel et al. (1997), the unavoidable outcomes from the practice of disposing solid waste on landfills are the generation of landfill gas and leachate as a result of microbial decomposition, climatic conditions, solid waste characteristics and the operations that occur on the landfill. The solid waste disposed into landfills generally undergoes a series of interrelated biological and chemical reactions which determines the composition and quantity of leachate and gas produced and hence is valuable in determining the management needed (Mihelcic and

Zimmerman, 2010). The landfill gas which is produced as a result of the anaerobic decomposition of the organic composition of the disposed solid waste can be recovered via the gas collection system and eventually burned with or without energy recovery to minimize the greenhouse gas emissions (Hoornweg and Bhada-Tata, 2012). With the bioreactor landfill technology, Manfredi and Christensen (2009) show that the technology allows the gas collection period a possible reduction from 40 to 15 years when a life cycle assessment was carried out.

The major constituents of landfill gas are carbon dioxide and methane gas; other components of landfill gas include nitrogen, oxygen, ammonia, sulfides and hydrogen. Oxygen present in the void spaces in the landfill ensures aerobic decomposition to occur whereby biodegradable organic waste reacts with this oxygen and CO_2 is released in the process (El-Fadel et al., 1997). Upon the depletion of the oxygen, anaerobic decomposition phase occurs where organic waste is further converted to CO_2 and methane. The following processes take place: hydrolysis, acidogenesis, acetogenesis and methanogenesis. Table 2.7 depicts the major constituents of landfill gas.

Table 2.7: Landfill gas constituents (Source El-Fadel et al., 1997)

Component	Concentration Range percentage (Dry Volume Basis)
Methane	40 – 70
Carbon Dioxide	30 – 60
Carbon Monoxide	0 – 3
Nitrogen	3 – 5
Oxygen	0 – 3
Hydrogen	0 – 5
Hydrogen Sulfide	0 – 2
Trace compounds	0 – 1

Leachate is formed as a result of the removal of soluble compounds through the process of non-uniform and intermittent percolation of water through the buried waste materials. According to Blight (1996) and Mudua (2012), the potential for leachate generation on a landfill is evaluated by the probability that the annual precipitation will exceed the annual evapotranspiration. As regards evapotranspiration in landfills, it can be measured through two main approaches: as a fraction of American standard A-pan evaporation and the Symons S-pan. The difference between these two approaches lies in the difference in dimensions, conditions of exposure as well as colour. El-Fadel et al. (1997) suggest that the quantity of generated leachate on a landfill is site-specific and also on a function of the following: availability of water, weather conditions, the solid waste characteristics, the landfill surface and underlying soil. The quality of the leachate however is dependent on the following: the fermentation stage of the landfill, solid waste composition, and the operational procedures occurring on the site. Novella (1998) agrees that quality and composition of leachate is linked to the type of waste being landfilled as well as the processes which occur within the landfill. Leachate is usually channelled to an evaporation pond or a detention pond where it is treated before being discharged to a natural water body or left to evaporate.

There is a general consensus in the literature reviewed that the generation of landfill gas and leachate are inevitable consequences of solid waste disposal by landfill. However, the quantity of what is generated would be dependent on the adopted landfill technology. Also, quality of the generated landfill gas and leachate is dependent on a number of factors which have been stated earlier and this also appears to be the general consensus across the review of literature. It is important to understand how to harness the positive aspects of the landfill gas and leachate while preventing the negative aspects from affecting the environment, which would contribute significantly to a sustainable landfill. A sustainable landfill should be the type where air space, processes, use of products and residues are at an optimum, and where minimal negative effects on the environment are detected (Novella, 1998).

2.6 Zero Waste to Landfill

According to Davidson (2011), an efficient way of managing waste is to avoid dealing with the waste itself; which leads to waste diversion and minimization of the waste as primary targets for most integrated waste management plans. This ideology introduces the concept of 'zero waste to landfill'. Researchers (Matete and Trois, 2008; Davidson, 2011) define the concept of *zero waste* as a waste management and planning approach which emphasizes the prevention of waste as opposed to 'end of pipe' waste management. In other words, it is a 'back end' solution which ensures that recycling of waste product is maximized and at the same time minimizing the generation of waste. It can be applicable to any part of the waste stream, from generation to disposal.

Another definition for the concept *zero waste* given by the Institute for Zero Waste in Africa (IZWA, 2009.) is that it is a goal which is as visionary as it is pragmatic, to guide people in emulating sustainable natural cycles. It involves a process where all materials that have been disposed of become resources for others to utilize. The philosophy of *zero waste* should be seen as more of ideal situation rather than a hard target as it focuses on the restructuring of production and distribution systems to prevent waste from being manufactured in the first place or in situations where waste is created; it can easily be re-integrated back into products and processes in a safe manner (IZWA, 2009 and Davidson, 2011).

The concept of *zero waste* is becoming more accepted globally and has been adopted in several countries such as Canada, New Zealand, the UK (Davidson, 2011) and South Africa (IZWA, 2009). Some business organizations have adopted a successful zero waste programme into their integrated waste management system such as Kimberly Clark and Hewlett-Packard (Davidson, 2011). In South Africa, the concept was adopted as a national target to be achieved by 2022 during the Polokwane Declaration in 2001. It is also the vision of the City of Johannesburg's waste managers: Pikitup (CoJ, 2014). According to the IZWA report, there are five basic principles of *zero waste*:

1) Redesigning products and packaging: this principle encourages advance planning regarding minimization of the use natural resources and energy. It also advocates the phasing out of the production and use of toxic materials, and over-packaging products.

2) Producer responsibility: this principle places the primary burden of responsibility on the manufacturers and holds them liable for the various environmental impacts their

materials and products would have. It maintains that these manufacturers should be responsible for the financial and physical responsibility for their products and processes.

3) Infrastructural Investment: this principle encourages community investment into new material resource recovery facilities as it would support social development from the sustainable re-use of natural resources.

4) Monetary Efficiency: this principle advocates the implementation of policies that ensures that manufacturers pay for the true cost of using "virgin natural resources" as raw materials. It is expected to drive up their cost, hence encouraging the use of recyclable materials as a strategic choice for the manufacturers.

5) Job creation: according to several studies, the process of sorting and processing recyclables is capable of sustaining ten times more jobs as compared to landfilling these wastes.

Matete and Trois (2008) show that inculcating the concept of *zero waste* to landfill into an existing waste management system in South Africa is attainable by developing a *zero waste model*. The study in Nazareth and Mariannhill Park emphasizes the need for participation as well as establishing a positive attitude towards recycling amongst individual households in order to ensure the success of such scheme. 'Zero waste to landfill' initiative in South Africa has been documented in some reports such as the Recycling and Economic Development Initiative of South Africa (REDISA, 2015) report where it is suggested that public private collaboration can aid in achieving a successful solid waste management where zero waste to landfill can be an achievable task. Eden district municipality is cited as an example where the municipality works with REDISA in spreading the awareness of sustainable waste management practices and keeping the local communities free of waste and especially avoiding as much waste been disposed at the landfills. In Makana municipality, a 'two-bag system' for waste collection was established in 2009 which is in line with the Integrated Waste Management Plan (IWMP, 2008) for the municipality. The system was established to achieve the zero waste to landfill initiative where Grahamstown residents are expected to place all recyclable material in a clear (transparent) bag while the remaining disposable waste are placed in a black bag. This system aims to save residents the task of transporting different recyclable materials to the various recycling depots around the town as this has not been successful in the past. However, report shows a significant success rate with the 'two-bag system'.

Another concept synonymous with the 'zero waste to landfill' is the 'cradle to cradle' as opposed to the more common 'cradle to grave' concept of waste management, which is the one-way flow of materials from natural resources into waste that would be disposed of at landfills. The 'cradle to cradle' emphasizes designing industrial systems to ensure a closed loop cycle of material flow. This ensures that the waste is reduced, and the waste materials can be re-used or recycled (Davidson, 2011). Figure 2.6 illustrates a cradle to cradle system.

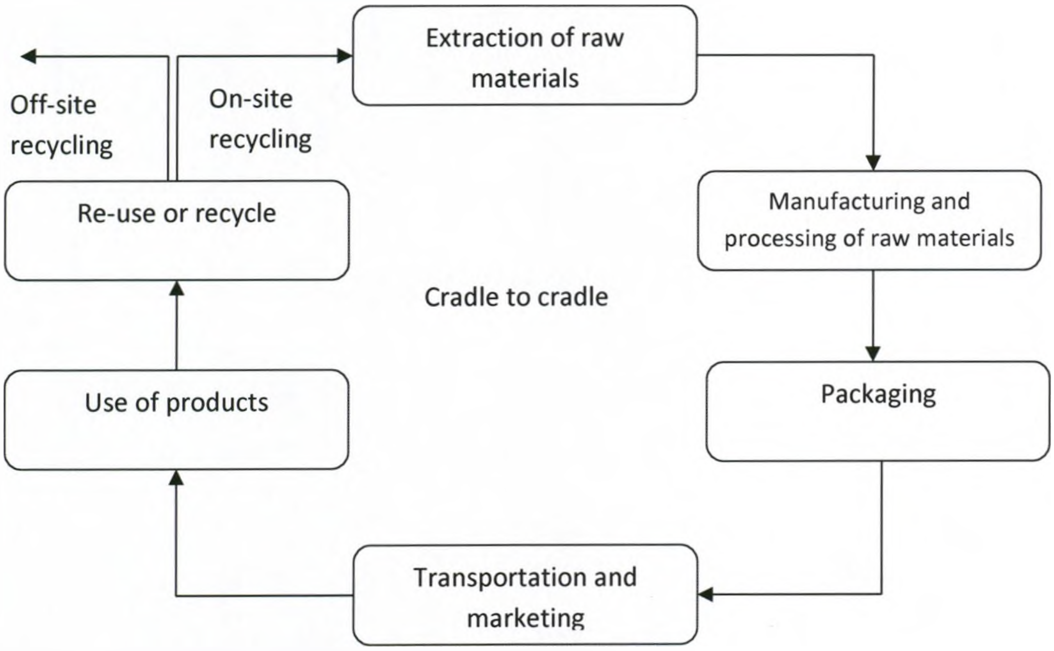


Figure 2.6: Cradle to cradle system (Source: Davidson, 2011)

2.7 Integrated Solid Waste Management

Solid waste management differs across countries and cities. Research has found that waste management is peculiar to the type of waste and the characteristic of the area the waste is generated (Rodic et al., 2010). There is no typical solution that can be applied to all towns and in all situations; while the management of municipal solid waste cannot be replicated from one area to another, nevertheless it is necessary for there to be global benchmarks against which to measure each city's unique approach. The main limitation in evaluating solid waste management systems in various cities is the absence of consistent global solid waste and recycling baselines (Rodic et al., 2010).

The need for stakeholders in the waste management sector to engage and develop innovative and sustainable ideas and solutions cannot be overemphasized (Mecklenburg County, 2013). Stakeholder engagement has been proven globally as an effective way of implementing innovative solutions in solid waste management such as in Mecklenburg County in USA and in Brazil. An Integrated Solid Waste Management (ISWM) is usually designed to meet specific goals by including stakeholders' needs and perspectives. The ISWM should also incorporate the local context such as the socio-economic, cultural, technological, environmental and institutional aspects and to ensure an optimized combination of accessible and appropriate methods of prevention, reduction, recycling, recovery and landfilling (Marshall and Farahbakhsh, 2013).

Stakeholders' engagement in South Africa appears to be of a minimum standard from studies reviewed (Nhamo, 2008; Spamer, 2009; Hanekon, 2015) with a collective recommendation on a more detailed stakeholder engagement process to achieve more successful outcomes. According to Hanekon (2015), the DEA created governance platforms for the purpose of stakeholder engagement with the aim of positively impacting on policy development. However, the report also states that there is limited waste management awareness programmes directed to the citizens. This simply shows that the stakeholders' engagement process is not as effective as it ought to be. Another report which depicts this contradictory situation of the stakeholders' engagement process is presented by Nhamo (2008). It documents the formulation and implementation processes of the Plastic Bag Regulation in May 2003. The study shows that although the regulations resulted in significant reduction in plastic shopping bags getting into the South Africa's environment, the major focus was on the down-turn of profits from shopping bag manufacturing industries coupled with the subsequent job losses which lead to about 25% reduction in employment and related social impacts. Key stakeholders such as the shopping bag manufacturing industry, businesses and labour lobbied against the implementation of the plastic bag regulation but without success. With the review of these cases, the author also agrees that stakeholders' engagement process as regards solid waste management ought to be a more detailed participatory process to ensure its effectiveness and to attain a level of general agreement to policy developments and implementations.

A system will not be sustained by a society and will not perform as designed if the procedures are forced upon the system users rather than being negotiated with the users of the system. It will also fail if the mode of collection is not in line with citizens' inclination and needs, nor if the waste authorities lack the knowledge and aptitude to effectively monitor the actions of a private service provider. Furthermore, even if the most advanced technology is used, if the points listed above are not met, the system will fail (Rodic et al., 2010).

Globally, the overarching aim in solid waste management is to divert as much waste as possible for resource recovery in order to reduce pollution and extend the life of any material. Integrated Solid Waste Management is based on the principle of reduce, reuse and recycle. The primary objective of an ISWM is the maximization of reduction in final quantities of waste via waste recovery techniques and the generation of revenue from these recovered wastes to finance waste management operations. According to a United Nations Environmental Programme (UNEP) report (2009) on developing integrated solid waste management plan, the ISWM system after being tested in several locations (China, India, Lesotho) was found to be accepted by the local waste authorities and it was further discovered that with effective sorting and recycling, considerable amount of waste could be prevented from going to landfills and rather used as a resource (UNEP, 2009). According to the UNEP (2009) report, the ISWM theory can be analyzed with respect to three viewpoints: lifecycle of any product; waste reduction; and waste management.

ISWM is based firstly on the point of view of a lifecycle assessment of any product/material and is concerned with the production and consumption phases of the product. The reuse of 'supposed waste' within the production process as against the use of new resources can produce a reduction in the amount of waste generated at the product end-of-cycle, therefore, less labours and capital would be necessary for the final disposal of the waste (UNEP, 2009).

Secondly ISWM is based on the concept of waste generation from different sources including domestic, construction, commercial, and agriculture. The waste could then be categorized as hazardous and non-hazardous waste if necessary. The hazardous waste must be separated at the source of its production and prepared for disposal via effective treatment specified by laws and regulations of the land. The reduction, reuse and recycle approach can be applied at the source of generation as well as along the entire chain of the solid waste management - collection, transportation, treatment and disposal (UNEP, 2009).

Thirdly, ISWM is based on the concept of management. This includes legislation, regulations, technology and impact of the various players in the solid waste management sector (UNEP, 2009).

An integrated solid waste management plan is an overall strategic method for the management of solid waste in a sustainable manner which encapsulates all aspects and sources, covering generation, transfer, segregation, treatment, recovery and disposal in an integrated method. Emphasis should however be focused on maximum utilization of resource use efficiency (Memon, 2010).

To be effective, an ISWM must develop innovative ways of preventing, recycling and managing solid waste to ensure the protection of human and environmental health (USEPA, 2002). According to Marshall and Farahbakhsh (2013), the ISWM aims to attain a balance between three dimensions of waste management which are:

i. Social acceptability;

ii. Economic affordability, and

iii. Environmental effectiveness.

These three dimensions are depicted in Figure 2.7

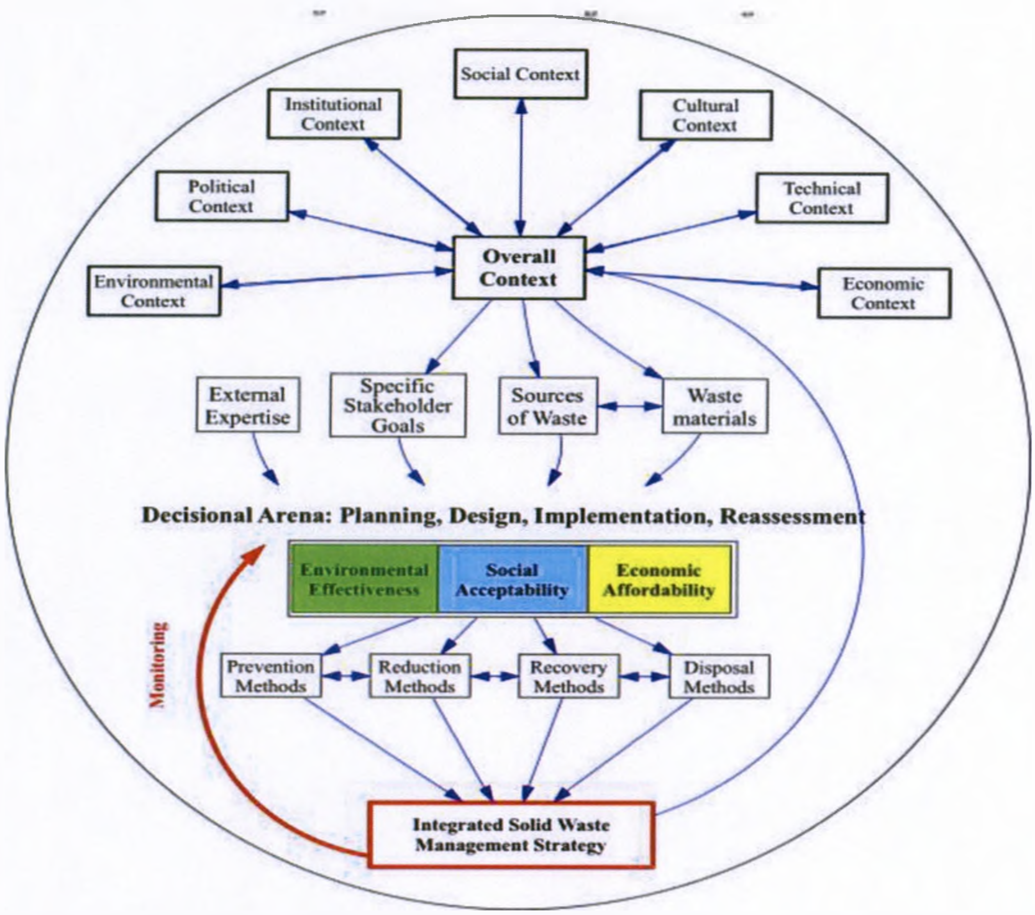


Figure 2.7: Integrated Solid Waste Management Paradigm (Source: Marshall and Farahbakhsh, 2013)

The ISWM process involves assessing current conditions prior to selecting and integrating the most feasible waste management action for those conditions. There have been studies and projects on developing a sustainable ISWM in some countries through the United Nations (UN) Habitat programme. For this programme, the use of Material Flow Analysis (MFA) was employed as the methodological approach which aided decision making (Tang and Brunner 2013). A more detailed look at MFA as methodological tool for solid waste management is presented in section 4.3.

2.8 Municipal Solid Waste Characterization

For successful management of municipal solid waste, accurate and up-to-date data of the rate of generation of waste and the characterization of the waste is essential for sound decision making towards an appropriate and sustainable solid waste management system (Palaniel and Sulaiman, 2014).

As mentioned in section 2.2, the type and quantity of waste produced by a community depends on the dominant culture and the income per capita; the wealthier communities discard more goods as compared to the poorer communities, the waste of which is characterized by more organic and less recyclable materials in the waste (Blight and Mbande, 1996; Yenice et al., 2010). Similarly, the general composition of waste in developing countries differs from that of developed countries. Within countries of similar economic characteristics, differences in the waste compositions are attributed to the nature of the culture, climatic conditions, differences in the source of fuel and dietary pattern (Mudau, 2012). Other factors stated by Yenice et al. (2011) that causes the variations in the composition of waste are the geographic location, seasonal conditions, and population density.

As mentioned in Chapter 1, Sethi et al. (2013) classify waste characterization into three:

1) Physical Waste Characteristics;
2) Chemical Waste Characteristics, and
3) Geotechnical Waste Characteristics.

As regards methodologies adopted for characterization of municipal solid waste, the United States Environmental Protection Agency, USEPA (1996) describes two basic approaches to estimate the quantities of the different components of the municipal waste stream. The first approach is site specific which entails sampling, sorting and weighing the respective components present in the waste stream, which is known to be useful in defining the waste stream at a local scale. The second approach entails the adoption of a material flow analysis tool to estimate the individual components of the waste stream.

The relevance of waste characterization has been documented in several studies. A physical and chemical characterization of waste was carried out by Mor et al. (2006) to determine the proportion of degradable organic matter in conjunction with a First Order Decay simulation model (FOD). An estimation of the methane generation potential for Gazipur landfill in India was attained. Yenice et al. (2011) carried out a solid waste characterization according to the standard method for determination of raw municipal solid waste composition for the city of Kocaeli in Turkey. The results of this study have been used by waste planners in managing the municipal solid waste.

Sebola et al. (2014) carried out a study on waste characterization at the Doornfontein campus, University of Johannesburg, South Africa to examine the amount of bio-waste generated from the campus. The aim of assessing the quantity and type of waste produced was to convert it to energy for use as vehicular fuel. A solid waste characterization exercise was carried out on a nationwide scale by the USEPA (1996) where the historical municipal solid waste database for a 34 year waste characterization (by weight) of the respective components of the waste stream was analyzed. The information derived from the study is important for planners in establishing trends and highlighting the variations that occurred over the years in types of generated waste and the methods by which they are managed. It would help in evolving a successful and sustainable management system and also be useful in assessing solid waste management needs and policies on a nationwide scale.

To carry out an in-depth look at solid waste characterization, it is important to identify the sources of waste. According to Ogola et al. (2011) there are six general sources of waste generation, namely:

1. Domestic waste: households appear to be the highest producers of domestic waste in the municipal waste stream. It usually contains paper and cardboard, glass, plastic, food remnants, metal cans and at times electronic waste;
2. Natural waste: this comprises plants, leaves, tree branches, and carcasses of animals. It mainly contains biodegradable components that are generated as part of natural processes;

3. Commercial waste: the composition of this is quite similar to domestic waste but in different proportions. They are generated from business premises, market places, stores, malls and restaurants.

4. Industrial waste: this refers to waste such as construction and demolition debris and food processing excess. It also contains potentially hazardous waste from a wide range of industrial processes.

5. Agricultural waste: this also constitutes a large percentage of the waste in a solid waste stream comprising agricultural activities that include vegetation cultivation, waste from livestock rearing, and waste products from the dairy and poultry farms. These wastes also contain predominantly biodegradable components.

6. Institutional waste: this refers to waste generated from offices, schools, banks and the likes. It consists mainly of paper and cardboard; with some traces of food remnants and electronic wastes.

Figure 2.8a shows waste composition of general waste in percentage by mass for South Africa in 2011, Figure 2.8b shows waste composition of municipal solid waste in percentage by mass for Gauteng province in 2008 and Figure 2.8c shows the waste composition of municipal solid waste by source for the City of Johannesburg in 2004.

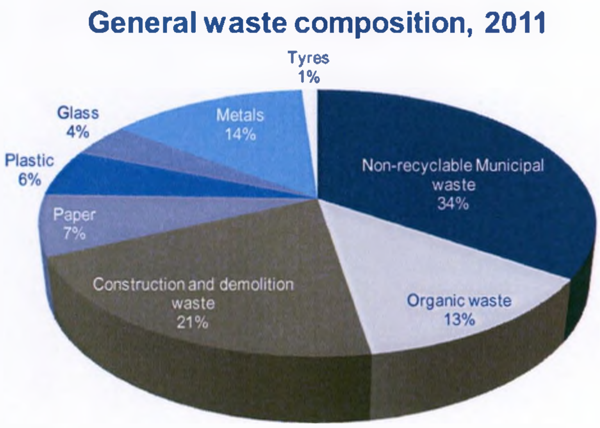


Figure 2.8a: The waste composition of general waste in percentage by mass for South Africa in 2011 (Source: DEA, 2012)

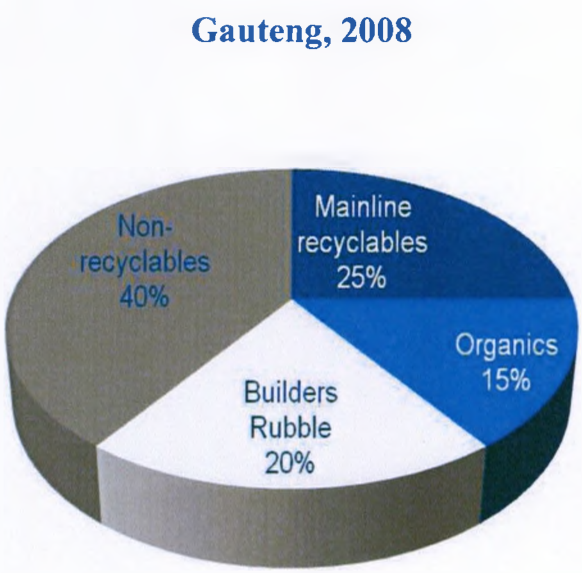


Figure 2.8b: Municipal waste composition in percentage by mass for Gauteng (Source: DEA, 2012)

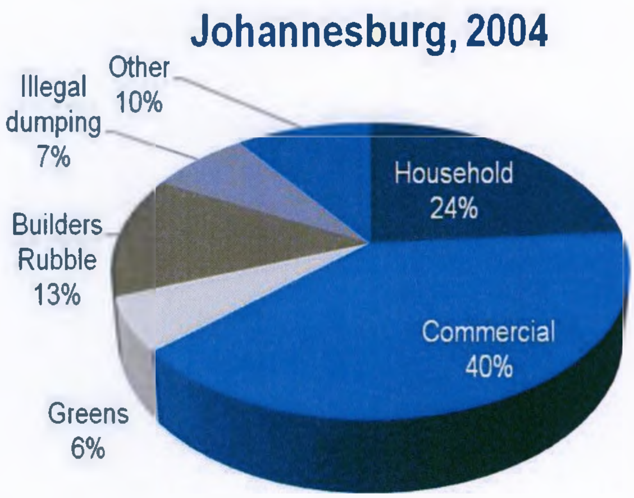


Figure 2.8c: Municipal solid waste composition by source for the City of Johannesburg (Source: DEA, 2012)

According to Mor et al. (2006), municipal solid waste is generally made up of various organic and inorganic components such as food, plastics, wood, metal, paper and other inert materials.

This article explains why the need to ascertaining the composition of the municipal solid waste reaching the landfill sites is important, as it facilitates estimating the amount of landfill gas emission potential of the landfill site. Landfill gas contains 30 - 40% carbon dioxide (CO_2), 50 – 60% methane and traces of other various chemical compounds, including chlorinated organic compounds, aromatics and sulfur compounds (Khalil, 1999; Mor et al., 2006). Greenhouse gases (GHGs), methane and CO_2 have a considerable effect on global warming. However, a report from the United States Environmental Protection Agency (US EPA, 1994) highlights that the volume of methane emissions from these landfills depends on the composition of the solid waste that has been discarded at the site; hence it is important to do a comprehensive waste characterization of the sites. Figure 2.9 depicts a waste characterization flow diagram.

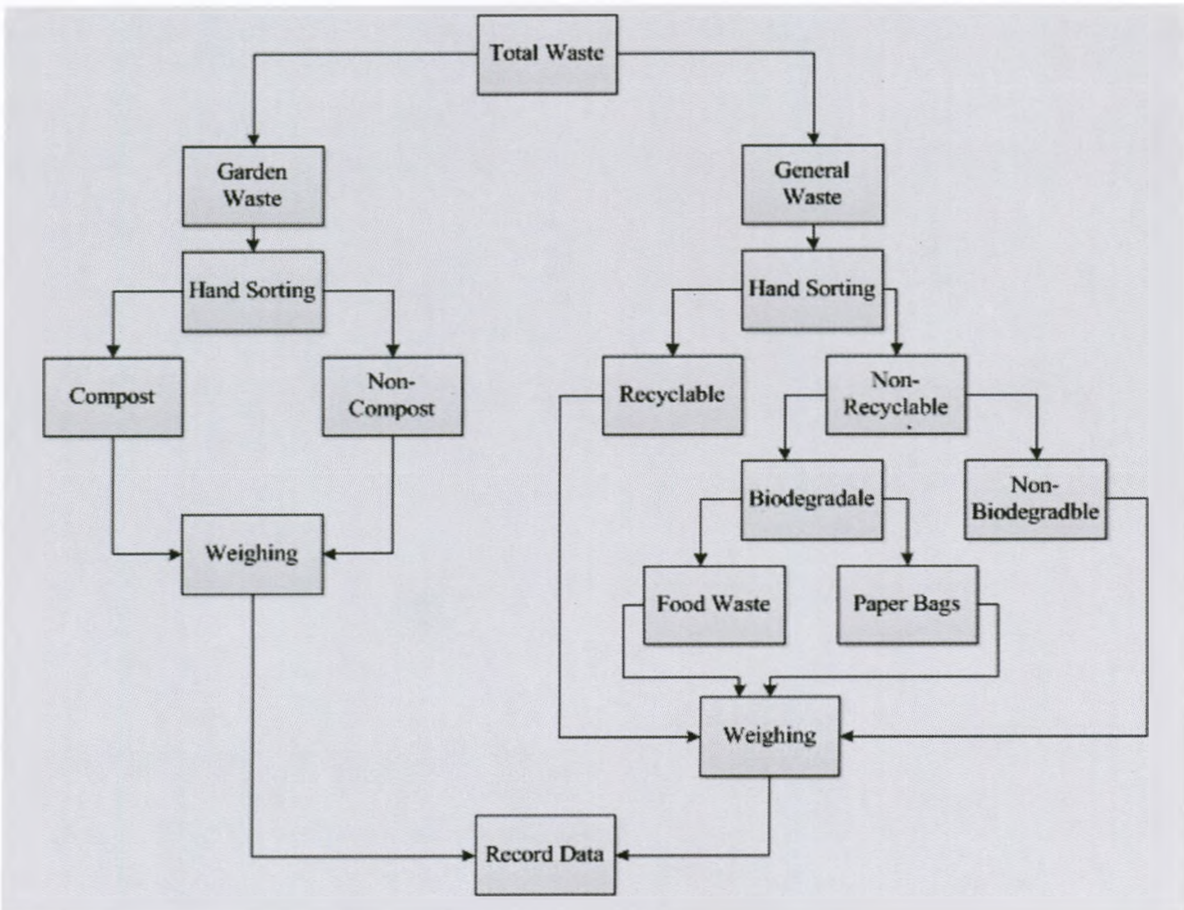


Figure 2.9: Waste Characterization Flow Diagram (Source: Sebola et al., 2014)

An aspect of solid waste characterization as regards landfilling is the generation of leachate which is a result of decomposition of the buried waste on the landfill. According to El-Fadel et al. (1997), the major factors influencing this decomposition and hence the formation of leachate are the kind of site operations and management, climatic and hydrogeological conditions of the location, the disposed waste characteristics and the internal landfill process. Adequate knowledge of the composition of the leachate discharged on a landfill is just as important as having a good knowledge of the solid waste composition. It is essential for making projections of long-term undesirable ecological impacts of the landfilling process (Mudau, 2012). It is however quite challenging to characterize leachate due to the fact that its concentrations and compositions depend largely on the factors of waste age, technology of landfilling, the actual solid waste composition, geology, temperature, moisture content and other hydrological factors (Kjeldsen et al., 2002).

The study by Kjeldsen et al. (2002), classifies municipal landfill leachate into four main classes:

a) Dissolved organic matter: these are mainly quantified as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and volatile fatty acids.

b) Inorganic macro-components: these include ammonium (NH^{4+}), calcium (Ca^{2+}), chloride (Cl^{-}), hydrogen carbonate (HCO^{3-}), iron (Fe^{2+}), manganese (Mn^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), Sodium (Na^{+}), and sulfate (SO_4^{2-})

c) Heavy metals: these include cadmium (Cd^{2+}), chromium (Cr^{3+}), copper (Cu^{2+}), lead (Pb^{2+}), nickel (Ni^{2+}) and zinc (Zn^{2+})

d) Xenobiotic organic compounds (XOCs): hydrocarbons, chlorinated aliphatics, phenols, plasticizers and pesticides.

From this composition, the major potential effects of the release of leachate to the surface water are expected to be changes in the stream bottom fauna and flora community, depletion of oxygen in part of the surface water body which eventually leads to euthrophication and ammonia toxicity (Kjedsen et al., 2002). The study breaks down the individual effects of respective classes. The dissolved organic matter tested for different landfill site leachate was found to have low composition of below 1%. Its major effect is however the depletion of oxygen in the surface water body.

As regards inorganic macro-components, several researchers have identified ammonia as the most significant component of leachate for the long term. Ammonia-nitrogen is said to have a general concentration of a range within 500 – 2000 mg/L (Kjedsen et al., 2002). When ammonia (NH_3) dissolves in water, it reacts to form an ionized element called ammonium (NH_4^+). It becomes toxic to a surface water body when at concentrations ranging from 0.53 – 22.8 mg/L. Other inorganic macro-components such as calcium, magnesium, iron and manganese are present in low compositions according to several researchers.

As regards the effects of heavy metals present in leachate, data from Kjedsen et al. (2002) show that the average concentration is low and the overall effect caused by heavy metals is minimal. Xenobiotic organic compounds (XOCs) are from household or industrial chemicals which are present in relatively low concentrations, usually below 1mg/l of individual compounds. The effects of these XOCs are however quite toxic to the aquatic environment, although there is not enough information regarding the specific effects of the XOCs (Kjedsen et al., 2002).

2.9 Summary on Review of Literature

From the review of literature, it is certain that the main objectives of modern solid waste management are to protect the health of humans and the environment, preserve natural (renewable and non-renewable) resources and to develop an orientation to treat or preferably minimize the waste that is eventually discarded to the landfill. Researches reviewed (Troschinetz, 2005; Chandrappa and Das, 2012) relate increase in generation of solid waste in cities to increase in population.

As regards waste generation in South Africa, Nahman et al. (2012) also relate the volume of waste generated to the income status of a location. It is shown that high income communities generate more waste than that of the lower income communities. This is similar on a global scale with countries having higher GDPs generating more waste than their lower counterparts as discussed by Guerrero et al. (2013). There were inconsistencies in the table presented, but an explanation for this is the collection of these waste generation data from several sources which lead to the disparities. It is however agreed by several studies like Shedar (2009) that economic situation of a location affects the generation of waste.

The issue of sustainability pertaining to solid waste management has been extensively covered in literature (Brundtland, 1997; Troschinetz, 2005; Williams et al., 2013) with consensus that sustainable solid waste management should involve efficient technologies or practices adopted to meet the present needs of managing the waste without compromising the applicability and capability of meeting the needs of future generations. However, what is termed sustainable practices as regards solid waste management differs slightly in the literature in terms of emphasis. Williams et al. (2013) looks at sustainability in terms of the social, environmental and economic aspects, whereas Karani and Jewasikiewitz, (2007) focus more on sustainable landfilling practices with emphasis on improving carbon credits as well as targeting a reduction in the landfill gas emissions.

Troschinetz, (2005) focuses on tracking and regulating the waste streams through well developed record keeping system in conjunction with the adaptation of legislation and policies that support sustainability. South African legislation (Municipal System Act No. 32, 2000) also supports sustainability. The inculcation of all these aspects highlighted will ensure a well structured sustainable solid waste management system. Generally accepted sustainable solid waste management practices highlighted in this review are: waste prevention, recycling and composting, re-use and waste to energy initiative.

Of particular interest to this study is landfilling. Several studies (El-Fadel et al., 1997; Fourie, 1998; Shekdar, 2009; Mihelcic and Zimmerman, 2010) identify landfilling as the most economic and attractive form of disposal of a city's solid waste. These studies also point out that more developed countries have adopted more sustainable technologies of operating a landfill site whereby the amount of waste actually being buried is minimized significantly thereby reducing the leachate generation and GHGs emission. Harnessing of methane gas to generate electricity is also now being adopted on several landfill sites globally with South Africa recently adopting such practices but not yet on at an operational stage. An interesting concept discussed is the *zero waste* to landfill which several authors (Matete and Trois, 2008; Davidson, 2011) view as both an ambitious and practical way of managing waste by diversion and minimization of these waste as primary targets for most integrated waste management plans.

As regards integrated solid waste management, it should be designed to meet specific goals by including the needs and perspectives of stakeholders. Similar to the objectives of solid waste management, an integrated solid waste management system should be designed based on the principle of minimization of waste, re-use, recycling and energy recovery techniques. Another critical point highlighted by Marshall and Farahbakhsh, (2013) is the three dimensions of sustainable waste management which should be inculcated into an integrated solid waste management plan. They are: social acceptability, economic affordability and environmental effectiveness.

In a view to sum up the review of literature, it can be ascertained that the study's research question: '*What are the main sources of waste generation in the City, the composition of waste deposited on landfill sites and the ratio being recycled or recovered?*' can be answered from the literatures as a guide. Literature has clarified the tools required to acquire data such as sources and composition of municipal solid waste.

Also from the review of literature, it has been acknowledged that solid waste management is peculiar to the type and characteristics of the area in which the waste is generated and as such, there is no universal solution that can be applied to different cities and circumstances. Hence, it is therefore important to acquire adequate and updated data on the type and characteristics of waste generated and disposed of in the City of Johannesburg; this information can further aid in the design of sustainable solutions to the solid waste management issues. This information would be useful to the general body of knowledge as regards to solid waste management. This research report gathers data peculiar to Robinson Deep landfill site and analysis of these data through a Material Flow Analysis (MFA) system is carried out in other to offer possible sustainable solutions to the solid waste management setbacks synonymous with the City of Johannesburg with the literature reviewed as a guide. To the best of the author's knowledge, such analysis using MFA as a tool has not been carried out in the City of Johannesburg context.

Chapter Three

3.0 Review of Solid Waste Management Policies and Legislation

This chapter presents the regulatory framework for solid waste management in South Africa and a review of literature related to it is also analyzed to understand where South Africa is now as regards to best practices on waste management.

Many countries (developed and developing) have established legislation regarding solid waste management, with more emphasis on the municipal waste as the responsibility of urban local authorities (Chandrappa and Das, 2012). The efficiency of these services provided is dependent on the manner in which the urban local authority manages its allocated finances and its manner of administration and execution.

This section begins with a brief look at the current solid waste management policies and legislation in several countries such as in USA, UK, Malaysia and India. This is compared to South Africa's solid waste management policies and legislation (which features in section 2.12) in order to assess if the current policies and legislation in South Africa are efficient enough to ensure a sustainable integrated solid waste management system. A particular area of interest to this study is the minimum requirements for a landfill which the then South African government Department of Water Affairs and Forestry (DWAF) established a committee to prepare a set of minimum requirements for siting, designing, operating and closure of landfills (Blight, 2006; Mudau, 2012). Since South Africa has poor communities which are not able to afford elaborate payments and stringent regulations prescribed in developed countries, this has brought about minimum requirements which neighbouring countries like Botswana, Namibia and Swaziland have also adopted (Mudau, 2012).

In USA, there is the Solid Waste Disposal Act (42 U.S. Code 6901-6992k) which is generally referred to as the Resource Conservation and Recovery Act, 1976 which gives the Environmental Protection Agency (EPA) the authority to control municipal solid waste and hazardous waste from the cradle to grave. This entails the generation, transportation, treatment, storage, and disposal of the solid and hazardous waste. The objectives of this Act are to protect human health and the eco-system from the potential risks of disposal of waste, to preserve energy and natural resources, to minimize the amount of generated waste, and to ensure that these wastes are managed in an ecologically sound manner (USEPA, 1998). Assessing this statement, it is evident that it complies with the basic objectives of solid waste management.

Another fact to point out is that recycling and waste data management are key components for USA's sustainable materials management program. Trischinetz (2005) presents the aim of the municipal solid waste policies which is to divert as much of the waste from landfills. The study also highlights three main influential policy types present in USA which are: command and control; social-psychological incentives; and economic incentives. It concludes that the latter two are best at shaping positive attitudes and behaviour towards the generation and disposal of waste.

The UK has the Control of Pollution Act 1974 which is in line with the rest of the European Union (EU) countries. Similar to USA, they base their waste policies and legislation on solid waste management objectives, namely - the reduction of generated waste, maximizing recycling and re-use of materials, limiting incineration to only non-recyclable materials, achieving a zero waste to landfill (or reducing landfilling to non-recycling and non-recoverable materials). It is apparent that best practice should ensure that basic objectives of the solid waste management should be a foundation of the waste management policies and legislation. The EU ensures complete implementation of the waste policy targets to all constituting member states. Listed below are the main elements of the European waste legislation:

a. Framework legislation which includes waste definition, permit requirements and infrastructure;

b. Technical standards for the operation of waste facilities to ensure a high standard of environmental protection;

c. Requirements for specific waste streams which entails strategies to increase recycling or to minimize the adverse effects of the waste.

In Malaysia, prior to 2007, the Local Authorities were responsible for the solid waste and public cleansing management. The role of the Federal Government then was restricted to establishing policies, awareness, financing of facilities, collection vehicles and equipment to be used as requested by these Local Authorities (Yahaya and Larsen, 2009). This practice of allocating the responsibility of managing the solid waste at a municipal level is common to many developed and developing countries, including South Africa.

However, in 2007, the Malaysian Government passed a new Act on solid waste and public cleansing management which saw a transfer of authority and primary responsibility from the Local Authorities to the Federal Government, with the establishment of new federal institutions (Department of National Solid Waste Management, and Solid Waste Management and Public Cleansing Corporation) to manage it. The Act supports stricter regulations, enforcement tools and tools that impose greater responsibilities on the stakeholders. The author identifies some pros and cons with the Federal Government taking much of the responsibility of managing solid waste. An advantage is that there would be one uniform form of management, and vices like corruption can be curbed in a situation of a transparent government while a disadvantage is the difficulty in managing all the solid waste data across the country.

In India, the present municipal solid waste management policy (Management and Handling Rules, 2000) evolved over a six years period from September, 1994 to September, 2000 (Patel, 2008). The solid waste management in India is covered under various regulations through the Federal as well as the State level, with bodies such as the Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCB). The key objectives of these rules are to provide scientific management of municipal solid waste; to ensure proper collection, segregation, transportation, processing and disposal of the solid wastes; and to upgrade the existing facilities to curb soil and ground water contamination (Pune, 2006). These objectives are also in line with the primary objectives of solid waste management and as such are in line with global best practice. Other regulatory frameworks applicable to solid waste in India are:

a. Maharashtra non-biodegradable garbage (control) Act, 2006;

b. The recycled plastics manufacture and usage Rules, 1999 (amended in 2003);

c. The Maharashtra plastic carry bags (manufacture and usage) Rules, 2006

d. The batteries (management and handling) Rules, 2001; and

e. The hazardous wastes (management and handling) Rules, 1989 (amended in 2003).

The municipal solid waste handling Rules, 2000 focus on the recycling or re-use of segregated materials and ensuring participation from the community in the waste segregation process. It also ensures that recoverable resources are to be recycled through the existing informal sector which has seen a large percentage of women and children as waste pickers (Patel, 2008). Similar practices (recycling by the informal sector) are seen in the South African context but are not present in the policies or legislation governing the management of municipal solid waste.

With the large population in India, it was imperative to have legislation and policies that would involve the people as it would be difficult to manage such wastes generated. A number of best practices regarding solid waste management have been documented in various cities in India such as in Calcutta, where there is 80% house to house collection of waste using a combination of the municipal staffs and informal sectors (wheelbarrow pushers). Other cities like Mumbai, Surat and Nasik have similar structures in place in conjunction with private groups that do doorstep collection.

This brief review on solid waste management legislation and policies in some parts of the world shows that most of these policies are formulated on the foundation of solid waste management objectives that align with global best practice. However, the practices, technologies and managerial styles involved in these countries are dependent on how developed the country is. Developed countries such as USA and member countries of the European Union have stricter regulations, the communities adopt sustainable practices and these countries have more advanced technologies than the developing countries. It is necessary for developing countries to adopt some of these policies but contextualize them to suit each country's characteristics. The next section focuses on the solid waste legislation and policies in South Africa.

3.1 South African Waste Management Legislation and Policies

In South Africa, various environmental policies have been established to protect the health and safety of the citizens and the environment (Nwokedi, 2011). The overall objective of these policies is to minimize the waste generation and potential ecological impacts of the various types of waste. From section 2.11, it is seen that the main objectives of these policies appear to be general across the globe and hence it is best practice to base the policies on solid waste management objectives. It is anticipated that South Africa's socio-economic development, public health and quality of the environmental resource would no longer be impacted negatively by the effects of waste if the waste regulations are strictly adhered to (NWMSI, 2004).

The Constitution of South Africa (Act 108 of 1996, schedule 5B) states that waste management is a local government competence that must be executed to protect the health of humans and the eco-system (Constitution, S.24). The management process must ensure a healthy, safe and sustainable environment to ensure that the rights of the people are protected. With regard to these rights, all stakeholders involved must accept co-responsibility for optimally reducing the impact of waste and ensuring the sustainability of the environment.

South African White Paper on Integrated Pollution and Waste Management (2000) presents new views by the government as regards pollution and waste management. The past policies focused mainly on the 'end-of-pipe' treatment, which prioritizes minimization of waste, prevention of pollution and avoiding degradation to the environment. There is a comprehensive National Waste Management Strategy and Action Plan (2011) to execute this policy.

In 2001, the Polokwane Declaration was established from the first National Waste Management Summit. The declaration was established to mitigate the waste generation, cut down te volume of waste discharged by 50%, to accomplish a 25% cutback in disposable wastes by 2012 and to develop a zero waste plan by 2022 (Nwokedi, 2011). With a view to acknowledging the Polokwane declaration and adopting global best practices, the National Environment Management: Waste Act (NEMWA) of 2008 (Act 59 of 2008) was promulgated. The main objectives of this Act are:

a) To protect the public health and well-being of the environment by providing reasonable measures for avoiding and reducing waste generation and consumption of natural resources; reducing, reusing, recycling and recovering of waste and a host of others (refer to the NEMWA 2008 Gazette)
b) To ensure that the public are aware of the health and environmental risks that could be caused by waste
c) To provide for compliance with the measures set out in part (a); and

d) To give effect to section 24 of the Constitution in order to secure an environment that is not harmful to health and well-being

Upon the endorsement of the NEMWA, 2008 (Act 59 of 2008) the Integrated Waste Management Plan (IWMP) was introduced which has become a statutory requirement. It should be noted that there is the National Environmental Management: Waste Amendment Act No 26 of 2014 which has some roles (such as those of the provincial departments) redefined and some definitions substituted or deleted.

As mentioned in the landfill section in chapter 2, legislation in South Africa requires that landfill developments are designed, constructed and operated to government guided levels of sophistication (Strachan et al., 1998). It also requires that landfills are to be operated in a sustainable manner so as to harness the positive aspects and limit as much as possible the negative aspects of landfilling to the human health and environment. As regards the design of a sustainably operated landfill, the Council for Scientific and Industrial Research (CSIR, 2011) highlight considerations that should be given to the mode of operation to be adopted. It should ensure the following best practice:

a. There should be a daily cover of 15 mm if it is crushed bricks, tarmac or concrete, earth, soil, sub-soil or other similar natural materials used and should be compacted daily. Other types of cover material that can be used on landfills are geo-synthetic materials, woodchips, plastic films and stabilized bio-waste.

b. There should be a reduction in both wind-blown litter and vermin. The level of reduction however needs to be significant enough as the author would suggest at least a 50% reduction.

c. A reduction in the production of leachate, and

d. There should be a strategic selection of the type of landfill equipment required on the site.

3.2 Provincial Legislations and Policies

According to a City of Johannesburg (2011) report, there are policies, standards and regulations pertaining to the Gauteng province. Listed below are a few of them:

a) Gauteng Provincial Integrated Waste Management policy (IWM), which is legislation to facilitate and support the Gauteng IWM policy. It is also expected to encourage uniformity between the national, provincial and local waste management requirements.

b) First Generation Integrated Hazardous Waste Management Plan for Gauteng

c) Gauteng Provincial Standards and Regulations which focus on the waste information regulation and the general waste collection standards which the provincial government set in 2004 and 2007 respectively.

3.2.1 Municipal System Act, 2000 (Act 32 of 2000)

This Act defines the alternative strategies that should be adopted in municipal service delivery and the procedures to be taken when such alternative strategies are given consideration. To this effect, City of Johannesburg has been given the directive to provide waste collection, disposal and cleansing services to all residents and businesses within this area. Currently, there are five key divisions involved directly in the provision of waste management services in the City of Johannesburg, which are:

1 Infrastructure and Services Department (ISD) which is responsible for managing all sections tasked with waste management delivery services on behalf of City of Johannesburg;

2 Environment Department tasked with the major policy formation and strategic planning;

3 Environmental Health to implement the Health Act (Act No.61 of 2003) in which waste management duties are expected to be carried out by environmental health officers;

4 Johannesburg Metropolitan Police Department (JMPD), a sub-unit of which is tasked with the enforcement of the city waste by-laws;

5 Pikitup (PTY) Ltd, an establishment that is wholly owned by the City of Johannesburg with the purpose executing all operational functions in terms of collection and disposal of waste.

3.2.2 Local Level Legislation

As regards legislation in this tier of government, the Waste By-laws are the predominant legislation that is being adhered to in the City of Johannesburg. In terms of the City of Johannesburg Waste Management By-laws (2013), it goes by the following principles:

1) Waste generated in the council's jurisdiction:

    a. Must be collected, conveyed, treated and discharged or recycled in accordance with the By-laws

    b. In terms of waste management hierarchy (shown in Figure 3.1), it must be adhered to during the collection, conveying, treatment, disposal or recycling of such waste.

2) The establishment of a waste management hierarchy in the order of priority as follows:

    a. Waste Reduction (or avoidance/minimization)

    b. Reuse

    c. Recycling (treatment and reprocessing), and

    d. Disposal

3) Rational cognizance of the waste management hierarchy must be shown by authorized officials.

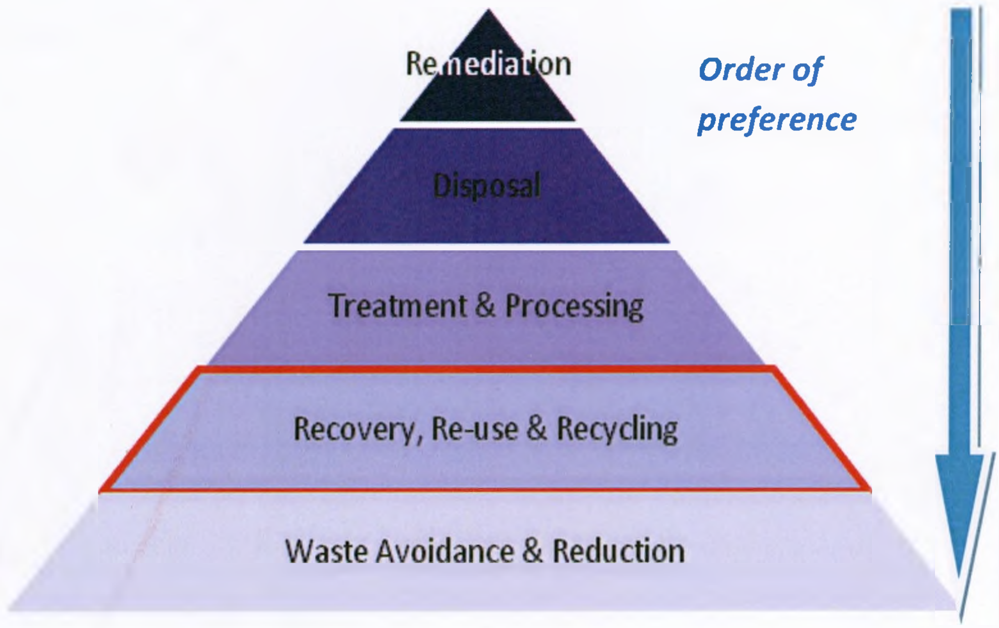


Figure 3.1: Waste Hierarchy (source: NWMS 2010)

According to the National Waste Management Strategy report (2010), the inclusion of the remediation of polluted or contaminated waste measures as a last option instead of disposal, this inclusion was implemented to protect the public health and ensure a safe environment. The Municipal Solid Waste Tariff Strategy presents a framework for municipalities in setting appropriate tariffs that align with the objectives of the National Waste Management Strategy (NWMS, 2011). Listed below are specific objectives of the tariff strategy:

i. To support the local government;

ii. Aid in alleviating poverty;

iii. Enhance financial sustainability;

iv. Provision for a basic of regulation;

v. Aid in the extension of municipal solid waste services, and

vi. To study the impact the tariff strategy has on reduction, reuse, recycle and disposal. This process assists the municipalities to adequately plan for new practices, technologies and adjustment in waste tariffs consequently.

The Minimum Requirements for Waste Disposal by Landfill which was handled by the then DWAF and more recently by the Department of Environment and Tourism (DEAT) is of more importance to this study as it is the main legislation guiding landfills in South Africa. The aim is to ensure that the same standards and objectives are applied across South Africa whilst at the same time not applying a "one size fits all" strategy. It basically elevates the waste management standards in South Africa, to ensure compliance with international standards as regards the Basel convention (DWAF, 1998).

This legislation facilitates the implementation of the disposal authorization system as regards section 20 (1) of the Environmental Conservation Act (ECA), 1989 (Act 73 of 1989) and later amended in 2003 (Act 50 of 2003). Initially, landfill permits were issued by DWAF officials but the responsibility has been transferred to the DEAT officials in the third edition (2005) of the minimum requirement document. However, this document has recently been amended in August of 2013. This amendment makes it quite expensive to establish a landfill site as requirements are stringent; however this helps the local municipalities optimize the current land space as there are hardly suitable locations available in City of Johannesburg.

According to Karani and Jewasikiewitz (2007), the South African government promotes an integrated approach to pollution and waste management as the main aspect in achieving sustainable development. The study also lists relevant international agreements pertaining to waste management which South Africa has endorsed:

i. Dumping at Sea Control Act (No 73 of 1980)

ii. Prevention and Combating of Pollution of the Sea by Oil Act (No 6 of 1981)

iii. Conservation of Agricultural Resources Act (No 43 of 1983)

iv. Prevention of Pollution from Ships Act (No 2 of 1986)

v. International Conservation relating to Intervention on the High Seas in Cases of Oil Pollution Casualties Act (No 64 of 1987)

vi. Environmental Conservation Act (No 73 of 1989)

vii. Nuclear Energy Act (No 113 of 1994)

viii. Antarctic Treaty Act (No 60 of 1996)

However, the most relevant to the City of Johannesburg is the Environmental Conservation Act (No 73 of 1989) which entails significant areas such as the protection of the natural environment, control of environmental pollution and control of activities which may have detrimental effect on the environment. Under the control of environmental pollution, matters such as the landfill permits as mentioned earlier is covered.

3.3 Conclusion

A general practice that can be deduced from the review of solid waste management legislation and policies globally and in South Africa is that the main responsibility of managing a city/community's solid waste lies specifically with the Local Government/Authority. There are cases such as Malaysia where the Federal Government took over the responsibility as a result of corruption at the Local Government level. The consensus tends towards the management of the solid waste being handled at the Local Government level, with stricter monitoring of compliance by higher levels of government.

South Africa currently has policies and legislation that supports a sustainable solid waste management system. These policies however should continually undergo frequent reviews and amendment to suit the unique socio-economic situation of the country which possesses characteristics of first and third-world countries.

Chapter Four

4.0 RESEARCH METHODS

4.1 Introduction

This chapter focuses on the procedures that were followed in the acquisition of data required for this research which were acquired from primary and secondary sources. Due to the practical nature of this research, primary data which is acquired from site visits and personal communication with experts on site are the main sources of data. Secondary data is acquired from literature which is used to substantiate the research's findings and generate the scenarios that are the basis for the analysis and interpretation of the data. According to the research's method of data acquisition and analysis, a quantitative research method is adopted as it involves the generation of models, collection of empirical data and the modelling and analysis of data.

This chapter also provides a brief introduction of the case study area and its operations. Material Flow Analysis (MFA) is the methodology adopted for this research which is discussed in detail. The tool adopted for carrying out the MFA is modelled mathematically with Microsoft Excel. This chapter introduces machine learning tool to project future waste patterns that might occur on the landfill. However, due to limited data set acquired, this is not used in the main analysis as the reliability of future waste pattern projections would be questionable. The modeling of future waste pattern projections is carried out with Visual Basic.Net programming language, on Microsoft.Net framework version 4.5 Common Language Runtime (CLR) and. A research methodology framework is developed in this chapter.

4.2 Area of Study: Robinson Deep Landfill

Robinson Deep landfill site was established in 1930 and catered for the waste generated by the early settlers of Johannesburg. It is located on the farm Robinson Deep 81 IR and Portion 184 (a portion of portion 1) of the farm Turffontein 100 IR (Pikitup, 2010). The property is approximately 121 ha with the current waste body is situated on an approximated 61 ha of the landfill site. It is situated between the M5, Eastwood street and Heronmere road within the Johannesburg Metropolitan City with the following geographical coordinates: 26° 13' 59.03" S 28° 02' 14.77" E (UNFCCC report 2013). The landfill site is located on an area which was previously used for gold mining activities hence some mining shafts still exists on site. The site serves the surrounding areas of Booysens, Turffontein and major parts of the City of Johannesburg.

The landfill is managed by Pikitup Johannesburg (Pty) Limited which is the city's official waste management service provider. The landfill is currently about 1, 780 meters above sea level which is about 75 meters from the landfill's ground level. Robinson Deep landfill site is classified as G:L:B^- and consequently, can only accept general waste. Data acquired shows that no formal lining system exists which are normally laid at the inception of a landfill site to prevent contamination of the groundwater. However, the landfill was started on an old brick yard and slimes dump. Generally, each landfill site must obtain a license based on its waste component in compliance with section 20 of the Environment Conservation Act (ECA, 1989). Robinson Deep Landfill is in possession of a permit. Internal and external audits are normally carried out on this landfill site to ensure compliance

The Robinson Deep Landfill site is one of two landfill sites that Pikitup has earmarked for free dumping of construction and demolition waste to avoid littering such waste in the city. There are restrictions however to what can be dumped, for rubbles must be smaller than the average brick of 70mm x 220mm x 100m while soil particles must not be greater than 20mm (CoJ, 2014). Garden waste has just been recently approved to be dumped on site as the site now wants to engage in composting activities. Figure 4.1 shows a satellite image of the area.

Figure 4.1: Satellite image of Robinson Deep Landfill (Source: Google Earth)

4.2.1 Situational Analysis of the Site

The waste deposited on this landfill site is collected from the centre, southern, eastern and western part of Johannesburg. There are approximately 350 trucks that deposit waste in this site on a daily basis and these trucks are initially weighed on the weigh-bridge before dumping the waste. Currently, a daily average of 2,800 tonnes of waste (this value varies seasonally, and also depends on the operational conditions of other landfills) is delivered on site which comprises approximately 1,800 tonnes of general waste and 1,000 tonnes of construction debris; however over 2,000 tonnes of this waste is actually land filled (about 75% of the total waste is buried). The construction debris is crushed and used for road construction on site. As regards storm water management, a concrete-lined storm water drain runs around the perimeter of the site and carries mainly runoff generated within the site. There is no separation of contaminated and uncontaminated runoff, which discharges to a clay-lined detention (or evaporation) pond. The leachate produced on site is also diverted to this pond.

The waste disposed on site is spread out, compacted and the waste is covered daily. In order to achieve this, a single cell usually of 900 m^2 is constructed where the waste is dumped and eventually covered at the end of the day. Compaction is an integral part in the effective operation of the landfill as it extends the life of the site, controls wind scatter, saves on the daily cover volume required and reduces the percolation of rainwater through the waste and thus reduces the potential of the site to produce leachate (Pikitup, 2010). The compaction is carried out using compactor machines which go over the waste a minimum of 3 to 4 times to achieve a compaction density in the order of 750 kg/m^3 to 1,200 kg/m^3. As it goes over the debris, the cleats of the compaction machine chews it up into smaller pieces to enhance compaction. The compaction is carried out on a slope ranging from 1:6 to 1:8.

A sand cover of about 150mm (which is an immediate cover) is spread over the compacted waste; the sand is acquired from construction sites such as the on-going construction at the proposed Mandela Hospital. A Final sand 'capping' of 500mm is applied over the compacted area. As regards air pollution control, chemicals are sprayed on the landfill to reduce the odor generated by the waste in compliance with the odor control regulations. Well stations are situated at various points on the landfill to monitor the groundwater quality and to check possible seepage of leachate. The groundwater is analyzed from the four existing boreholes by Johannesburg Water with a view to assessing the compliance with prevailing standards. An image of the well station can be accessed in the Appendices.

As mentioned in section 2.5.2, methane and carbon dioxide are the main constituents of landfill gas formed via anaerobic breakdown of the waste with a composition of about 49% and 50% respectively. Other gases like Nitrogen and Oxygen are of minute composition. These gases (methane and CO_2) are part of the Green House Gases that contribute to global warming. The methane in particular poses a potential hazard as it is easily combustible. To prevent this from happening, the landfill gas is harvested from the landfill by gas pumps which are stationed throughout the landfill area to collect the gas and pump it to the gas flaring station.

Several surface emission monitoring (SEM) points are located on the site to monitor the gas emission from the landfill. Images of the gas flaring station and the SEM can be accessed in the Appendices. There are currently 68 gas wells installed which is expected to be increased subsequently to cover the entire site. Data from the Pikitup officials indicate that there is a daily pumping rate of landfill gas at $1400m^3/h$. The plant can attain an optimum pumping rate of 2000 m^3/h when it is operated at full capacity. At the gas flaring station, the pumped landfill gas is burned which disposes of the combustible constituents safely and it also aids in odor control, minimizing possible health risks and negative impact to the environment.

There is a current plan to extract methane from the landfill gas and combust it to produce electricity for export to local power purchaser as the second phase of the waste-to-energy project which the City of Johannesburg has embarked on. It is envisaged that there will be excess landfill gas when such initiative kick starts, however the excess gas not used for electricity generation would be flared. Pikitup reports indicate that the landfill site has produced 137,888 Certified Emission Reductions (CER) and flared out $18,288,457Nm^3$ of landfill gas which would otherwise have been released to the air from May 2011 to October 2013.

There is a clean material recovery facility (MRF) located on the landfill site which is presently undergoing an upgrade so as to increase the capacity of recovered waste which was approximately 500 tonnes (about 25%) prior to the upgrade to approximately 1,500 tonnes (about 75%). As at the time of this research, a make-shift material recovery facility is being used to sort and store the recyclable materials; which is located at the former gas flaring plant. The site as at the time of this research has about 80 waste-pickers that sort the waste from the point of disposal on the landfill to the point it is transferred to the make-shift material recovery facility to be sold as a resource material. Figure 4.2 shows the make-shift material recovery facility where the recovered material is further sorted in terms of its characteristics. More images of the site processes and facilities can be accessed in the appendices.

Figure 4.2: Robinson Deep make-shift material recovery facility (Source: Author, 2015)

4.3 Material Flow Analysis: A Review

Material Flow Analysis (MFA) is a systematic assessment of the stocks and flows of materials within a system defined in space and time (Brunner and Rechberger, 2004). MFA is based on two well-established scientific principles which are the law of mass conservation/mass balance principle and systems analysis. It is defined as material/substance flows entering, settling and leaving a system including related processes such as transformations and transportations. Basically an MFA is defined by system boundaries in space and time (Tang and Brunner, 2013). Barrett et al., (2002) also portrays the use of MFA to trail and quantify the flow of substances within a defined boundary over time.

According to Achinas (2014), in MFA, materials/substances (which for the purpose of this study are municipal solid waste) are denoted as 'goods', and according to Cencic and Rechberger (2008), these goods are known as economic entities of matter with a positive or negative value although some are considered to possess a neutral value such as air. The transportation, transformation and storage of these materials are denoted as 'processes', which are described as black boxes. It simply means that specific information of the occurrence inside the boundary is not taken into account; usually only the inputs and outputs are of interest (Cencic and Rechberger, 2008). Processes are connected through the flow of goods (Belevi, 2002; Achinas, 2014). An MFA system flow of goods comprises of the following components (Brunner and Rechberger, 2004):

i. A system analysis which entails goods and processes;

ii. The determination of the mass fluxes of all goods per unit time;

iii. The determination of the concentrations of selected components of the goods;

iv. The calculation of the mass and component fluxes which are attained from the mass fluxes of the goods and the concentration of the components in the goods;

v. Finally, an interpretation and presentation of the results.

The principle of mass conservation of an MFA makes sure that all flows and stocks are taken into account, and also ensures that no residues or emissions are excluded, hence ensuring easy identification and analysis of leaks and losses. (Tang and Brunner, 2013). The concept of material flow analysis has been used in many studies to analyze the flow of materials or products within a defined boundary. A review of some of the studies is discussed below. The common objectives according to Gregory and Kirchain (2008) of material flow analysis are highlighted below:

i. To define system of material flows and stocks;

ii. To assess important flows and stocks quantitatively, verifying mass balance, sensitivities, and uncertainties;

iii. To minimize system complexities at the same time upholding the basis for decision making;

iv. To display system results in a reproducible, transparent and comprehensible manner, and

v. To apply the results obtained in managing resources (natural and economic), the eco-system and waste whereby it is able to monitor the gathering or reduction of stocks, future environmentally beneficial goods, processes and systems.

As regards studies that have made use of the concept of MFA, Barrett et al., (2002) apply it to follow and quantify the flow of the materials in a defined situation and over a set period. In their study, MFA was used to analyze the ecological footprint of York, in the UK with particular emphasis on adapting MFA to account for the energy saved by recycling. They show that a remarkable saving in energy and a smaller ecological footprint are achieved from recycling as opposed to making the products from virgin materials. Another aspect was the composting of green waste and its contribution towards sustainability. MFA was used to analyze the energy required and ecological footprint to compost green waste as compared to landfilling the green waste. The result showed a remarkable difference of 583 ha (i.e. 21 ha when composting green waste as compared to 604 ha if it had been landfilled).

Several studies have adopted the use of MFA to look at the trail of waste in and out of cities. A similar study is that of Owens, (2008) who did a material flow analysis for a small pacific island. It was found that the waste trails can be monitored and managed effectively to improve the solid waste management of such regions. Common limitations experienced are the acquisition of reliable solid waste data. Tang and Brunner (2013) suggest that MFA offers a system approach which aids policy makers to put together measures that optimizes the overall performance of a goal-oriented waste management system. MFA is also applied to estimating the composition of the main types of waste constituting the municipal solid waste being generated in Irkutsk in Eastern Siberia, Russia. The MFA also estimates the amount and composition of the solid waste disposed of at the Alexandrousky landfill with the use of the mass and substance flow model (STAN), Starostina et al., (2014).

In the agricultural and environmental sector, a study by Achinas (2014) looks at the waste produced in the olive oil sector and provides perspectives for waste management for the major olive oil producing countries using the material flow analysis approach as a tool. Mastellone et al., (2009) report on a study of waste management for a waste emergency area. MFA is adopted to proffer future solutions for the waste crisis in Campania region in the south of Italy where transparent, reliable, impartial strategies and concepts are required. In the study, six scenarios are defined and assessed quantitatively through the MFA approach. Through thorough analysis of all scenarios, appropriate decisions can be made by waste planners and decision makers.

Studies of the application of MFA have also been carried out in the developing parts of the world such as the one carried out by Belevi (2002) where the author applies the concept of MFA to trace the flow of organic materials and waste fluxes (nitrogen and phosphorous were specifically targeted) in the City of Kumasi, Ghana. The analysis of data acquired for the study shows that private households are the key process contributors of the organic material fluxes which are characterized by large waste production. Further results also show that the nitrogen and phosphorous demands of about 30% of the entire urban and peri-urban agriculture could be met theoretically by co-composting fecal sludge in conjunction with solid waste that is being disposed of in the landfills. In Fada N'Gourma, Burkina Faso, MFA is used in evaluating the impact of sanitation options on urban water quality. The models developed ensure that each household can afford the proposed sanitation options with minimal ecological impacts (Koanda et al., 2010).

Other studies have utilized the application of MFA as a decision support tool as shown by Kral and Brunner (2011) where it is used in ballast management to determine material balances of ballast and copper for a 1km railway line. MFA as a decision support tool was concluded to be useful for waste producers, recyclers and government authorities. Klinglmair and Fellner (2010) apply MFA to examine the mining sector in terms of raw material shortage during World War 1 with copper management being the focus of the study which was carried out in Austria. The study obtains a holistic account of the copper (in Kg) per capita that was available throughout the war through the MFA approach.

A common illustration of material flow analysis for municipal solid waste management is shown in Figure 4.3 where the boxes represent processes and the arrows represent flows.

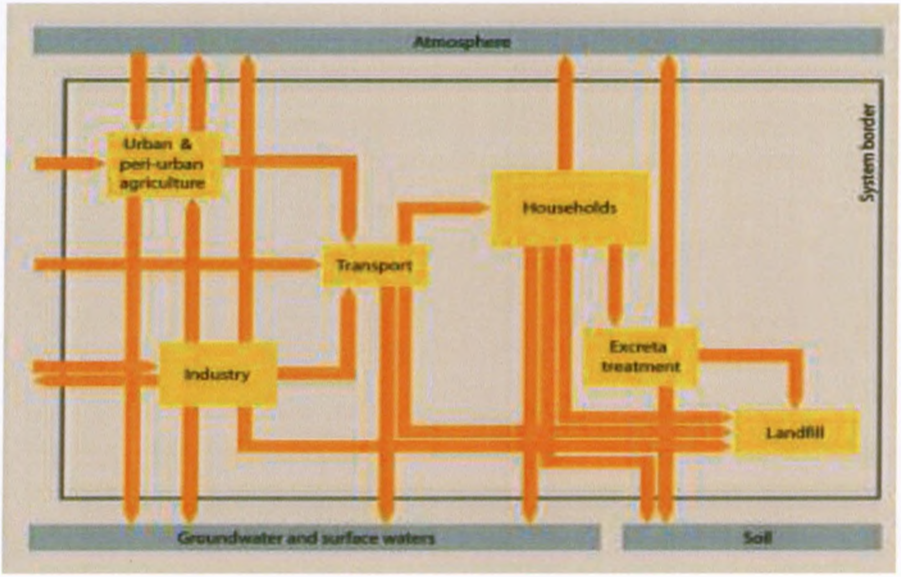


Figure 4.3: Material Flow Analysis on a Municipal Solid Waste (Source: Yiougo and Spuhler, 2012)

General applications of MFA are extensive as indicated by a sample of these applications highlighted below (Yiougo and Spulher, 2012):

i. In the environment engineering and management field: it is used for designing air pollution control strategies, conducting environmental impact assessments, conducting sewage sludge management, remediation of hazardous waste sites, and development of environmental policy for hazardous materials;

ii. In resource and waste management: it is used for analyzing, exploitation, upgrading, planning and the allocation of resources. Likewise, it can also be applied in evaluating material management performance in recycling or treatment facilities.

iii. In industrial ecology: it is used for controlling pathways for materials use and industrial processes.

iv. In human metabolism: it is used for assessing the metabolism of the anthroposphere. It is also applicable in evaluating key processes and goods where material inputs such as food, water, buildings, etc are analyzed with their outputs such as solid waste, off-gas and sewage.

The use of MFA presents the flows of the waste through the landfill from which the ratio of what is being recycled, recovered and buried can be attained. This information could equip the waste managers in developing innovative strategies of saving landfill air space as well as extending the life span of the landfill.

In this study, mathematical modelling and simulations are carried out as the tool to performing the material flow analysis of the land fill site. A situational model (status-quo) which is the actual flow of materials through the landfill site is developed which can be compared to several probable scenarios with a goal of accessing possible and viable options of extending the landfill's life-span as well as saving air space.

4.4 Waste Characterization on Site

Referring to chapter 1, a waste characterization is normally performed on an existing municipal solid waste stream or landfill to evaluate its suitability for other sustainable waste processing technologies (Sethi et al., 2013). A physical and visual waste characterization exercise was adopted, which involved the actual sorting out of the disposed solid waste materials into groups of similar physical compositions. To carry out the waste characterization exercise by sorting, assistance was required from the waste pickers present on site. This methodological approach is based on material flows that enter into the site on a daily basis.

The major data that is used for this study is obtained from Pikitup's Landfill officials. However, due to the generalized classification/characterization of the solid waste contained in the database, a site characterization needed to be carried out in order to further break-down certain generalized characterization to more specific groups.

Waste trucks were selected based on the constituents of waste each type carries, such as the municipal solid waste trucks, the construction rubble trucks and the garden waste trucks. As mentioned earlier, the waste pickers present assisted in sorting the waste into various categories while the author recorded the findings. This exercise was carried out once a week (the days were picked randomly) for three (3) months. A sample of the field data exercise is presented in Appendix E. This was to ensure that random but different waste trucks routing different locations were picked. The author's findings show that the volume of recyclable materials recovered from a waste truck routing the higher income areas of the City is a lot higher as compared to that routing the low income areas of the City.

There were limitations experienced such as not being able to obtain the actual weight of individual category of waste in respect to the total volume of waste discarded by the truck due to the site's faulty weighing equipment (the weigh bridge inclusive). However, a generalized database of waste tonnages obtained from Pikitup would be used for this study. Table 4.1 shows the findings from the waste characterization exercise carried out for this study.

Table 4.1 Robinson Deep's solid waste composition (Adapted from Yenice et al., 2010, Pikitup, 2015; modified by Author, 2015)

Waste Category	Waste Source	Waste Constituents
Builder rubble (clean)	Construction and demolition wastes	Broken bricks, crushed concrete and sands
Builder rubble (mixed)	Construction and demolition wastes	Broken bricks, crushed concrete, dried up cement, broken ceramic, and steel mesh
Compacted refuse, container services, general household waste (single and multi-family homes).* Here, toxic waste such as batteries, gas cylinders, aerosol containers when discovered are removed and transferred to the hazardous waste site.	Kitchen waste	Food wastes, bread, vegetables, fruits.
	Paper	Newspapers, magazines, notebooks
	Cardboard boxes	Milk boxes, fruit juice boxes, household appliances cardboard boxes
	Plastic	All plastic materials

	Wood	Old furniture
	Glass	Broken glass materials, glass cups and bottles.
	Metal	Metal boxes, metal utensils
	Other combustibles	Textiles, napkins, shoes, slippers, carpets.
Cover soil and Garden refuse	Construction and demolition waste, park and garden wastes	Tree branches, leaves, grasses, yard trimmings
Street cleaning and illegal dumping	Park and garden waste	Leaves, grasses, yard trimmings
	Electronic waste	Telephones, radios, microwaves, computers
	Other-volume incombustible waste	Undefined-volume incombustibles, stones, sands
	Others	Unclassified materials
Destruction (Biodegradable) foodstuff/restaurant waste and market waste	Kitchen waste	Food wastes, bread, vegetables, fruits.
	Other combustibles	Textiles, napkins, shoes, slippers, carpets.
Office and Institutional waste	Paper	Newspapers, magazines, notebooks
	Electronic waste	Telephones, radios, computers
Dry industrial un-compacted non solid waste (sludge)	Factory incombustibles	Unclassified dry sludge materials

The purpose of this classification is to ascertain what category of waste contains recyclable materials which is crucial information when carrying out the data analysis.

The materials flow methodology adopted here is not easily applied to waste quantification in relation to specific sources. For example, waste paper in bulk volume is mostly from offices, but it is also generated in institutions and residences. Similarly, wastes such as electronic waste, garden waste and kitchen waste cannot be traced to the specific source of generation. This methodology only generalizes the waste composition and estimates the total quantity of discarded waste and not the respective places of generation.

To carry out a system analysis of the solid waste material flow at the Robinson Deep landfill, a holistic representation is depicted in Figure 4.4 which shows the various flows and processes occurring.

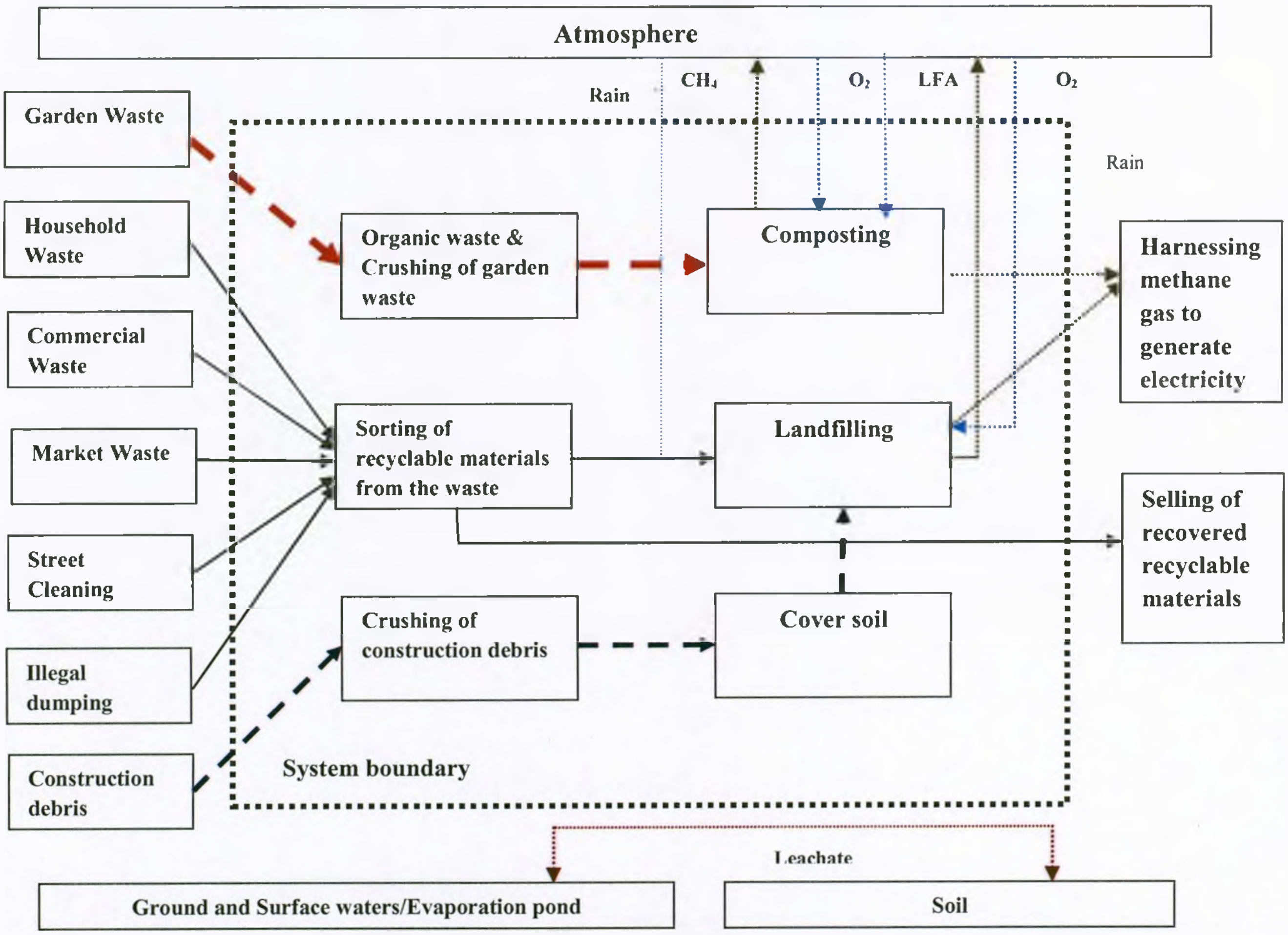


Figure 4.4: System analysis of solid waste material stream through Robinson Deep Landfill (Author, 2015)

4.5 Data acquisition, forecasting and scenario development

As regards data acquisition, this research acquired data from the past 3 years. In order to model (through forecasting process) waste tonnages getting to the landfill by the projected year the landfill would attain its full capacity (estimated at 7 years), dataset for at least 20 years would be required to obtain reliable projections. Data uncertainty can be identified as a barrier to a broader use of this approach, particularly as a tool for policy decision. This study presents the process of projecting data which would be useful for waste planners and designers. It is however stated that 3 years dataset cannot provide reliable projections, and due to the limitation of not being able to acquire historical data of the site, this study would only present the *'forecasting process'* as a means of managing and planning of waste management systems.

Data set for three (3) years of waste tonnages getting into the landfill site was attained from the Pikitup waste manager. This data was from June 2012 to May 2015. The data includes the classification and tonnages of the respective breakdown of the waste getting into the landfill site which is measured in kilograms (Kg). Data from June 2012 to present (May, 2015) was significant to obtain as this study uses this dataset to forecast up to 2022 which is the projected year to which the landfill would attain its full capacity. It would be stated again that this dataset is insufficient to attain reliable projections. The forecast is based on the past trends of incoming waste, materials recovered from waste and those landfilled. In this research, a new algorithm based on *empirical probability* was used to model the projection, which learns from the frequency distribution of wastes, as presented in the data from previous years. This method is a 'trivial machine learning technique'.

4.5.1 Empirical Probability

An empirical probability (also known as relative frequency or experimental probability) is a form of probability based on some event occurring, which is calculated using acquired empirical evidence. (Investopedia, n.d). Empirical probability could simply be stated as the ratio of the number of times an event (A) occurs to the total number of repeated trials or total number of sample size. It relies on actual experience to determine the likelihood of outcomes. A simple mathematical expression for empirical probability is represented in equation 1.

$$P(A) = \frac{Number\ of\ times\ event\ A\ has\ occured}{Total\ number\ of\ times\ the\ experiment\ has\ been\ performed}$$ Equation (1)

A similar mathematical expression is also given in equation 2.

$$P(A) = \frac{Freuency\ of\ the\ class\ of\ data}{Total\ frequency\ in\ the\ distributioin\ of\ data\ set} = \frac{f}{n}$$ Equation (2)

Where, P (A) is the probability of an event A occurring,

f is the frequency of the class of data, and

n is the total number of data sets.

Empirical probability is based on observation of acquired data and is normally applied when the outcome of future data is not so likely to predict. A probabilistic (future) model is a tool for decisions when the outcomes of future events or trends depend on circumstances where the outcomes are known partially or in situations where randomness plays a role. In this research's waste data, it was observed that the past waste trend was alternating based on certain factors spanning from the seasonal weather conditions to diversion of waste to other landfill sites as a result of operational faults, to a host of others. Hence the adoption of empirical probability to develop a learning algorithm to forecast future waste trends was significant for this study. As mentioned earlier, a learning algorithm is a model which learns from the frequency distribution of data (wastes) from previous years.

The empirical probability mathematical expression adopted for the probability and learning exercise of the data was modified from equation (2). Hence:

$$f_i | 1 \leq i \leq N = \frac{n_i}{N} = \frac{n_i}{\sum_{k=1}^{N} n_k}$$ Equation (3)

Where,

f_i is the frequency of increase of the waste data set,

i is an instance of a month (in this case, i goes from 1 to 36 since there are 36 months for the 3 years of data to learn from),

n_i is the number of increase or decrease in waste data across the years,

N is the total number of years (in this case, it is 3 years),

n_k is every data point within the range.

Using equation (3), an algorithm to learn the empirical probabilities of the waste data trends was developed in order to present forecasted data with similar increase or decrease in pattern. This learning algorithm model is shown in the Appendix. As mentioned earlier, the solution depicted by this algorithm was implemented with Visual Basic.Net programming language, on Microsoft.Net framework version 4.5 Common Language Runtime (CLR). The code listing that was developed in the programming process can be accessed in the Appendix. However, a simplistic and brief account of the new learning algorithm programming process is depicted Box 4.1

Box 4.1: Algorithm (Learn and Forecast)

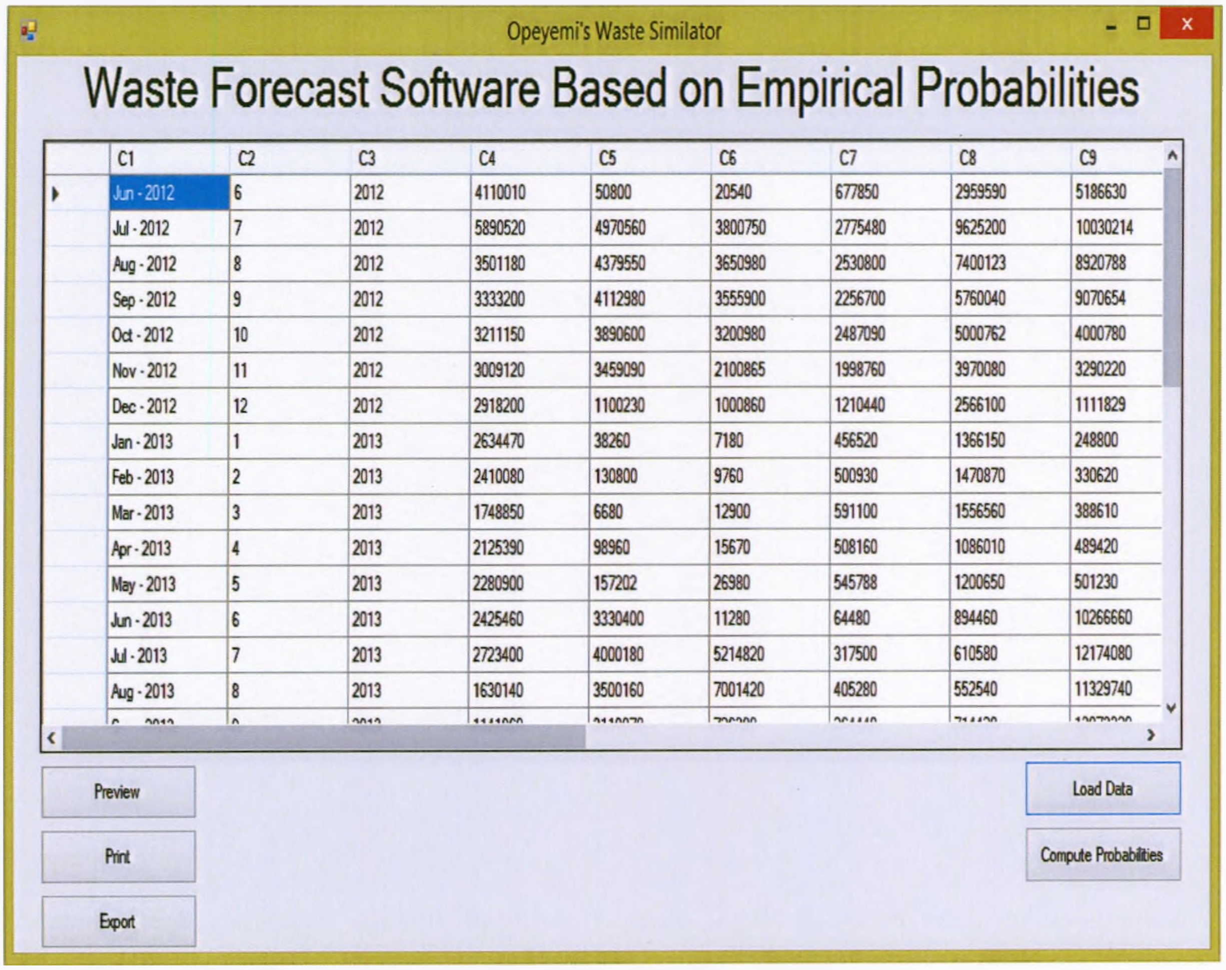
```
Foreach waste category

        // Learn first
        foreach datarow in the history of this waste category
                Learn (increase or decrease, rate of fluctuation, time of year)
                Store (Learning, time of year)
        end for

        foreach fact in Learn
                keep track of the minimum and maximum value of waste in kilograms
                for each time of the year

                keep track of the minimum and maximum rate of fluctuation of waste
                in kilograms for each time of the year
        end for

        //Forecast with pattern learned
        foreach future year {2015, 2016, ..., 2022}
                foreach month of the year {Jan, Feb, ..., Dec}
                        compute probability that this waste will increase in this
                        month using Learned pattern

                        compute probability that this waste will decrease in this
                        month using Learned pattern, i.e. (1 - Probability(increase))

                        get a random rate that is in the interval of [minimum rate,
                        maximum rate]

                        get a random future value that is in the interval of [minimum
                        value of waste, maximum value of waste]

                        if (waste increased with respect to probability of increase)
                        then
                                forecast = random value + random rate
                        else if (waste decreased with respect to probability of
                        decrease) then
                                forecast = random value - random rate
                        end if

                        // normalize forecast here
                        if (forecast is <= 0) then
                                forecast = random value
                        end if

                        Display (forecast for this future month and year)
                end for
        end for
end for
```

4.5.2 Machine Learning Algorithms

Machine learning is an aspect of Artificial Intelligence (AI); it is a semi-automated extraction process of knowledge from existing data. It requires many smart decision-input by human capacity. In general, there are three types of machine learning:

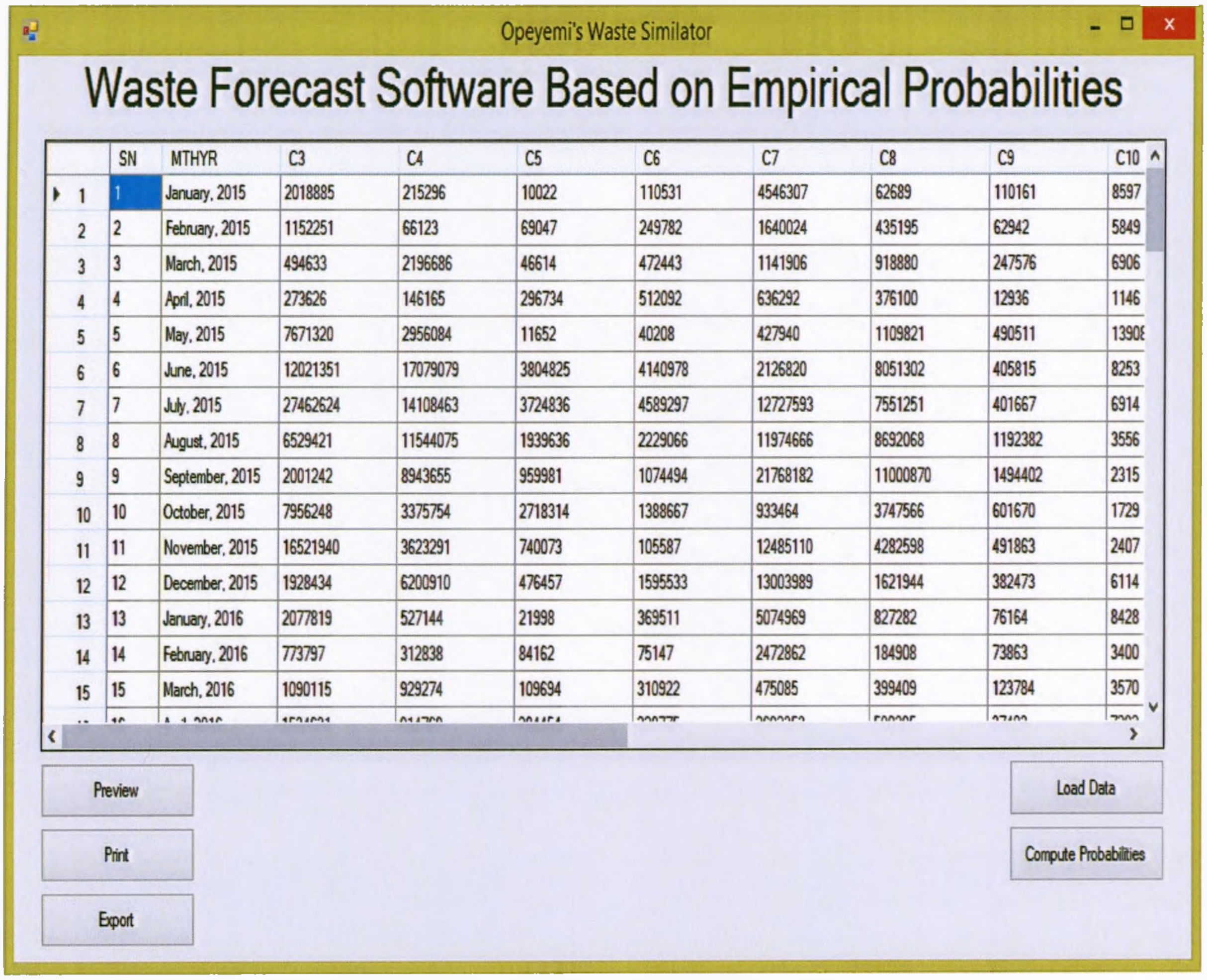
1. Supervised learning, which involves making predictions using acquired data. It generates a function based upon assigned labels that map inputs to desired outputs. A model is usually developed through a training process where it is required to make predictions and corrections are made when the predictions are wrong. This goes on until a desired level of accuracy is attained (Brownlee, 2013).
2. Unsupervised learning, which involves extracting structure from data set. It looks for patterns native to data sets and models it. According to Brownlee (2013), the input data is not labelled and has no known result. The model is however prepared by deducing structures found in the input data.
3. Reinforcement learning, which involves the provision of input data as stimulus to a model from an environment whereby the model would respond and react. Unlike the supervised learning where feedback is given through a teaching process, the reinforcement learning goes through a *rewards* and *punishments* process. (Brownlee, 2013)

To carry out the forecasting, the author adopted the use of supervised machine learning algorithms with the use of Visual Basic.Net programming language, on Microsoft.Net framework version 4.5 CLR. According to Schapire (2007), machine learning studies how to automatically learn to make accurate forecasts based on past trends. It is linked to mathematic optimization which delivers approaches, theory and application domains to the field. In carrying out this forecast, the population of the waste producers of the city was not factored in as it was not originally indicated in the acquired data set. A probability model (mentioned in the previous section) of the waste trend was developed which was inculcated into the machine learning algorithm model in order to forecast future waste data based on this trend. The forecasted waste data can be view in the Appendix. Screen shots of the input waste data and the eventual forecasted waste data in the Visual Basic.Net programming language environment is depicted in Figure 4.5 and 4.6 respectively.



C1	C2	C3	C4	C5	C6	C7	C8	C9
Jun - 2012	6	2012	4110010	50800	20540	677850	2959590	5186630
Jul - 2012	7	2012	5890520	4970560	3800750	2775480	9625200	10030214
Aug - 2012	8	2012	3501180	4379550	3650980	2530800	7400123	8920788
Sep - 2012	9	2012	3333200	4112980	3555900	2256700	5760040	9070654
Oct - 2012	10	2012	3211150	3890600	3200980	2487090	5000762	4000780
Nov - 2012	11	2012	3009120	3459090	2100865	1998760	3970080	3290220
Dec - 2012	12	2012	2918200	1100230	1000860	1210440	2566100	1111829
Jan - 2013	1	2013	2634470	38260	7180	456520	1366150	248800
Feb - 2013	2	2013	2410080	130800	9760	500930	1470870	330620
Mar - 2013	3	2013	1748850	6680	12900	591100	1556560	388610
Apr - 2013	4	2013	2125390	98960	15670	508160	1086010	489420
May - 2013	5	2013	2280900	157202	26980	545788	1200650	501230
Jun - 2013	6	2013	2425460	3330400	11280	64480	894460	10266660
Jul - 2013	7	2013	2723400	4000180	5214820	317500	610580	12174080
Aug - 2013	8	2013	1630140	3500160	7001420	405280	552540	11329740

Figure 4.5: Screen shot of waste data input in the Visual Basic.Net programming language environment



	SN	MTHYR	C3	C4	C5	C6	C7	C8	C9	C10
1	1	January, 2015	2018885	215296	10022	110531	4546307	62689	110161	8597
2	2	February, 2015	1152251	66123	69047	249782	1640024	435195	62942	5849
3	3	March, 2015	494633	2196686	46614	472443	1141906	918880	247576	6906
4	4	April, 2015	273626	146165	296734	512092	636292	376100	12936	1146
5	5	May, 2015	7671320	2956084	11652	40208	427940	1109821	490511	1390
6	6	June, 2015	12021351	17079079	3804825	4140978	2126820	8051302	405815	8253
7	7	July, 2015	27462624	14108463	3724836	4589297	12727593	7551251	401667	6914
8	8	August, 2015	6529421	11544075	1939636	2229066	11974666	8692068	1192382	3556
9	9	September, 2015	2001242	8943655	959981	1074494	21768182	11000870	1494402	2315
10	10	October, 2015	7956248	3375754	2718314	1388667	933464	3747566	601670	1729
11	11	November, 2015	16521940	3623291	740073	105587	12485110	4282598	491863	2407
12	12	December, 2015	1928434	6200910	476457	1595533	13003989	1621944	382473	6114
13	13	January, 2016	2077819	527144	21998	369511	5074969	827282	76164	8428
14	14	February, 2016	773797	312838	84162	75147	2472862	184908	73863	3400
15	15	March, 2016	1090115	929274	109694	310922	475085	399409	123784	3570

Figure 4.6: Screen shot of the forecasted waste data in the Visual Basic.Net programming language environment

From this, the forecasted data can be imported into Microsoft Excel for further analysis.

4.5.3 Forecasted data Analysis

From the machine learning algorithm process, forecast of the waste pattern up to the year 2022 (estimated year for the landfill to attained full capacity) was developed. A graphical representation is present in Figure 4.7 which depicts the forecasted waste pattern from 2015 – 2022. Factors such as population increase or decrease across the years was not factored into the machine learning algorithm. However, from the graphical representation, it can be deduced that the amount of waste getting to the landfill increases with time although there are some years which turns out to produce lower volumes of waste getting to the landfill. An explanation for such occurrence is that the learning algorithm through the probability variances from the past data, predicted that there might be some years where external factors such as temporary closure of the site for maintenanace or upgrade could lead to a lower volume of waste accepted on the site. This however cannot be regarded as reliable projections as there is not enough historical data to show how often this spike in tonnages occur. The rate of recovery of materials remains constant through out the years, varying from 25 – 30%. Hence the amount of waste getting buried also appears to be on the increase as compared to the total waste getting to the site.

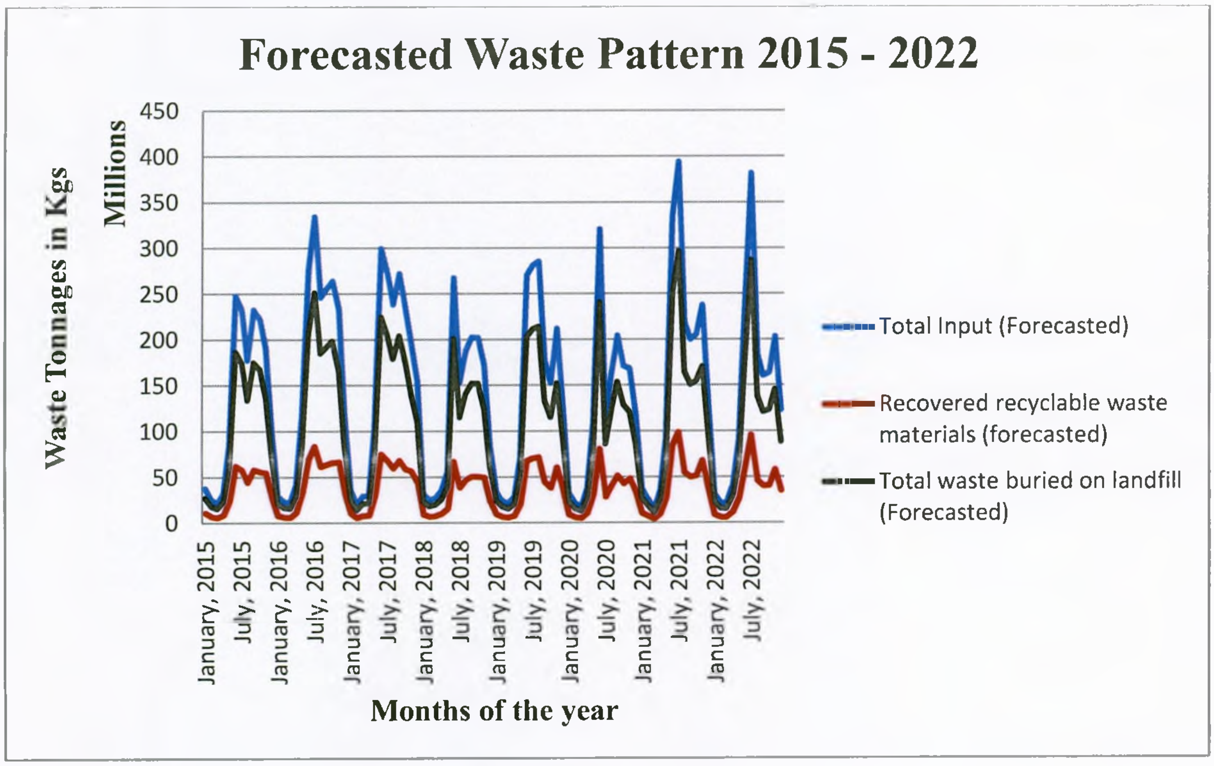


Figure 4.7: Forecasted waste pattern from 2015 to 2022

From Figure 4.7, it can also be deduced that there appears to be a drop in waste getting to the landfill within December and January of each year. It appears that within this period, a lot of people actually travel out from the City to other provinces for the festive period, hence less waste generated.

4.5.4 Scenario development

In creating scenarios, the status quo of the current municipal solid waste management in Robinson Deep landfill is analysed and depicted in Figure 4.8. In the status quo, about 70 – 75% of the entire amount of waste is landfilled, that is, only about 25 – 30% of entire amount of waste is recycled. This study does not consider the total air emissions and leachate produced from the analysis as lack of data makes tracking the flow of all air emissions and leachate produced a difficult task to achieve.

As regards global best landfilling practice, this current system has the following shortcomings:

a. The amount of waste being recovered (recycled) is relatively low;

b. There is currently no functioning waste-to-energy recovery process occurring on the site; and

c. The landfilling of biodegradable waste will eventually result in voluminous and long term emissions in terms of landfill gas and leachate. This shows an ineffective use of the landfill space.

In a bid to surmount these shortcomings, scenarios have been developed. Each of these scenarios represents a different combination of management or/and treatment options resulting in the specific flows of goods (all waste and recovered materials) through the landfill.

b. Scenario 2: Where all recyclable materials are recovered before landfilling.

c. Scenario 3: where there is some level of separation at the source of generation (10%). At the landfill site, there is a functional material recovery facility coupled with an incineration cell. Landfilling follows afterwards.

d. Scenario 4: Where the municipal solid waste initially passes through a Mechanical Biological Treatment (MBT) facility on the landfill site then goes through an incineration cell before it is eventually landfilled.

The analysis and discussion of these scenarios are presented in chapter 5. To summarize this chapter, a research methodology framework is however in Figure 4.9

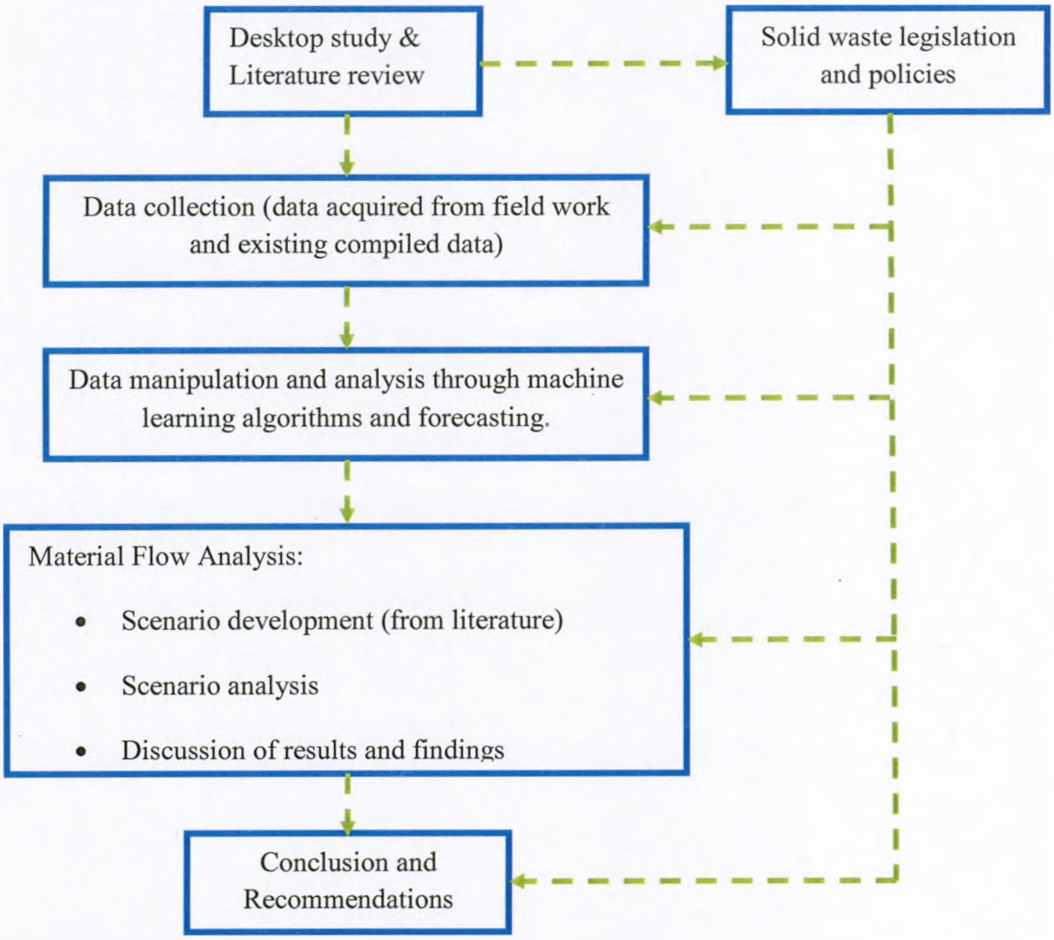


Figure 4.9: Research Methodology Framework

Chapter Five

5.0 ANALYSIS AND DISCUSSION

5.1 Introduction

This chapter entails the analysis of the scenarios created and compared with the status quo. Discussion of the analysis is presented with a view of determining what option would be best suited in order to extend the time the landfill would attain its full capacity. It also explores the relative costs and management complexity associated with each scenario's waste management technology which complies with global best practice. This chapter aims at answering the research question – "*what are the main sources of waste generation in the City, the composition of waste deposited on landfill sites and the ratio being recycled or reduced*?". Moreover, it aims to address the research objectives which are to:

(1) Analyze the material flows of the municipal solid waste which is deposited at a selected landfill site in the City of Johannesburg. In this case, Robinson Deep landfill.

(2) Analyze the relative impact of the current waste technology adopted on the case study site, and four developed scenarios of different waste technology on the environment and health of the public; and how this knowledge can help facilitate future waste management practices.

(3) Determine the reliability and accuracy of data relating to solid waste being deposited to landfill sites. It will also test the applicability of Material Flow Analysis (MFA) in providing a holistic characterization of municipal solid waste as a means to generating optimized management solutions.

A significant component of a MFA is the establishment of system boundaries. As mentioned earlier, the perimeter of Robinson Deep landfill site is the system boundary of this study. In tracing all material flows and fluxes coming to the landfill as well as those buried and those recovered, graphical representations are presented in this chapter. MFA for different scenarios are developed and also presented graphically.

The status quo for the material flow which was presented in chapter four is broken down in this chapter for further analysis of the situation. The material flow is for a 3 year period (from June

2012 to May 2015). In a situation where historical data of over 20 years can be obtained, it would be possible to model reliable projections through machine learning algorithms as to how future waste patterns could appear.

Figure 5.1 shows a graphical representation of the total waste materials entering the site while Figure 5.2 also shows a graphical representation of the total waste entering the site with the exclusion of the months July to December of 2014 where there is a sudden spike in tonnages due to exceptional circumstances which are stated below.

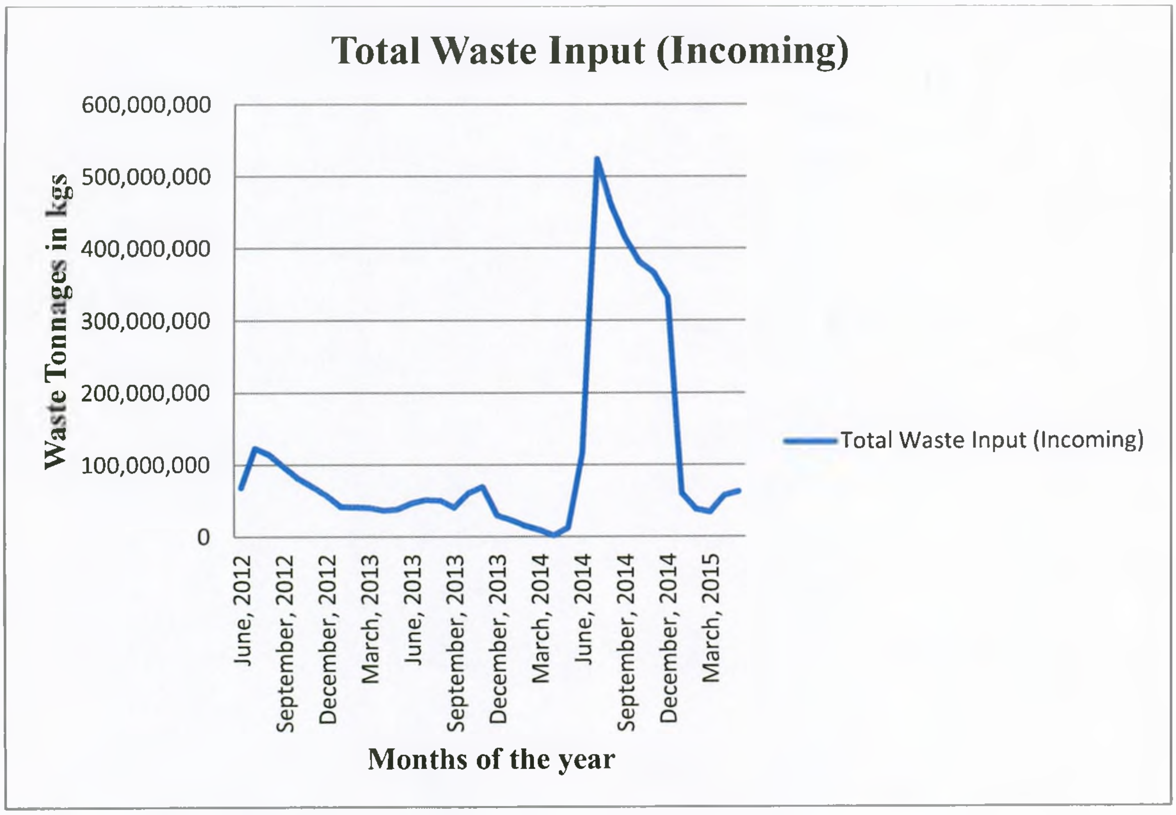


Figure 5.1: Total waste materials getting into Robinson Deep Landfill site from June, 2012 to May, 2015

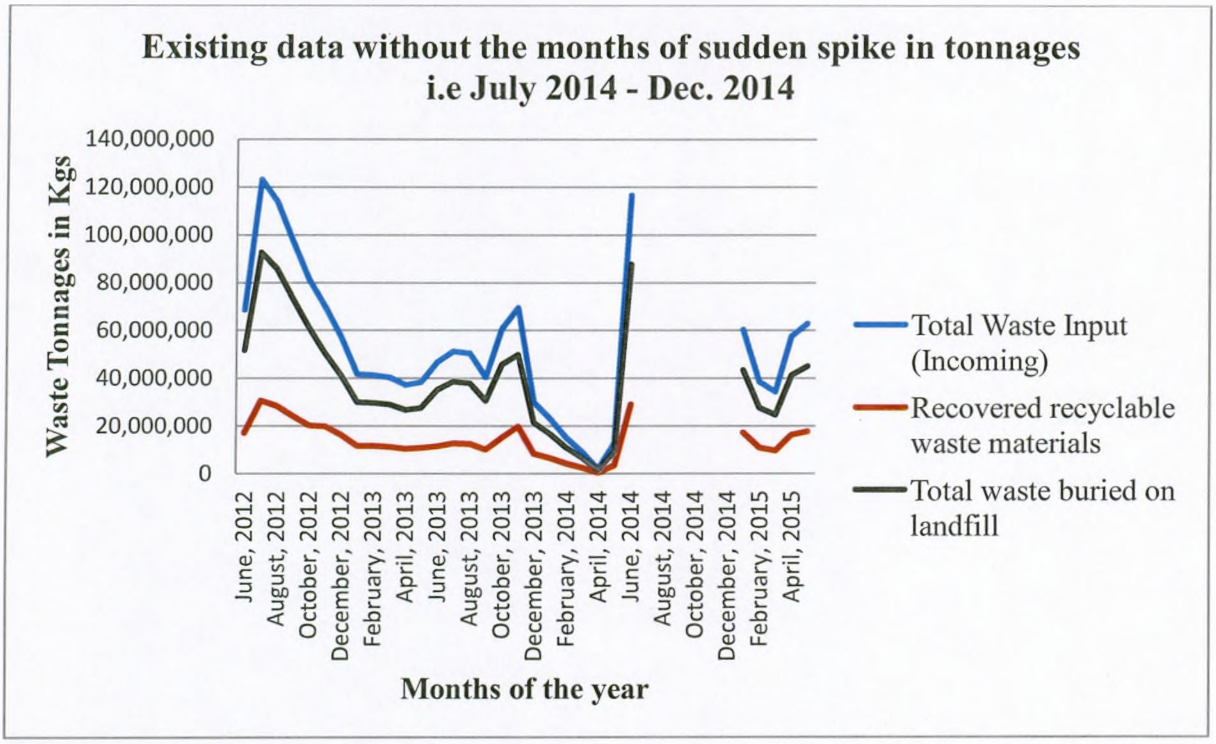


Figure 5.2: Existing data without the months of sudden spike in tonnages i.e. July 2014 – Dec 2014

From Figure 5.1, major activities appear to have occurred on the site mid-2014 (from July to December) and peaked at over 500 million kilograms of waste. This could be attributed to a number of reasons such as a situation where another landfill in the Gauteng region was temporarily closed due to operational upgrade or maintenance. Due to this exceptional occurrence and lack of extensive historical data to determine the frequency of this occurrence, the study analyzed the dataset including this exceptional occurrence (spike in waste tonnages) as well as the dataset excluding the spike in waste tonnages. From studying the 3 year dataset, it was determined that the months of July, 2014 to December, 2014 experienced the spike. The month of June, 2014 appears to be high but going back to the year 2012, there appears to be a high volume of waste getting into the landfill of similar tonnages. Hence, the study assumes this is a normal occurrence. In the month of May, 2014, the site experienced less activities on the landfill as a result of making provisions to accommodate the large volumes of waste that were expected to arrive on the landfill in the subsequent months of July to December, 2014.

From Figures 5.1 and 5.2, it can be deduced that the annual seasonal changes also affect the total waste materials getting to the landfill site. The waste tonnages in the summer period appears to be more than in the winter period because people tend to recycle their waste more in the winter period as a source of alternative energy (heating). As a result of this, recovery of materials on site is slightly less than in the summer period.

Figures 5.3 and 5.4 depict graphically waste materials that have been recovered and those that have been buried. The rate of recovery of waste ranges from 25 – 30% that is to say 70 – 75% of the total waste entering the site is buried.

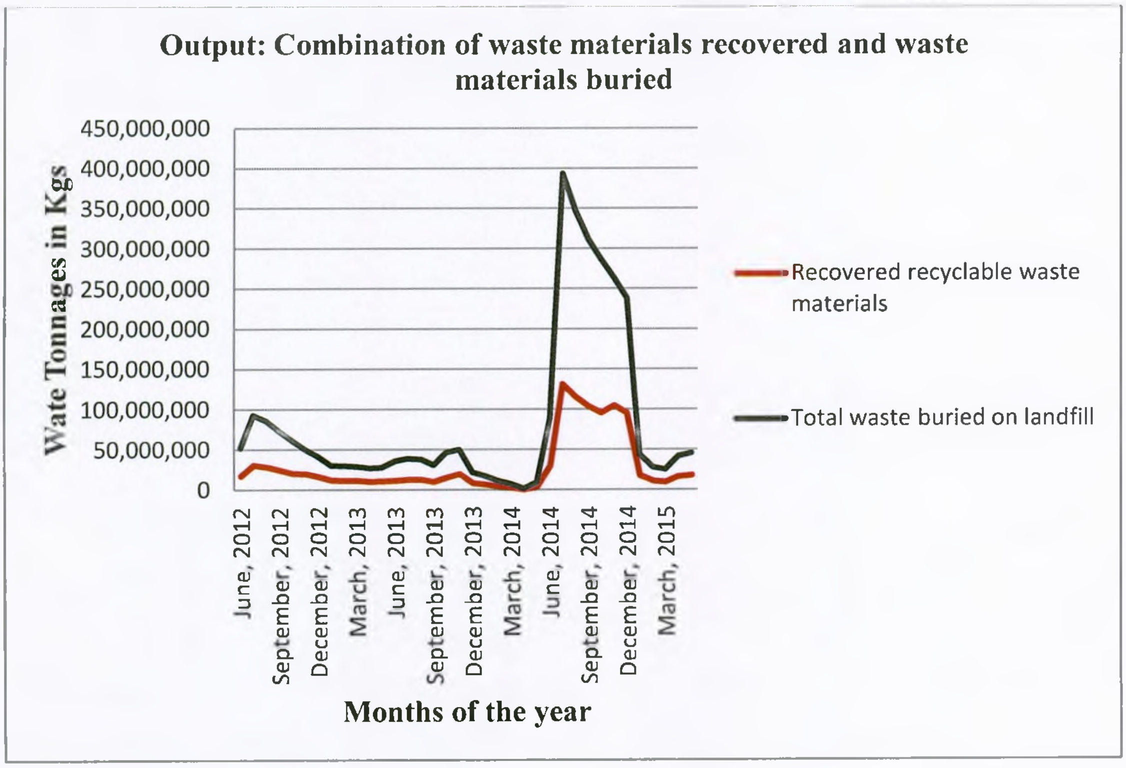


Figure 5.3: Material recovered compared with the waste material buried

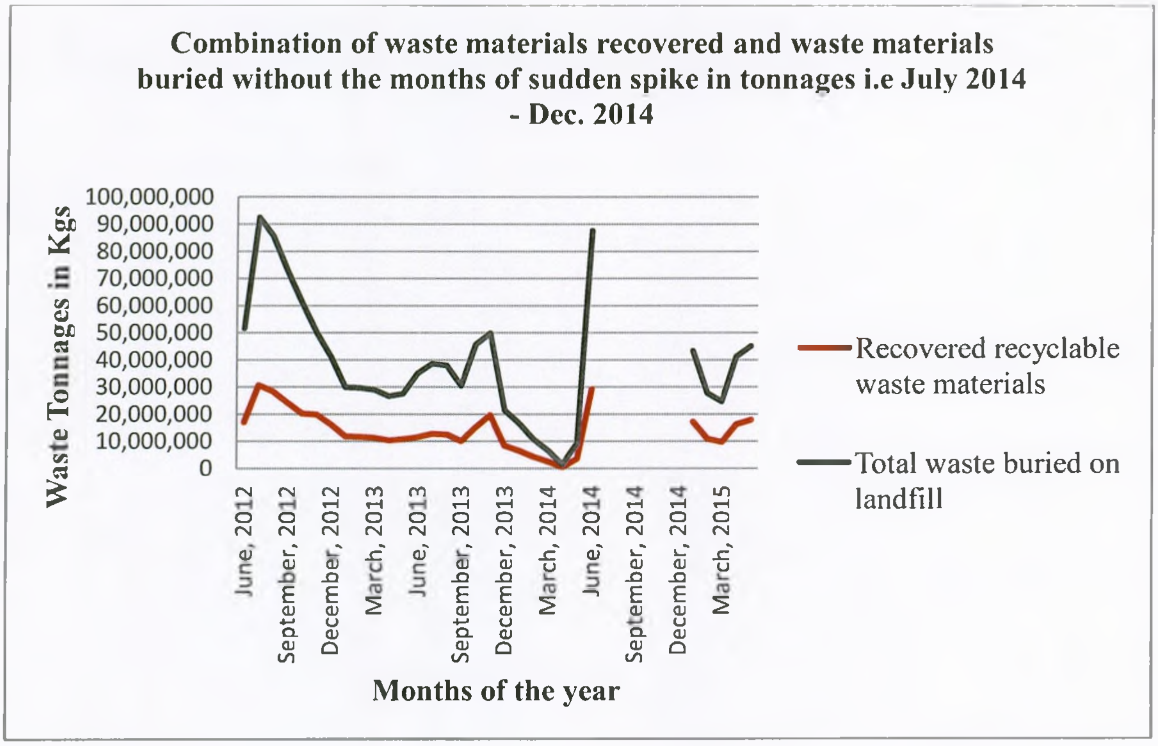


Figure 5.4: Material recovered compared with the waste material buried without the months of sudden spike in waste tonnages i.e. July 2014 – December 2014

The Figures 5.1, 5.2, 5.3 and 5.4 follow the well-established principles of material flow analysis which operates on the law of conservation of mass or mass balance, that is: matter cannot disappear or be created spontaneously. The expression is presented in Equations 4 and 5:

Input = Output + Accumulation   Equation (4)

This is be interpreted in the landfill context as:

Waste coming to the landfill	= Waste recovered	+	Waste buried	Equation (5)
(Input)	(Output)		(Accumulation)	

It should be stated again that due to the lack of data, factors such as the generation of landfill gas and leachate is not factored into the analysis. It is assumed that the leachate and landfill gas generation constitutes part of waste accumulated on site.

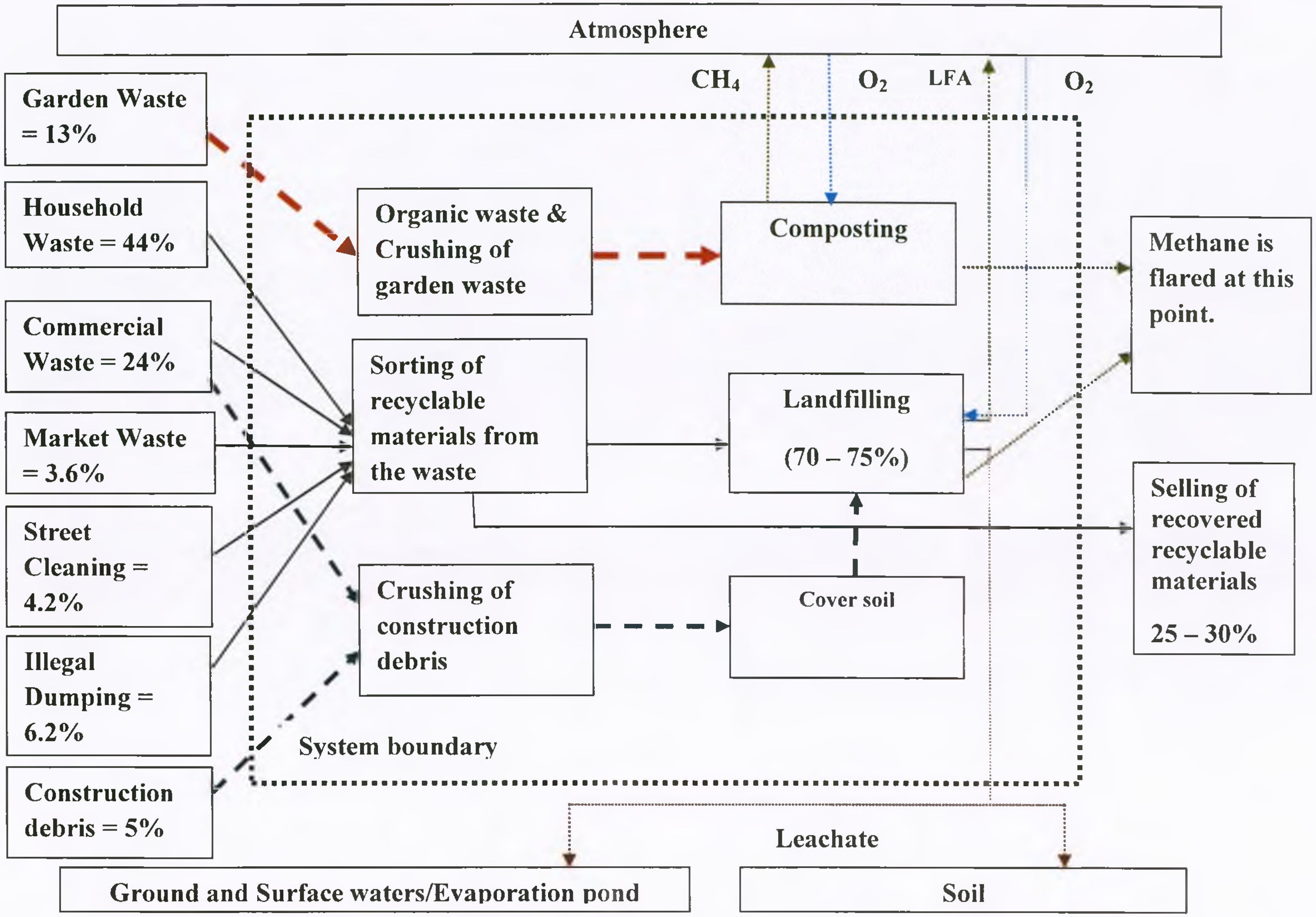


Figure 5.5: A breakdown of the material flow in Robinson Deep Landfill

Figure 5.5 shows the breakdown of waste categories for the 3 years of data obtained for this study. The classification of the waste is based on the waste characterization exercise carried out on site and depicted in Table 4.1. The percentages were attained from the waste data acquired which contains the respective breakdown of waste categories. It can be seen that household and commercial waste constitutes the majority of the waste category getting to the landfill site. Still referring to Table 4.1, the composition of these waste categories (household, commercial, illegal dumping, street cleaning and market waste) contain high levels of recovery materials as indicated in the table. This study classifies composting as a form of material recovery/recycling. Hence, garden waste constitutes an important part of the waste at the landfill, constituting about 13% of the total waste getting to the site. Utilizing all of the garden waste would ensure that 13% of the waste is diverted from being landfilled.

Figure 5.6 depicts a further breakdown of the various categories of waste as regards its source for the 3 year while Figure 5.7 depicts a similar breakdown with the exclusion of the months which experienced a spike in the waste tonnages on the landfill. From both figures, it can be seen that round collected refuse category constitutes the highest composition of the waste getting into the site. It is composed of recyclable materials such as paper, cardboard boxes, plastics and metals; and also non-recycled waste materials such as food waste. These are also categorized under household waste. Material recovery at full capacity from this category of waste also suggests that there would be a significant diversion of waste materials from being landfilled, hence saving landfill space and increasing the life span of the landfill. It can be seen from Figure 5.7 that in the month of June, 2014, a total tonnage of about 58,000,000 kg was deposited as opposed to an average of 20,000,000 kg. The month of June, 2014 was decided not to be included in the category of exceptional category as there appears to be a significant difference in tonnages with the 6 months that exhibits the spike in tonnages. Another reason is that there is a similar increase which was experienced in 2012; hence it is assumed that it is a normal occurrence for a slight increase in tonnages to occur.

Other categories of waste that contribute significantly to the accumulation of waste on the landfill are garden refuse, household waste, illegal dumping and street cleaning (constituting some garden waste, electronic waste, large volumes of unclassified waste materials), construction waste and market waste. From field work assessment and data acquired, the composition of recyclable materials from these categories listed is significantly high. It can be assumed that there would be a significant diversion of the volume of waste from the landfill if these materials are recovered from the waste stream, hence prolonging the life span of the landfill. In terms of biodegradation of these wastes, researches have broken down the time frame it can take for certain waste materials to decompose. This can be seen in Table 5.1.

Table 5.1: Degradation rates for common materials (Source: Mihelcic and Zimmerman, 2009)

Material	Biodegradation Time	Source
Cotton rags	≈ 1 – 5 months	Mihelcic and Zimmerman, 2009; Owens, 2008
Paper	≈ 2 – 5 months	Mihelcic and Zimmerman, 2009; Owens, 2008
Orange peels	≈ 6 months	Mihelcic and Zimmerman, 2009; Owens, 2008
Cigarette butts	≈ 1 to 12 years	Mihelcic and Zimmerman, 2009; Owens, 2008
Plastic coated paper milk cartons	≈ 5 years	Mihelcic and Zimmerman, 2009; Owens, 2008
Plastic bags	≈ 10 – 20 years	Mihelcic and Zimmerman, 2009; Owens, 2008
Tin cans	≈ 50 – 100 years	Mihelcic and Zimmerman, 2009; Owens, 2008
Disposable diaper	≈ 75 years	Owens, 2008
Aluminium cans	≈ 80 – 100 years	Mihelcic and Zimmerman, 2009; Owens, 2008
Glass bottles	≈ 1 million years	Mihelcic and Zimmerman, 2009; Owens, 2008
Plastic bottles	> 1 million years	Mihelcic and Zimmerman, 2009; Owens, 2008
Styrofoam	> 1 million years	Owens, 2008

From Table 5.1, it can be deduced that common materials such as cigarette butts, plastic bags or bottles, tin and aluminium cans, disposable diapers, glass bottles and Styrofoam materials are harmful to the environment as it takes a very long time for the materials to degrade. Hence, it is important that such materials are recovered, treated or incinerated as opposed to burying such materials.

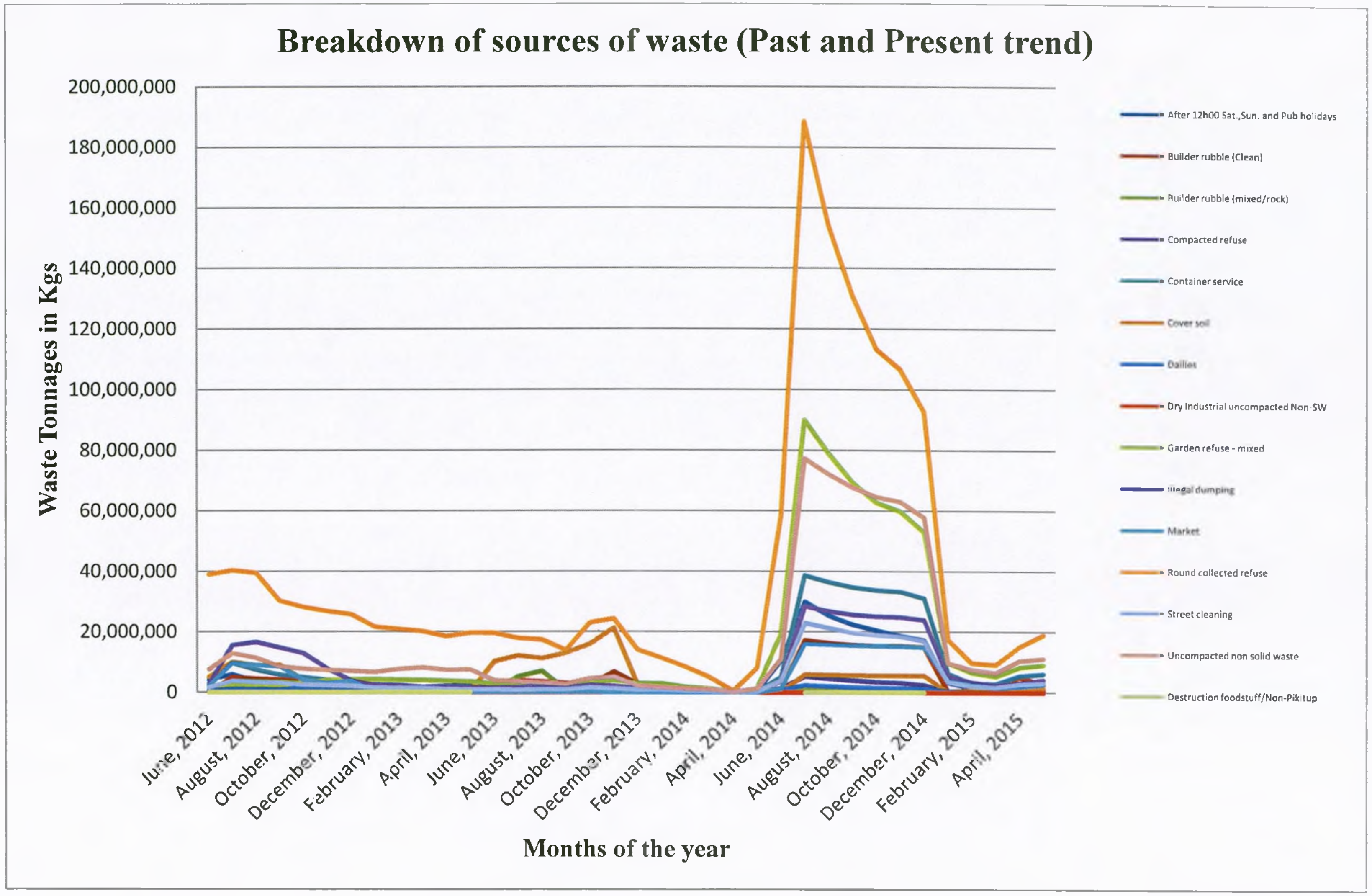


Figure 5.6: The categories and tonnages of waste getting into Robinson Deep landfill for a 3 year period

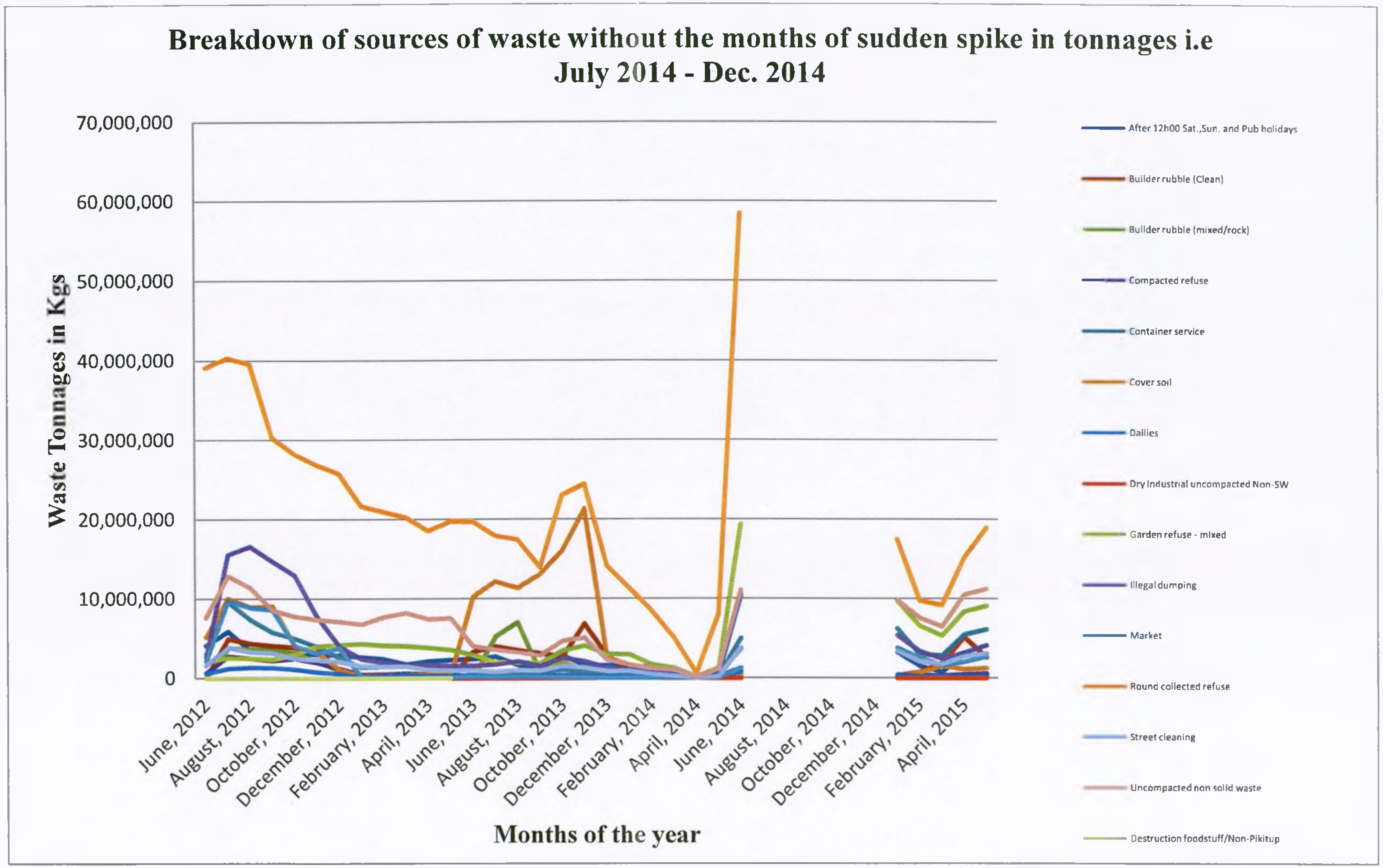


Figure 5.7: The categories and tonnages of waste getting into Robinson Deep landfill for a 3 year period without the months of sudden spike in tonnages i.e. July 2014 – Dec 2014.

5.2 Scenario Analysis

As described in section 4.5.4, the scenarios are developed with the aim of achieving global best practice which entails the conservation of resources (material and energy), the minimization of landfill space by adopting certain waste pre-treatment processes before it is landfilled, the utmost use of waste-to-energy processes and most importantly to ensure no harmful impact of landfill emissions on human health and the environment. The following scenarios have therefore been developed and are applied to the available data:

a. Scenario 1: The rate of recovery of materials from the total incoming waste is doubled on site.

b. Scenario 2: All recyclable materials are recovered before landfilling.

c. Scenario 3: There is some level of separation at the source of generation (10%) and at the landfill site there is a functional material recovery facility coupled with an incineration facility. Landfilling follows afterwards.

d. Scenario 4: The municipal solid waste initially passes through a Mechanical Biological Treatment (MBT) facility on the landfill site then goes through an incineration facility before it is eventually landfilled.

5.2.1 Scenario 1: The rate of material recovery is doubled on site

In this scenario, the rate of material recovery is doubled from what it is in the existing data. Hence, from discussion with the landfill manager, this would involve that the state of the material recovery facility is working at efficient capacity and would also involve a higher man-power level from the current state. It would definitely involve investing more funds to accommodate the processes involved such as upgrading the MRF and increasing the labour force of the landfill. Figures 5.8 and 5.9 show the graphical representation of this scenario.

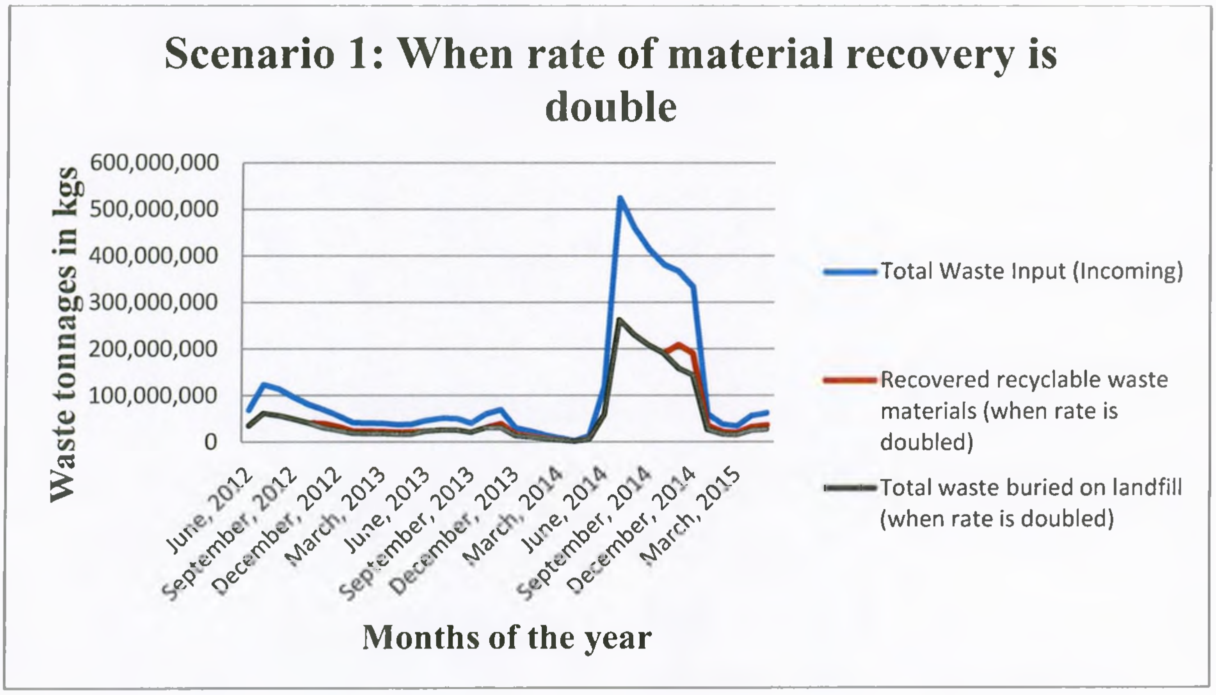


Figure 5.8: Scenario 1 – Doubled rate of material recovery

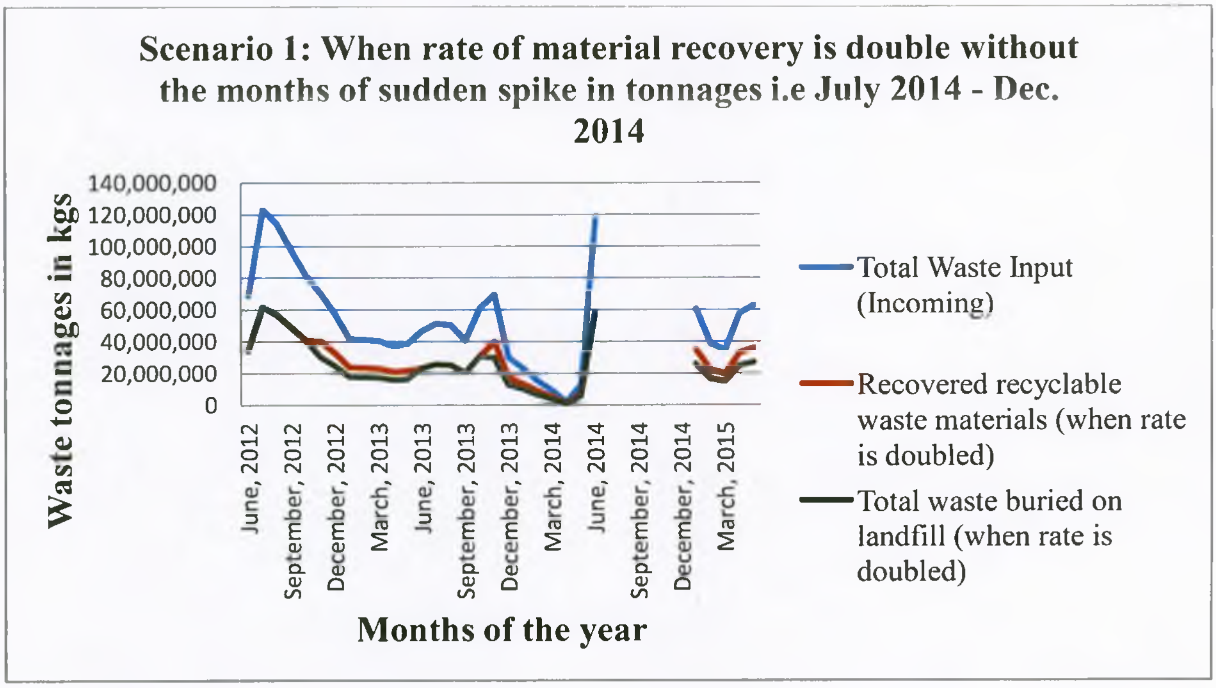


Figure 5.9: Scenario 1 – Doubled rate of material recovery without the months of sudden spike in tonnages i.e. July, 2014 to Dec, 2014

From the status quo, the total amount of waste getting into the landfill for the 3 year data acquired (June, 2012 – May, 2015) is approximately 4,070,000,000 kg and the total amount of waste landfilled during that period is approximately 2,900,000,000 kg, while the total amount of waste recovered within the same period is 1,170,000,000 kg. Hence, the ratio of waste materials buried to the waste material recovered is 2.5:1. This equates to about 25 - 28.5% recycling rate for the time frame. It also appears that the same rate of recycling was experienced during the period of the sudden spike of waste tonnages in 2014. According to the landfill manager, makeshift MRF and more waste pickers were available on site to accommodate the large volume of waste entering the landfill. For the purpose of the analysis carried out on the scenarios, it is assumed that all scenarios within the spike period entail activities to accommodate it as it would be during normal operational condition.

It has been suggested by the waste manager of the landfill that at this current rate of recycling (excluding the months of sudden spike in waste tonnages), it would take the landfill an estimated 7 years to attain its full capacity.

Comparing these values with scenario 1, it is clear to see that doubling the rate at which materials are recovered would significantly impact on the amount of waste landfilled. Figures 5.8 and 5.9 show that the amount of waste buried to that recovered appears to be of near equal quantity as compared to the status quo which has the rate of waste being landfilled to be significantly more than the rate of material recovery. From the analysis, Figure 5.8 shows that the total amount of waste getting into the landfill for the period: June, 2012 – May, 2015 remains 4,070,000,000 kg; the amount of waste landfilled within that period is 1,940,000,000 kg; while the waste material recovered within the same period is 2,130,000,000 kg. There appears to be a significant difference with scenario 1 as compared to the status quo as the ratio of waste material landfilled to that recovered is 0.9:1. This equates to an approximated 52% recycling rate for the time frame. For Figure 5.9, the total amount of waste getting into the landfill within the 3 years data set but excluding the spike in waste tonnages is approximately 1,600,000,000 kg; the amount of waste landfilled is approximately 750,000,000 kg while the total amount of waste material recovered is approximately 850,000,000 kg. Therefore, the ratio of waste buried to waste recovered is 0.8:1, which equates to an estimated 53% recycle rate. Hence, at normal working conditions, the estimated recycling rate would be 53%.

In terms of the environmental impact and achieving global best practice, this approach conserves more resources as shown by the figures obtained in the analysis. The energy that would be expended in this approach would be less than that of the status quo. A simple example would be considering the fuel consumption of the compaction machine used on the site to adequately compact the waste materials, there would be a significant reduction in the volume of fuel consumed with this approach as there would be less waste to compact and a lesser portion of the landfill to work. Regarding the minimization of the landfill space, this study speculates that with this approach, there would be significant contribution in minimizing the landfill space consumed annually as expressed in Equation (4).

The impact of this approach on the human health and to the environment would be considerably improved as compared to the status quo. Due to the level of reduction that occurred in this approach, the decomposition of some recoverable waste materials that could release harmful elements to the environment is cut down considerably as presented in the literatures reviewed (El-Fadel et al. 1997 and Alamgir and Ahsan. 2007). A holistic representation of this approach is provided in Figure 5.10.

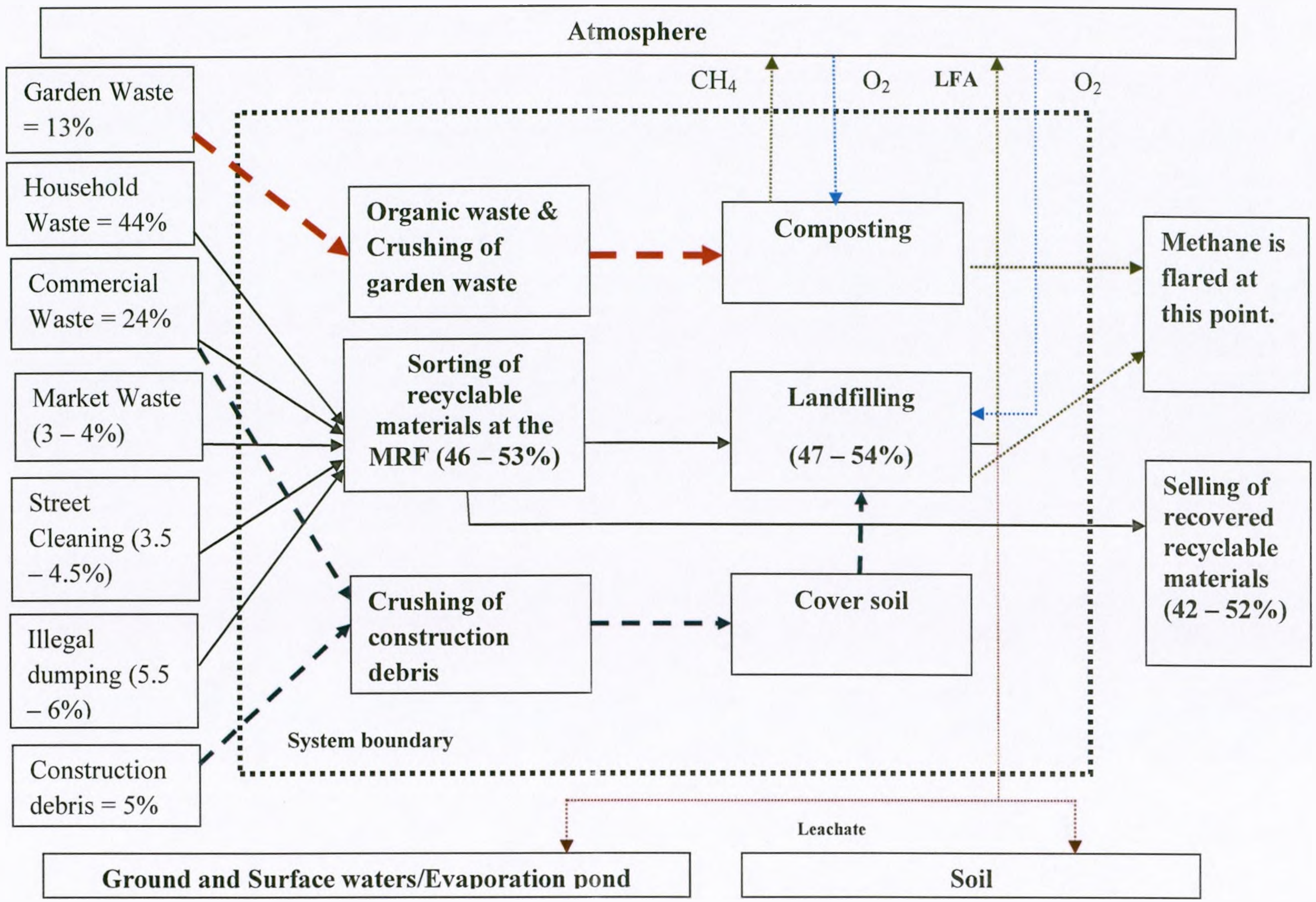


Figure 5.10: A holistic representation of scenario 1

In terms of adopting a waste to energy system, this approach still assumes that the current flaring of landfill gas still occurs and as such this approach falls short in exploiting the full potential of the landfill as a holistic integrated system which is globally accepted as good practice. The approach however would be able to be achieved and implemented within the current management system as the resources required for its implementation would be significantly less as compared to installing a waste to energy generating plant.

5.2.2 Scenario 2: All recyclable materials are recovered before landfilling

In this scenario, all possible recyclable material is recovered from the waste stream before it gets landfilled. This scenario would require considerable management and social change, but attainable nonetheless with the appropriate measures put in place such as 'the zero to landfill initiative'. South Africa, and of particular interest, the City of Johannesburg has adopted this initiative, with an expected target for the year 2022 (CoJ, 2014). From a scientific and pragmatic perspective, it does not seem attainable. As mentioned earlier in the review of literature, Matete and Trois (2008) and Davidson (2011) define the concept of *zero waste* as a waste management and planning approach which emphasizes the prevention of waste as opposed to 'end of pipe' waste management. The Institute for Zero Waste in Africa (IZWA, 2009) highlight that "it is a goal which is as visionary as it is pragmatic, to guide people in emulating sustainable natural cycles".

Hence, this study offers measures that have been adopted successfully in other countries in a view of attaining this goal. These measures are adapted from the New Zealand *zero waste* concept as it has proven to be successful there (Snow and Dickinson, 2001). The measures are as follows:

i. Identifying the key players/targets that need to be actively involved in achieving the initiative. The main players are central government, regional government, local government, industrial designers, manufacturers, secondary material handlers, universities and schools and households.

ii. Implementation and enforcement of policies that advocates for sorting of waste at the source of generation. In New Zealand, three core principles have been inculcated into their waste management policies. These principles are:

- End cheap waste disposal,
- Design waste out the system, and
- Engage the nation.

These core principles help develop strategies which can also be inculcated into the South African context. The strategies are:

- To create a national landfill levy fund which would assist in funding the *zero waste* initiative.
- To enforce the ban of toxic materials from landfills progressively,
- To enforce mandatory separation at the source.
- To enforce *pay as you throw* user fees. This applies to all waste generators and manufacturers.
- To establish an extended operator liability policy where operators are responsible for the environmental effects of waste disposal facilities on a long term basis.
- To establish an extended producer responsibility policy with incentives that encourage producers to take responsibility for the life-cycle of their products.
- Likewise, to establish a 'minimum packaging' levy on non-biodegradable and non-recyclable packaging. Similar policies include the deposit refund scheme which funds the recycling of used bottles and food containers. It also provides employment opportunities, hence, making it a sustainable mission.
- To provide funding for research into a sustainable design for the environment.
- Others include: resource recovery infrastructure, facility standards/permits, deconstruction standards, investing in jobs through reuse and recycling, mandatory corporate environmental reporting, community and national school education programmes.

iii There should be functional MRFs in all landfill sites with adequate staffs to ensure that all remaining recyclable materials are recovered before the remaining waste is landfilled. In these landfills, stockpiling of resources on site should be enforced to ensure that buyers are found, hence sufficient space must be allocated for this purpose.

This appears to be an elaborate program but results depicted in Figures 5.11 and 5.12 show that a very significant volume of waste materials would be diverted away from the landfill and hence would extend landfill's life span. According to information gathered from the Robinson Deep landfill manager, he estimates that there is about 75% of recoverable materials in the waste stream deposited at the landfill. Hence this study assumes that for all recoverable materials to be extracted from the waste stream, it would amount to 75% of the total waste stream.

This approach would involve the synchronization amongst all waste management parastatals and governmental bodies relating to environmental and social issues nationwide. It is however attainable as some of these strategies can easily be enforced in the South African context. It would also involve high resources and in the case of Robinson Deep landfill, administering this approach would be dependent on the implementation processes carried out nationwide.

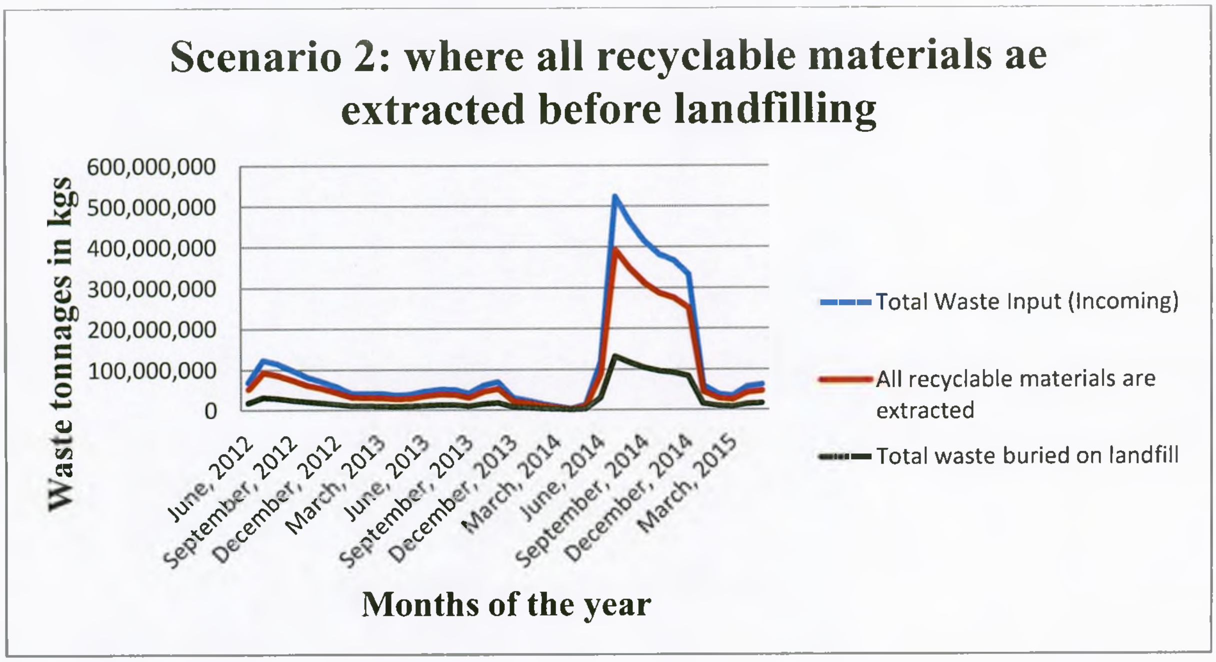


Figure 5.11: Scenario 2 – All recyclable materials are recovered before landfilling

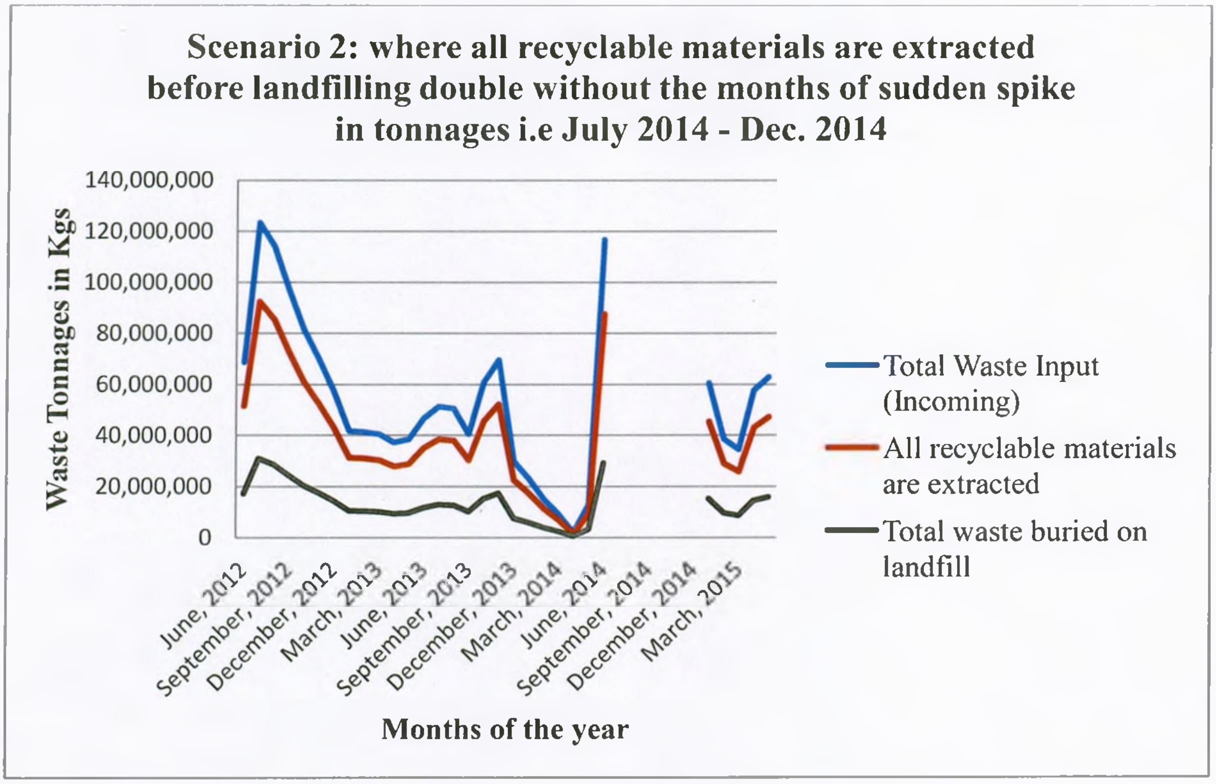


Figure 5.12: Scenario 2 – All recyclable materials are recovered before landfilling excluding months of sudden spike in tonnages i.e. July 2014 to Dec. 2014

From Figures 5.11 and 5.12, it can be seen that with this approach, an additional 50% of the tonnage of waste material in the data sample is diverted from being landfilled as compared to the status quo where an average of about 25% is diverted from being landfilled.

Further analysis shows that in Figure 5.11, the total amount of waste getting into the landfill for the period: June, 2012 – May, 2015 remains 4,070,000,000 kg; the amount of waste landfilled within that period is approximately 1,020,000,000 kg; while all the waste material recovered within the same period is approximately 3,050,000,000 kg. There appears to be a significant difference with this scenario as compared to the status quo and scenario 1. The ratio of waste material landfilled to that recovered is 0.3:1. As mentioned earlier, this is a 75% recycling rate for the time frame. For Figure 5.12, the total amount of waste getting into the landfill within the 3 years data set but excluding the spike in waste tonnages is 1,600,000,000 kg; the amount of waste landfilled is approximately 400,000,000 kg while the total amount of all waste material recovered is approximately 1,200,000,000 kg. Therefore, the ratio of waste buried to waste recovered is 0.3:1 which is similar to Figure 5.11. Hence, this also equates to an estimated 75% recycle rate.

In terms of the environmental impact and achieving global best practice, this approach appears to be suitable for South Africa's situation, comprising first and third world socio-economic characteristics. Benefits of recycling have been detailed extensively in literature reviewed (Matete and Trois, 2008; Masters and Ela, 2008; Manfredi and Christensen, 2009). According to Cabalova et al.(2012), the main benefit of recycling is in the reduction of the negative impacts on the environment and positive economical effects. Achieving total recovery of waste materials from being landfilled would also aid in conserving resources. The energy expended on the landfill site would also be greatly reduced as compared to the status quo. From the analysis carried out above, it has been deduced that this approach would contribute significantly in the minimizing the landfill space consumed annually.

Similar to scenario 1, the impact of this approach on the human health and the environment is also significantly improved as compared to the status quo. This approach also improves the social aspect of the people as they become aware of the impact of sorting of waste and recycling and how it affects their immmediate environment. It also helps the economy of the nation at large as the recycling industry would be able to create more employment opportunities for the people. A holistic representation of this approach is given in Figure 5.13.

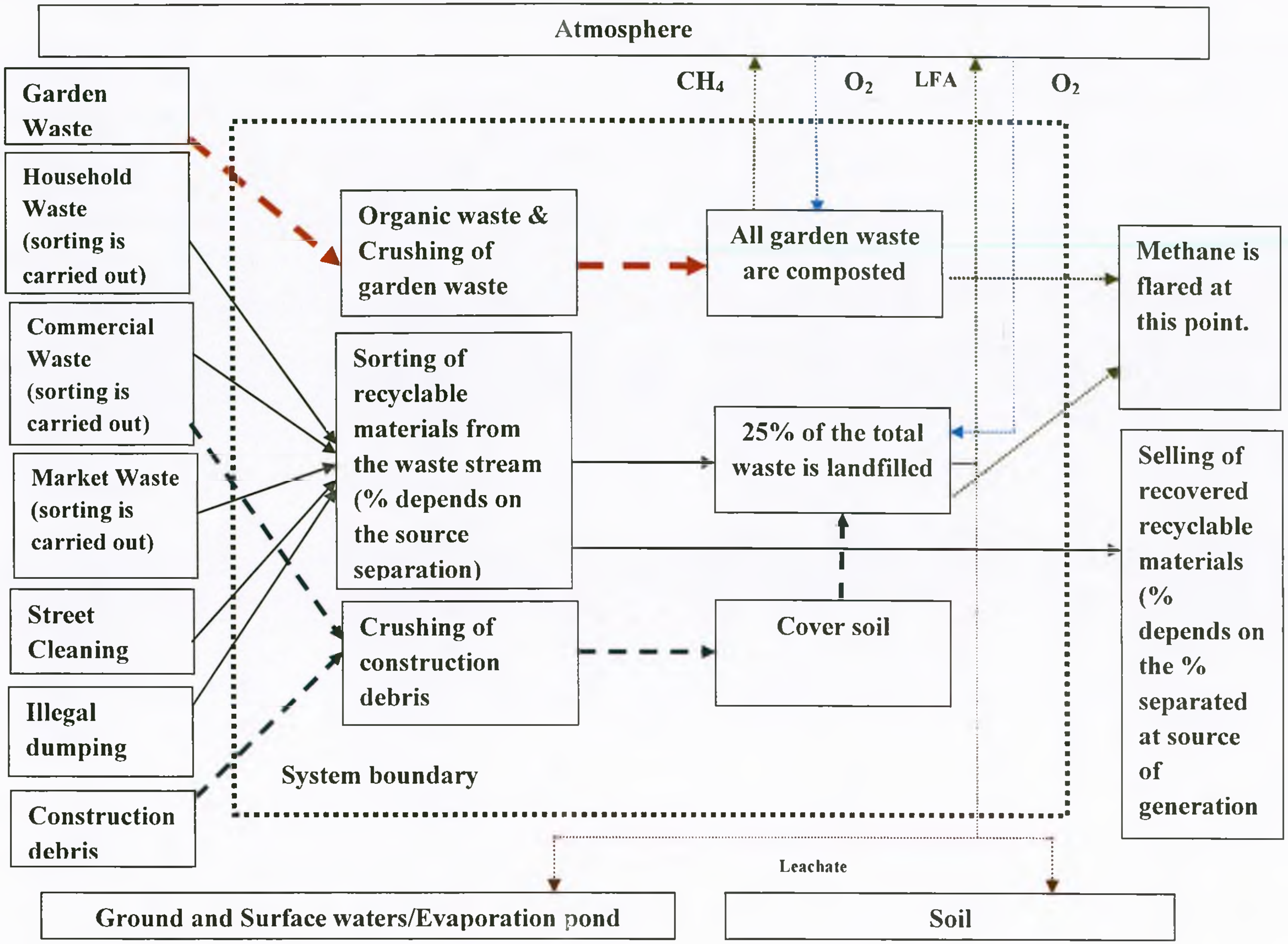


Figure 5.13: A holistic representation of scenario 2

This scenario also does not consider the implementation of a waste to energy system, hence the situation of the status quo as regards waste to energy still holds for this approach. It can be said that the system does not also exploits the full potential of the landfill as a holistic integrated system. But the overall impact of this approach supersedes the absence of a waste to energy technology. As mentioned earlier, this approach would only work efficiently if all factors involved are implemented successfully. However on a site scale, to achieve complete material recovery would entail expanding the MRF, the crushing unit for the construction debris and composting unit and increasing the labour force.

5.2.3 Scenario 3: 10% separation at the source, a functional MRF and an incineration cell

This scenario comprises three major sections that contribute to the recovery of recyclable materials and the diversion of a significant amount of waste from being landfilled. These sections are:

i. Sorting of waste at the point of generation. For the purpose of this study, it is assumed that 10% of the waste materials from the recyclable categories of the total waste stream is recovered from this procedure.
ii. Sorting of waste at the MRF on the landfill site. For the purpose of this study, it is assumed that 30% of the total waste getting into the landfill is recovered.
iii. The last section is the incineration section where 70% of the waste entering the incinernation facility is burnt out. This percentage was obtained from literature (Stanisavljevic and Brunner, 2014).

Realistically, this approach relies on high investment for upgrading the current MRF and establishing an effective incineration facility on site. This scenario would also require considerable management and social change but it is quite attainable nonetheless with appropriate measures put in place such as:

i. Implementation and enforcement of policies that advocates for sorting of waste at the point of generation. Similar to scenario 2, certain strategies can can be adopted to ensure its successful implementation (adopted from Snow and Dickinson, 2001):

- To enforce the *pay as you throw* user fees. This applies to the waste generators and manufacturers.
- To establish an extended operator liability policy where operators are responsible for the environmental effects of waste disposal facilities on a long term basis.
- To establish an extended producer responsibility policy where incentives encourage producers to take responsibility for the life-cycle of their products.

ii. Also similar to scenario 2, there should be adequate funding in place for research into sustainable design for the environment. Mandatory corporate environmental reporting should be enforced to ensure that the incineration facility is complying with appriopriate standards. Likewise, there should be community and nationa school education programmes on recycling.

The introduction of the incineration facility in this scenario makes a significant difference when comparing it with the status quo as well as scenarios 1 and 2. Figures 5.14 and 5.15 show the graphical representation of the waste stream where 10% of the recyclable materials is initially recovered from the point of generation and a further 30% is recovered from the MRF. The remaining waste is diverted to the incinerator facility where it is burned out leaving about 30% as ash which would be landfilled

Analysis of the scenario shows that the total waste coming into the landfill is 4, 070, 000, 000 kg from June, 2012 – May 2015 for Figure 5.14. After the whole waste management process on the landfill, an approximation of about 800,000,000 kg is eventually landfilled within this period with this approach. This means a total of 3,270,000,00 kg has been diverted from being landfilled. Hence, a ratio waste material landfilled to that recovered/treated is 0.24:1. This results to about 80% of the total waste getting into the landfill has been diverted from being landfilled. It can be deduced that with this approach, an additional 55% of the status quo value of waste material is diverted from being landfilled as compared to the status quo value where an average of about 25% is diverted from landfilling. Similarly, in Figure 5.15, the total amount of waste getting into the landfill within the 3 years data set but excluding the spike in waste tonnages remains 1,600,000,000 kg. Analysis shows that the amount of waste landfilled is approximately 310,000,000 kg while the total amount of waste material sorted from the source, recovered and treated on site is approximately 1,290,000,000 kg. therefore, the ratio of waste buried to that diverted from the landfill is similar to when there is the spike in late 2014 which is 0.24:1. This equates to an estimated 80% recovery rate.

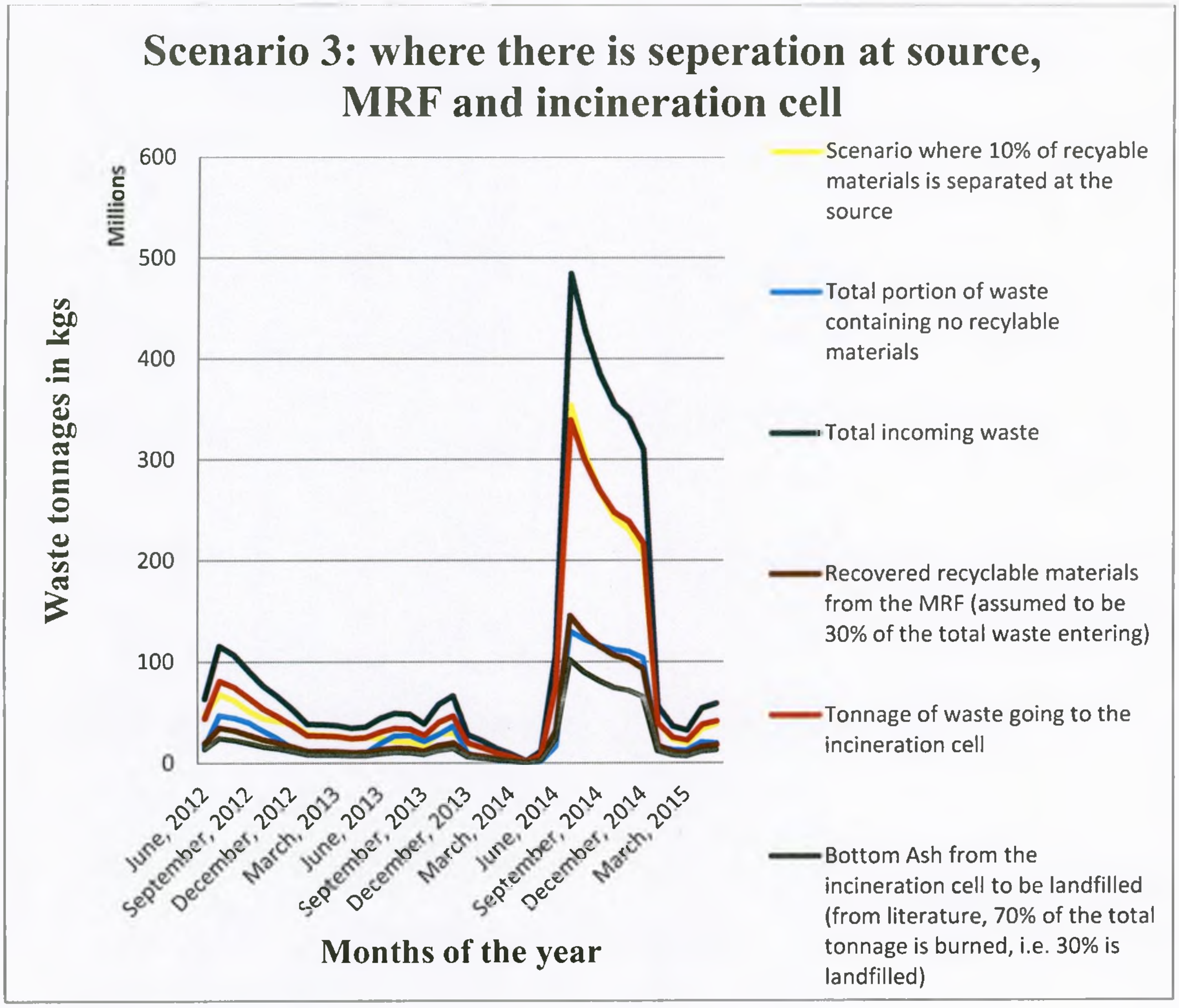


Figure 5.14: Scenario 3 – 10% seperation at the source, a functional MRF and an incineration cell

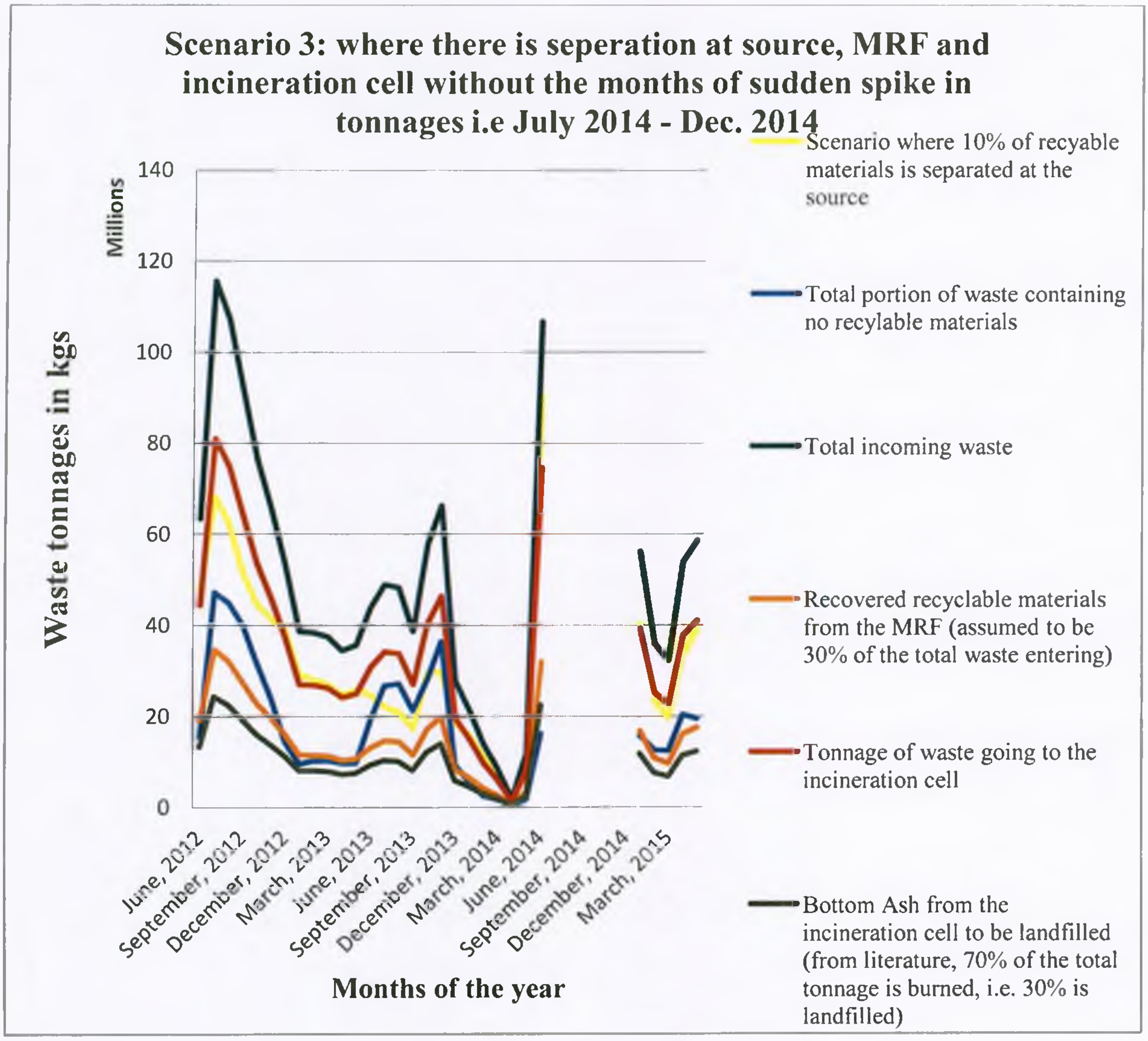


Figure 5.15: Scenario 3: 10% separation at the source, a functional MRF and an incineration cell without the months of sudden spike in tonnages i.e July 2014 - Dec. 2014

In terms of the environmental impact and achieving global best practice, it is pertinent to discuss incineration of municipal solid waste. According to Crowley et al. (2003), municipal solid waste incineration could release a wide range of volatile and gaseous emissions (depending on the composition of waste) which has the potential of compromising the environmental quality when in contact with the atmosphere. Common pollutants emitted are acid gases, oxides of nitrogen, metals, particulate metals, sulfur and innumerable substances of unknown toxicity. Likewise fly ash and dust from the incineration process can carry contaminants which could be hazardous to a sensitive eco-system. There have been studies that have associated the development of certain cancers such as primary liver cancer and lung cancer with those living close to sites with incineration facility. Other potential effects are respiratory symptoms, congenital abnormalities and hormonal defects (Sharma et al. 2013).

However, in recent times, technological advancement in the field of waste incineration facilities has significantly reduced their environmental impacts and it is generally accepted that incineration of waste with energy recovery is recognized as a necessary aspect of sustainable waste management (Morselli et al. 2008). For the purpose of this study, it is assumed that a recent technology that ensures minimal contamination to the environment is implemented.

In terms of energy and resource conservation, there would be a lot of resource and energy consumption used up by the incineration plant and the only way to manage this process sustainably would be to utilize the generating plant which harnesses the methane gas from the landfill to ensure that energy is recovered which would be used to power up the incineration facility. However, this option is not a long term sustainable approach as the methane generation in the pre-incineration fill would produce less methane over time.

This scenario assumes the recovery of energy from the incineration facility; and hence complies with global best practices. However, it would be an expensive project to implement on the landfill considering the site has an estimated seven (7) years left to attain full capacity. A holistic representation of this approach is depicted in Figure 5.16.

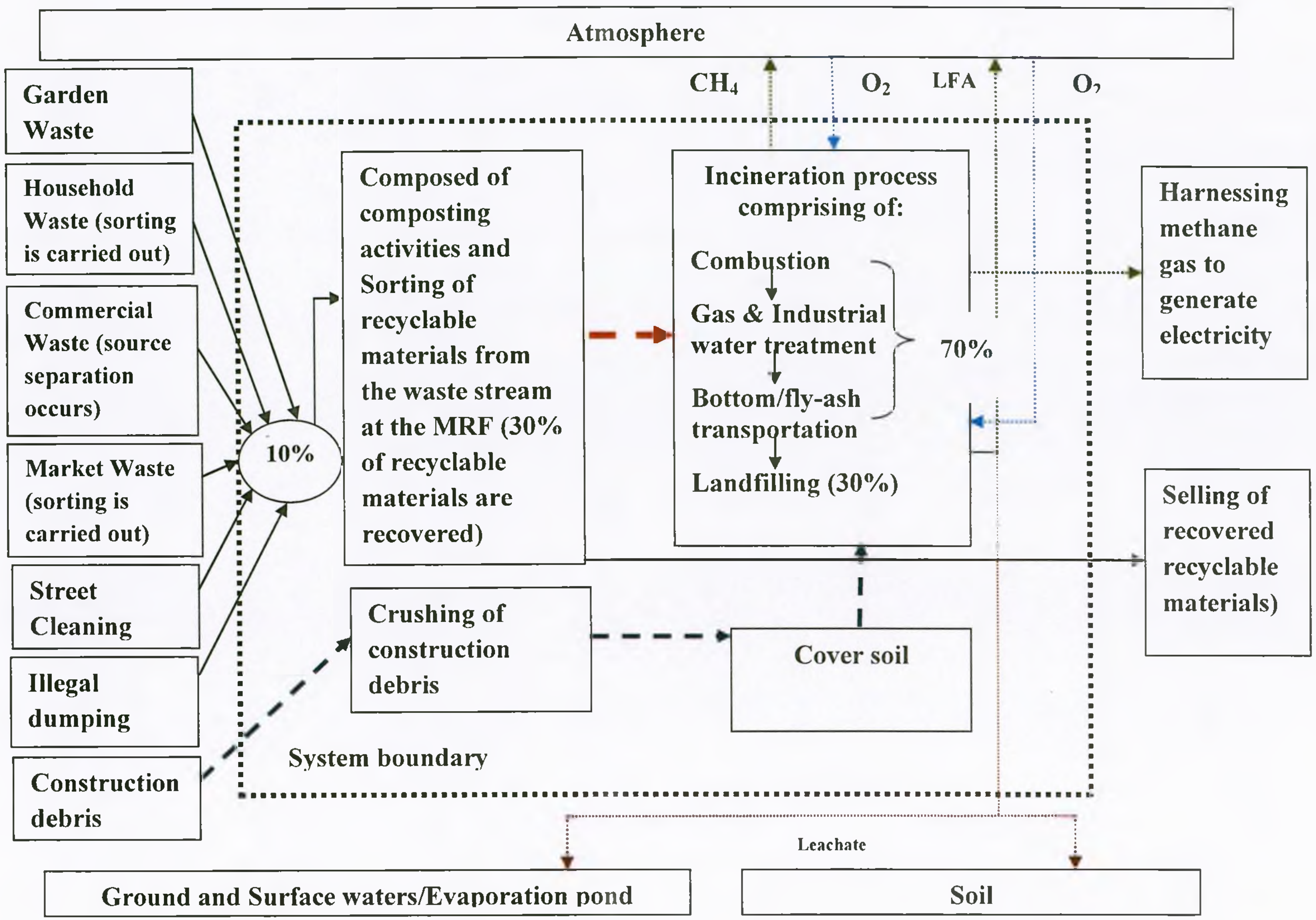


Figure 5.16: A holistic representation of scenario 3

5.2.4 Scenario 4: Mechanical Biological Treatment (MBT) then incineration cell before landfilling

This scenario comprises two (2) major sections that contribute in the recovery of the recyclable materials from the waste stream and the diversion of a significant volume of waste from being landfilled. These sections are:

i. The waste goes through a mechanical biological treatment (MBT) facility where processes such as mechanical sorting, pre-treatment and biological treatment occur. It is assumed that 50% of the incoming waste is recovered. This percentage is obtained from literature (Stanisavljevic and Brunner, 2014).
ii. The second section involves the incineration facility where 70% of the waste from the mechanical biological treatment facility is further burned. This percentage is also obtained from literature (Stanisavljevic and Brunner, 2014).

In terms of implementing this approach on Robinson Deep landfill, it would involve a significant capital investment in establishing the two facilities. However, the existing material recovery facility as well as the composting area can be upgraded to attain a form of mechanical biological treatment facility in order to reduce the total cost. This approach has major significant land saving potential as is analyzed below. The introduction of the combination of the MBT facility and the incineration facility on site would make a significant difference when comparing it with the status quo as well as scenarios 1, 2 and 3.

Figure 5.17 depicts the graphical representation of this approach where similar to scenarios 1, 2 and 3 as well as the status quo, the total waste getting into the site for the 3 year time-frame is approximately 4,070,000,000 kg. After the waste undergoes the MBT and the incineration processes, an estimated 3,470,000,000 kg of the waste is diverted away from being landfilled, while an approximate of 600,000, 000 kg eventually gets landfilled within this time frame. This equates to an estimated 85% of the total waste getting into the landfill being diverted from burial. It can be deduced that with this approach, an additional 60% of the status quo value of waste material is diverted from being landfilled as compared to the statuo quo value where an average of about 25% is diverted from being landfilled. Similarly, in Figure 5.18, the total waste entering the landfill excluding the spike period remains 1,600,000,000 kg. From this scenario, an approximation of 1,350,000,000 kg waste materials is diverted from being landfilled while about 250,000,000 kg waste materials is actually landfilled. This results to a ratio of waste materials being landfilled to that diverted from landfill to be 0.18:1. Similarly, this results to 85% of the total waste getting to the landfill has been diverted from being buried.

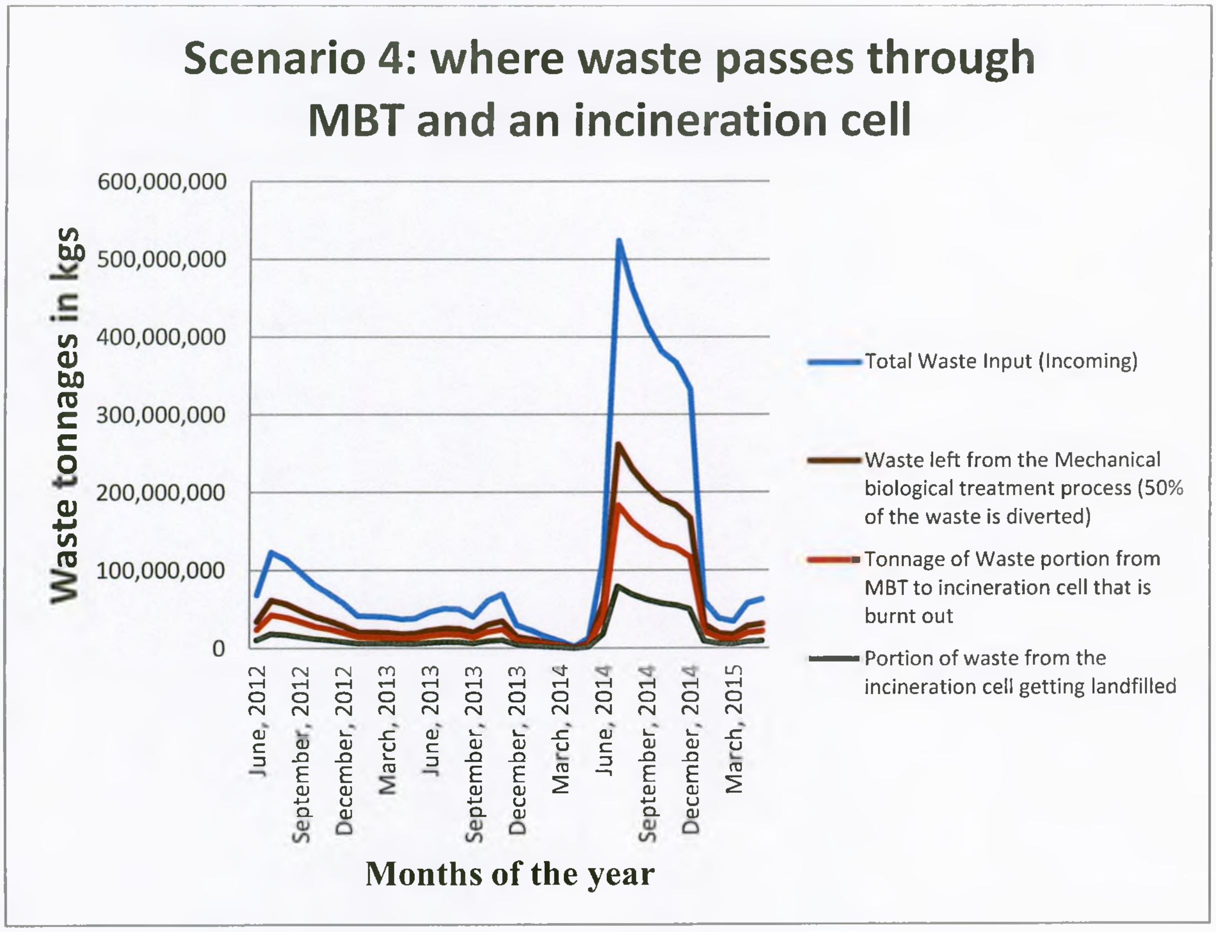


Figure 5.17: Scenario 4 – Waste passes through MBT and an incineration cell

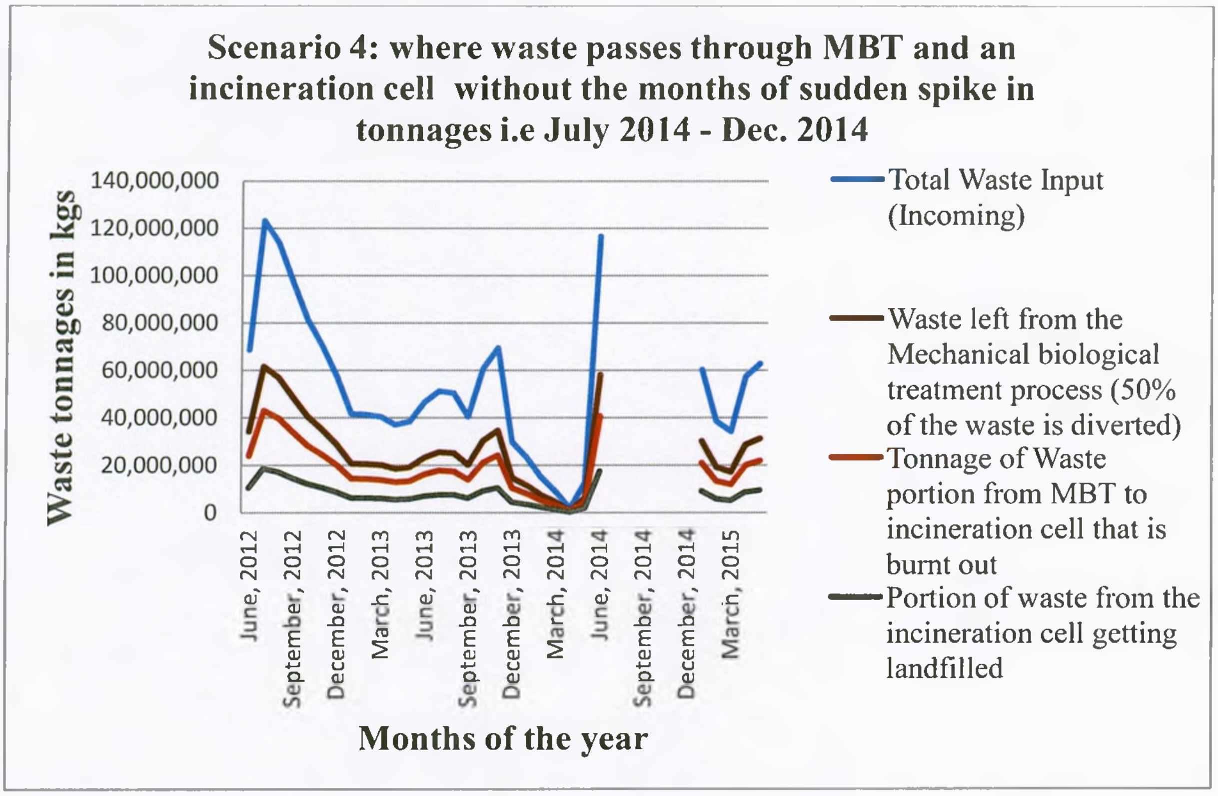


Figure 5.18: Scenario 4 – Waste passes through MBT and an incineration cell without the months of sudden spike in tonnages i.e. July 2014 – Dec 2014

In terms of the environmental impact and achieving global best practice, this study presents a brief discussion on mechanical biological treatment processes. This scenario assumes there is energy recovery from the incineration facility. According to the literature reviewed, an advantage of the energy recovery process leads to the reduction of greenhouse gases and other pollutants (Paulas et al., 2010 and Psomopoulos et al., 2009).

According to a report by DEFRA (2013), MBT is a generic term for an integration of different waste management processes and technologies such as the material recovery facilities and composting processes. As the name implies, MBT involves both mechanical and biological treatment processes. These technologies are pre-treatment technologies which contribute to the diversion of the waste from landfilling especially when operated as part of a wider integrated waste management system. Several studies (Molleda and Lobo, 2010; DEFRA, 2013) have suggested that MBT is an environmentally sound way of diverting the municipal solid waste from being landfilled. According to Modella and Lobo (2010), MBT process cause a significant reduction in landfill gas emission as a result of the shortened degradation phase involved. The study presents a graphical representation of the reduction of biogas (landfill gas) with time.

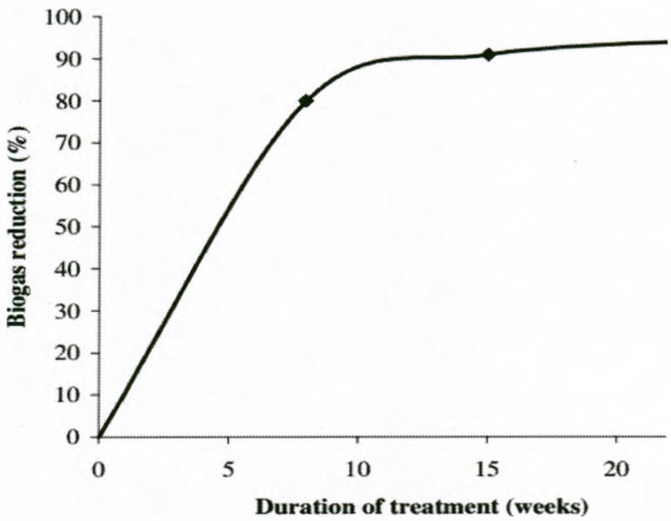


Figure 5.19: Reduction of biogas potential as a function of the duration of the forced aeration treatment involved in MBT (source: Modella and Lobo, 2010).

It is therefore safe to say that MBT is an environmentally sound process and hence would aid in reducing the negative effects landfilling has on the health of humans and the environment.

The major processes involved in a MBT technology are:

a) The pre-treatment of waste
b) Diversion of non-biodegradable and biodegradable waste through sorting of the recyclable waste materials mechanically
c) Stabilisation into a biodegradable waste with a compost-like output
d) Converting emissions into a combustible biogas which can be harnessed for energy recovery.

A holistic representation of this approach is depicted in Figure 5.20

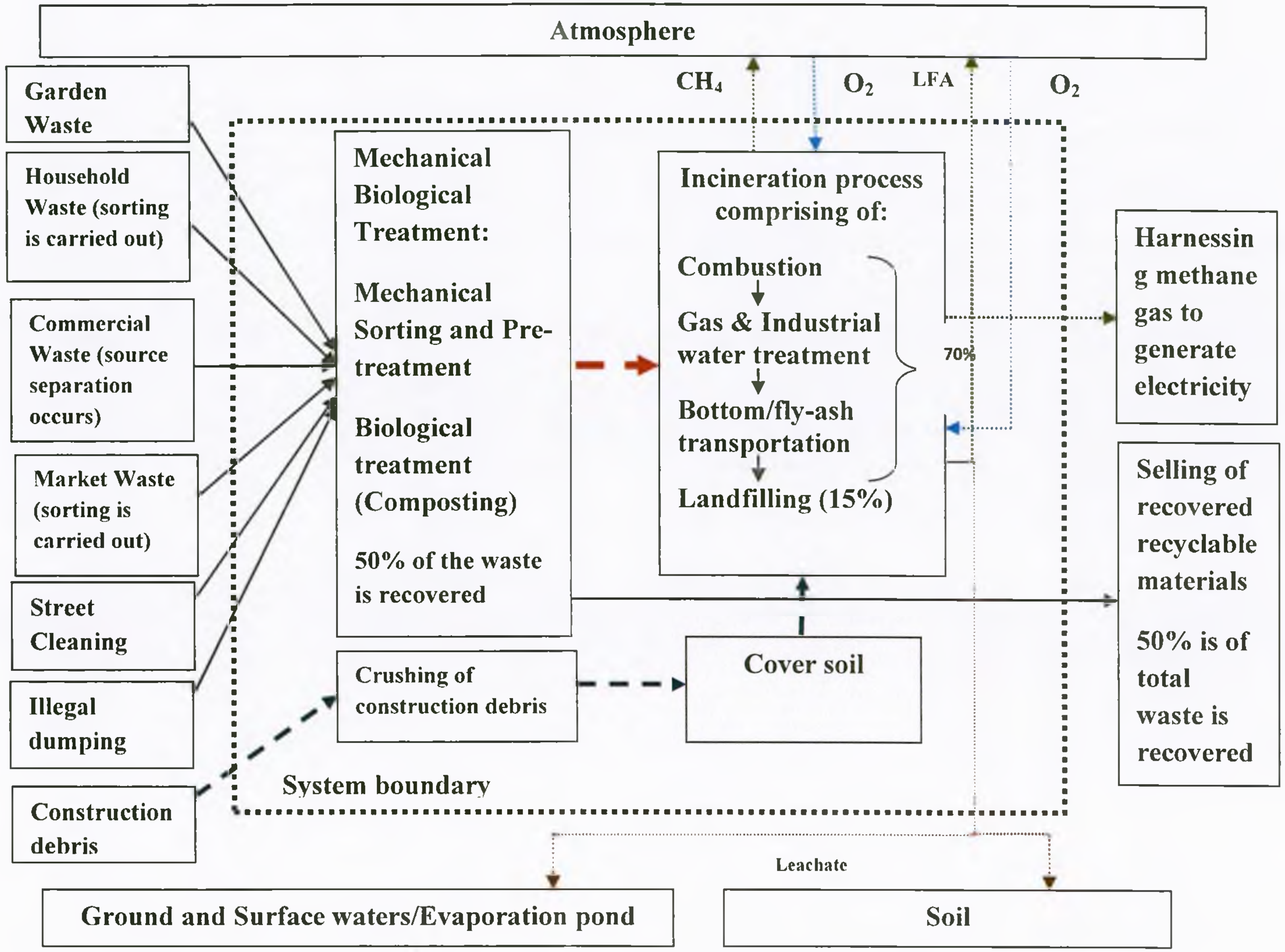


Figure 5.20: A holistic representation of scenario 4

Table 5.2: Summary of all scenarios in comparison to the status quo

	Approximated Ratio of waste landfilled to waste recycled	Speculated number of years of the landfill to reach full capacity	Compliance with global best practice				Cost implication
			A	B	C	D	
Status Quo	2.5 : 1	7 years	Below average	Average	Poor	Average	Average
Scenario 1	0.9 : 1	14.8 years	Average	Average	Poor	Above average	Average
Scenario 2	0.3 : 1	21 years	Good	Good	Poor	Above average	High
Scenario 3	0.24 : 1	22 years	Average	Good	Good	Above average	High
Scenario 4	0.18 : 1	24 years	Above average	Good	Good	Above average	High

i. A represents the conservation of resources (materials, energy and space).
ii. B represents the minimization of landfill space by adopting certain waste pre-treatment process before it is landfilled.
iii. C represents the utmost use of waste-to-energy process which involves utilizing the energy content of waste to cut down the fossil fuel consumption and corresponding emissions.
iv. D represents ensuring no harmful impact of landfill emissions on the human health and the eco-system.

5.3 Discussion

From Table 5.2, it can be seen that as regards the degree of compliance with global best practice, scenario 4 shows the highest degree of compliance in comparison to the status quo and the other scenarios. However, in the South African context, scenarios 1 and 2 exhibit significant degree of compliance. Although certain areas such as adopting the waste-to-energy process would ensure a cut down of fossil fuel consumption as well as harnessing the landfill emissions.

This study has made some speculations regarding when the landfill would likely attain full capacity based on the scenarios developed. These speculations are based on information acquired from the landfill manager who suggests that based on the business as usual operations on the landfill (without sudden spike in waste tonnages); the landfill is expected to attain full capacity in the next seven years. Hence, in order to speculate the time span to attain full capacity for the scenarios developed, this study adopts a simple algebraic equation of ratios and proportions. The mathematical expression starts from the year 2015 when normal business resumed after the sudden spike in waste tonnages.

Scenario 1

With this new recycling rate which is assumed commences from 2015, simple mathematical expression can be used to speculate an estimated number of years that the landfill would take to attain its full capacity. Equation 6 depicts this:

At 25% recycling rate (business as usual/status quo), it takes the site: 7years to attain full capacity, therefore:

$$25\% = 7\ years$$

$$53\% = x\ years$$

Cross-multiplying gives: $$x = \frac{0.53 \times 7 \text{ years}}{0.25}$$

$$x = 14.8 \text{ years} \qquad \text{Equation (6)}$$

Scenario 2

Applying the mathematical expression as in scenario 1, at the current rate of material recovery on site, it will take an estimated seven (7) years to attain full capacity which is 2022. Conversely, with this approach it is speculated to take approximately twenty-one (21) years to attain full capacity. The mathematical expression is given in Equation 7.

At 25% rate (business as usual/status quo), it takes the site: 7years to attain full capacity, therefore:

$$25\% = 7\ years$$

$$75\% = x\ years$$

Cross-multiplying gives: $$x = \frac{0.75 \times 7\ \text{years}}{0.25}$$

$$x = 21\ \text{years} \qquad \text{Equation (7)}$$

Scenario 3

It can be further deduced that with this approach, it is speculated to take the landfill approximately twenty-two (22) years to attain full capacity as compared to the estimated seven (7) years for the status quo. The mathematical expression that was used to derive this figure is given in Equation 8.

At 25% rate (business as usual/status quo), it takes the site: 7years to attain full capacity, therefore:

$$25\% = 7\ years$$

$$80\% = x\ years$$

Cross-multiplying gives: $$x = \frac{0.80 \times 7\ \text{years}}{0.25}$$

$$x = 22\ \text{years} \qquad \text{Equation (8)}$$

Scenario 4

Applying the mathematical expression, at the current rate of material recovery on site, it will take approximately seven (7) years to attain full capacity while with this approach, it is speculated to take approximately twenty-four (24) years to attain full capacity. The mathematical expression that was used to derive this figure is given in Equation 9.

At 25% rate (business as usual/status quo), it takes the site: 7years to attain full capacity, therefore:

$$25\% = 7\ years$$

$$85\% = x\ years$$

Cross-multiplying gives: $$x = \frac{0.85 \times 7\ \text{years}}{0.25}$$

$$x = 24\ \text{years} \qquad \text{Equation (9)}$$

A cost-benefit analysis through a life-cycle assessment of the landfill can be carried out by the waste practitioners and decision makers to evaluate the viability of adopting this option. It is stated once again that these projections as to when the landfill would attain full capacity are speculations based on simple mathematical expressions. In reality, there are certain factors (natural or man-caused) that could change the pattern of things.

From Table 5.2, it can be deduced that all scenarios (1 – 4) perform much better with the goals of waste management in comparison with the status quo. In particular, scenario 4 which has a functioning MBT and waste to energy technology performs significantly well in diverting most of the hazardous and valuable substances and materials to the appropriate sinks and recycling processes. This scenario however does not encourage the public's social responsibility of recycling their waste as most of the waste would be handled at the end-point of the waste stream.

In terms of realistic approaches to adopt, scenario 1 can be said to be easy to implement as it involves moderate capital investment in upgrading the existing system to achieve a doubled rate of material recovery. And with the current plan of implementing an energy recovery initiative, this would ensure an acceptable integrated waste management system which would not strain the allocated capital investment excessively. This scenario also improves the negative human and environmental impact. Similarly to scenario 4, this approach would not improve the public's social responsibility of handling and recycling their waste.

Scenario 2 is an elaborate approach as it requires the nation's waste management bodies to work in unison in achieving the zero to landfill initiative which in the context of this research involves extracting all recyclable materials off the waste stream. Results show that the initiative has high land saving potentials and it is an environmentally responsible approach. Moreover, it would improve the public's social responsibility of handling and recycling their waste, which as documented in literature would improve the livelihood of the nation at large, particularly in the developed countries. In the context of South Africa however, with a high GINI coefficient (a measure of statistical dispersion representing the distribution of income of a nation's residents, which is usually synonymous to the measure of inequality), this approach seems not to be the most efficient as the largest generators of recyclable waste materials are the more affluent people of the society which constitutes a very small percentage of the nation. A sort at landfill managed in a controlled environment by contrast, provides employment for the low skilled citizens as has been experienced in other developing countries. In Curatiba, Brazil, the recyclable waste is sorted in a central facility which proved to be effective and allowed many local communities manage their local resources in a sustainable manner (WWF, 2012).

Another setback to this approach in the South African context is that it would involve a high capital investment to set it up nation-wide although the benefits of a successful implementation vast out-weigh the initial investment. In New-Zealand and major developed countries, this approach as shown higher recovery rates and improved social behaviour as regards solid waste management (Snow and Dickinson, 2001). Narrowing it down to individual landfills, it would be a minimal capital investment as a significant portion of material recovery and sorting would have been done at the point of generation.

Implementing scenario 3 on Robinson Deep landfill would also be a relatively high capital investment due to the fact that an incineration facility would need to be established. Upgrading the MRF would not be as capital intensive as establishing a new one. Results also show that the combination of these technologies has high land saving potentials and its degree of environmental effectiveness depends mainly on the incineration technology being adopted. In terms of improving social responsibility of the public regarding handling waste, this approach encourages recycling to some level with at least 10% sorting of waste at the point of generation.

A sensitivity analysis could not be carried out on these scenarios as actual cost values have not been allocated to the respective scenarios within the parameters of this research report. Moreover, values for the status quo could not be obtained as such data was classified as sensitive and therefore withheld by the landfill manager.

Chapter Six

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The present study has demonstrated that it is possible to link material flow analysis (MFA) to model the flows of goods (waste materials) through a waste management system in a comprehensive manner. It also serves as a powerful tool to support waste management decisions when combined with additional evaluation methods. A holistic outlook of MFA was applied for the purpose of analyzing the solid waste stream that gets into Robinson Deep landfill. MFA is based on the law of conservation of matter, hence no material flows can get 'lost'. All inputs into the system such as all composition of the waste stream are tracked to the outputs of the waste management system. However, the quality of the output is only a reflection of the quality of the input data. Hence, limited input data tends to produce limited output. This was achieved by identifying and classifying waste materials into categories based on their source of generation, then quantifying these waste materials. The waste material flow is framed in the context of the fate of the material. The results of the scenario analysis carried out support what is found in literature.

This study also unequivocally supports what the literature says on the main objectives of modern solid waste management which are to protect the health of humans and the environment, preserve natural (renewable and non-renewable) resources and to develop an orientation towards treating or preferably minimizing the waste that is eventually discarded to the landfill. Hence, in order to develop a sustainable integrated solid waste management system, these are the priority factors to guide decision-makers. This study views sustainability in solid waste management as covering 3 main aspects: the social aspect: ensuring that the public are conscious of their waste through the practice of sorting and recycling of their waste; environmental aspect by minimising negative impacts on the health of humans and the environment such as reducing the landfill's gas emissions; and the economic aspects through ensuring that waste management practices regenerate income and provide employment opportunities. From this study, it is found that it is important for countries to support sustainable solid waste management through their legislation and policies. The South African legislation (Municipal System Act No. 32, 2000) supports sustainability of solid waste management but would need to revise these legislation and policies to more aggressive ones to be able to meet its objectives of the Polokwane Declaration in 2001.

The main sources of waste generators in the City of Johannesburg are similar to those found in major cities of the world; they are from households, commercial and educational institutions, construction and manufacturing industries, market centres and city parks. The study was also able to determine the composition of waste deposited on landfill sites and the ratio of materials that was recovered. It was found that household and commercial contained a lot of recyclable materials such as paper, cardboard boxes, plastics, wood, glass and metal materials. It also constitutes the majority of the waste category getting into the landfill.

A three year data set of monthly waste tonnages getting into the landfill was obtained. In this data set, there appeared to be a sudden spike in the months of July, 2014 to December, 2014 as regards the waste tonnages getting into the landfill. It was attributed to the unusual closure of other landfill sites in the Johannesburg region due to operational upgrade and maintenance of the landfills. Hence, analysis of data considered the 3 year data set without the spike in tonnages and the data set that includes the spike period. The MFA carried out on Robinson Deep Landfill provides a characterization by type and monthly tonnages of the solid waste accumulation. This information would be essential in future for waste managers and decision makers as it provides a long-term inventory of potential resources that could be recovered in the form of recyclable materials and energy recovery.

This study presents the machine learning tool to make future projections on waste trends through learning from the historic waste data trends. However, in order to ensure reliable future projections, a historic data set of over 20 years would be required especially in a situation like the one seen in this study where there is an irregular distortion (spike in waste tonnages getting to the landfill) in the data set. The historic data would allow the machine learning process to treat such distortions independently if such distortions rarely occur, or in a situation where this distortion happens occasionally, the machine learning process would factor in these distortions in its future projections. This aspect of forecasting future waste pattern would prove valuable for waste managers and decision makers in planning and designing strategic sustainable solutions to tackle matters of the City's waste. It is particularly a valuable tool that can be applied to all of the landfill sites across a municipality; it would account for or make possible projections of all upgrades, closures and other dynamics associated with the management of landfills. Moreover, it is able to make reliable plot trends in waste generation and mitigation measures if and when they are implemented.

The study developed four scenarios which were derived from the literature on possible solid waste management practices which can be adopted on Robinson Deep landfill in order to achieve sustainable practice and extend the life span of the landfill which is speculated to attain full capacity in the next seven years (2022). These scenarios were developed on the platform of conservation of resources (materials, energy and space), minimization of landfill space by adopting certain waste pre-treatment process before landfilling, the utmost use of waste to energy process which involves utilizing the energy content of waste to cut down the fossil fuel consumption and corresponding emissions and to ensure no negative impact of landfill emissions on the human health and the environment. In designing these scenarios, it was important to investigate the status quo critically in order to access which scenario to choose based on deficiencies of the status quo.

Results from the scenario analysis show that all scenarios perform better than the status quo as compared with the goals of waste management. Of particular interest to this study are scenarios 2, in which all recyclable materials are extracted before landfilling and scenario 4, where waste passes through MBT and an incineration cell. Figures from the analysis show that scenario 4, which is a sustainable integrated solid waste management practice, is able to divert 85% of the total incoming waste from being landfilled. Speculations from the author's algebraic equation also show that if the system were adopted in the year 2015, it would be capable of extending the life span of the landfill by 24 years. This scenario however does not encourage the public's social responsibility of recycling their waste as most of the waste would be handled at the end-point of the waste stream. It also involves high capital investment to establish such a system on the current landfill which may not be practicable, given the age and remaining capacity of this particular site.

Scenario 2 however would be recommended as the most promising option as it covers a spectrum of sustainable solid waste management practice. This scenario addresses the *zero to* *landfill* initiative and results show that this practice would be able to successfully divert 75% of the total waste produced from being landfilled. Also, speculations from the author's algebraic equation show that this scenario is implemented by 2015, it is capable of extending the life span of the landfill by 21 years. This option would also involve high capital investment and dedication to ensure a successful implementation as this would involve nationwide awareness campaigns on solid waste management. However, the benefits of this approach far outweigh the initial investments. Of particular interest would be its capability of making the nation socially responsible in handling and recycling their waste from an individual level up to provincial levels. Finally, it can be concluded that this scenario ensures that the three aspects of sustainability in solid waste management – social, environmental and economical - is achieved.

All scenarios except scenario 1 do not seem to be realistically feasible in terms of applicability to Robinson Deep landfill as 7 years is too limited to implement such elaborate measures and justify the associated investment. The knowledge of these more elaborate measures however would prove valuable for future designs of waste management systems and for landfill sites with longer anticipated lifespan.

6.2 Recommendations

Recommendations are based on the research problem which is rephrased as thus: ***"does the current situation of landfill sites around the City of Johannesburg appear to practice global best sustainable integrated solid waste management"?*** This research finds that after extensive site visits and desktop study on waste management practices across Johannesburg, the level of global best practice is currently on a minimum level. With this said, this study proffers some recommendations to improve the practices at this landfill to align with the level of global best practice.

1. It is recommended that waste management authorities make use of data sets of existing studies and improve these data sets by collecting and maintaining local data sets as a base for their waste management decisions.

2. As regards the scenario to adopt, this study would recommend scenario 2, in which all recyclable materials are extracted before landfilling. This option proves to have significant benefits which would compensate for the necessary investments.
3. It is recommended that *zero waste to landfill* initiative be aggressively pursued and not just as ambitious propaganda promoted by politicians. In order to achieve this, the South African government have to make major amendments to the existing solid waste management legislation and policies. The legislations and policies should be based on these principles:
    - End cheap waste disposal,
    - Design waste out the system, and
    - Engage the nation.
4. Key stakeholders and role-players ought to be actively involved in achieving the successful implementation of waste management legislation and policies. Such key players are the central government, the regional government, local government, industrial designers, manufacturers, secondary material handlers, importers, universities, schools and households
5. There should be functional MRFs in all landfill sites with adequate staffs to ensure that all recyclable materials are recovered before the remaining waste is landfilled. In these landfills, stockpiling of resources on site should be enforced to ensure that buyers are found, hence sufficient space must be allocated for this purpose.

6.2.1 Recommendations for further study

i. Further studies in tracking the municipal solid waste from the point generation to the point it is landfilled or recycled using MFA for the whole City of Johannesburg.

ii. Further studies on MFA on all landfills in the Gauteng province should be carried out in order to ascertain a holistic perspective of the flow of the solid waste stream in landfills in the province.

iii. Further studies on MFA and Machine Learning Application on the City's waste flow with focus on data availability, reliability and uncertainty to forecast future waste flow patterns.

iv. Further studies on a qualitative study and analysis of input data and reflection on human element in the waste stream.

v. Further studies on statistical reconstruction of existing data earlier than mid 2012.

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APPENDIX: A

Figure A1: Robinson Deep well station

Figure A2: Robinson Deep gas flaring station

Figure A3: Robinson Deep evaporation dam

Figure A4: Robinson Deep composting section showing various chippings

Figure A5: A concrete crushing plant on Robinson Deep

Figure A6: Sorting of waste according to waste category

Figure A7: Robinson Deep material recovery facility

APPENDIX: B

Table B1: Learning algorithm and probability values for the waste data over the 3 year data

Waste Category	Time frame	Probability of increase	Probability of decrease	Min possible value	Max possible value
Waste After 12h00 Sat., Sun. and Public Holidays	Jan – Feb	0.00	1.00	1545300.00	3249193.00
	Feb – Mar	0.00	1.00	1345280.00	2410080.00
	Mar – Apr	0.67	0.33	383040.00	1748850.00
	Apr – May	0.67	0.33	319049.00	2941315.00
	May – Jun	1.00	0.00	583440.00	2280900.00
	Jun – Jul	1.00	0.00	2425460.00	10431606.00
	Jul – Aug	0.00	1.00	2723400.00	29971135.00
	Aug – Sep	0.00	1.00	1630140.00	25337945.00
	Sep – Oct	0.33	0.67	1141860.00	22420935.00
	Oct – Nov	0.00	1.00	2885940.00	20487155.00
	Nov – Dec	0.00	1.00	1614200.00	18631245.00
	Dec - Jan	0.00	1.00	1588700.00	17166475.00
Builder rubble (clean)	Jan – Feb	0.67	0.33	38260.00	1004660.00
	Feb – Mar	0.33	0.67	130800.00	774458.00
	Mar – Apr	1.00	0.00	6680.00	1909808.00
	Apr – May	0.33	0.67	98960.00	5182345.00
	May – Jun	1.00	0.00	157202.00	167330.00
	Jun – Jul	1.00	0.00	50800.00	3330400.00
	Jul – Aug	0.00	1.00	4000180.00	17193303.00
	Aug – Sep	0.00	1.00	3500160.00	16278643.00
	Sep – Oct	0.00	1.00	3110070.00	15710593.00
	Oct – Nov	0.33	0.67	2692680.00	15403922.00
	Nov – Dec	0.00	1.00	3459090.00	15312402.00
	Dec - Jan	0.00	1.00	1100230.00	15021912.00
Builders rubble (mixed/rock)	Jan – Feb	0.67	0.33	7180.00	140100.00
	Feb – Mar	0.67	0.33	9760.00	133430.00
	Mar – Apr	0.67	0.33	12900.00	123103.00
	Apr – May	1.00	0.00	15670.00	386908.00
	May – Jun	0.50	0.50	26980.00	32640.00
	Jun – Jul	1.00	0.00	11280.00	465170.00
	Jul – Aug	0.33	0.67	1360421.00	5214820.00
	Aug – Sep	0.00	1.00	1252121.00	7001420.00
	Sep – Oct	0.33	0.67	726300.00	3555900.00
	Oct – Nov	0.00	1.00	1194861.00	3200980.00
	Nov – Dec	0.00	1.00	963880.00	2100865.00
	Dec - Jan	0.00	1.00	338420.00	1166941.00
Compacted refuse	Jan – Feb	0.67	0.33	152560.00	456520.00
	Feb – Mar	0.33	0.67	102720.00	500930.00
	Mar – Apr	0.67	0.33	49960.00	591100.00
	Apr – May	1.00	0.00	150700.00	508160.00
	May – Jun	0.50	0.50	235560.00	545788.00
	Jun – Jul	1.00	0.00	64480.00	1291230.00
	Jul – Aug	0.33	0.67	317500.00	5233470.00
	Aug – Sep	0.00	1.00	405280.00	4575470.00
	Sep – Oct	0.67	0.33	264440.00	3985810.00
	Oct – Nov	0.33	0.67	371740.00	3480260.00

	Nov – Dec Dec - Jan	0.00 0.00	1.00 1.00	417120.00 194460.00	3172120.00 2551330.00
Container service	Jan – Feb Feb – Mar Mar – Apr Apr – May May – Jun Jun – Jul Jul – Aug Aug – Sep Sep – Oct Oct – Nov Nov – Dec Dec - Jan	0.33 0.33 0.33 1.00 0.50 0.67 0.00 0.33 0.33 0.00 0.00 0.00	0.67 0.67 0.67 0.00 0.50 0.33 1.00 0.67 0.67 1.00 1.00 1.00	591480.00 423131.00 380920.00 80200.00 410360.00 894460.00 610580.00 552540.00 714420.00 1056160.00 831720.00 610340.00	6254809.00 2983920.00 2852220.00 5490160.00 1200650.00 5024736.00 38639829.00 36345979.00 34687309.00 33715689.00 33239919.00 31069459.00
Cover soil	Jan – Feb Feb – Mar Mar – Apr Apr – May May – Jun Jun – Jul Jul – Aug Aug – Sep Sep – Oct Oct – Nov Nov – Dec Dec - Jan	0.67 0.67 0.67 0.67 1.00 1.00 0.00 0.67 0.33 0.33 0.00 0.00	0.33 0.33 0.33 0.33 0.00 0.00 1.00 0.33 0.67 0.33 1.00 1.00	237260.00 159980.00 14020.00 79240.00 20600.00 106600.00 5888348.00 5722788.00 5697308.00 4000780.00 3290220.00 1111829.00	1675315.00 700638.00 1533940.00 1123160.00 501230.00 10266660.00 12174080.00 11329740.00 13073320.00 16053140.00 21373480.00 5573028.00
Dailies	Jan – Feb Feb – Mar Mar – Apr Apr – May May – Jun Jun – Jul Jul – Aug Aug – Sep Sep – Oct Oct – Nov Nov – Dec Dec - Jan	0.33 0.33 0.00 0.67 1.00 0.67 0.67 0.33 0.33 0.00 0.00 0.00	0.67 0.67 1.00 0.33 0.00 0.33 0.33 0.67 0.67 1.00 1.00 1.00	144300.00 58120.00 39900.00 7320.00 42180.00 368580.00 106840.00 200700.00 244440.00 371140.00 322560.00 218660.00	447020.00 305209.00 408420.00 304980.00 298060.00 804530.00 2346100.00 2001180.00 1657240.00 1468620.00 1395980.00 1265380.00
Dry industrial uncompacted non-SW	Jan – Feb Feb – Mar Mar – Apr Apr – May May – Jun Jun – Jul Jul – Aug Aug – Sep Sep – Oct Oct – Nov Nov – Dec Dec - Jan	0.33 0.67 0.67 1.00 1.00 0.67 0.00 0.33 0.00 0.33 0.33 0.67	0.67 0.33 0.33 0.00 0.00 0.33 0.67 0.33 0.67 0.33 0.33 0.33	3007.00 2060.00 1525.00 540.00 2000.00 5000.00 6200.00 3040.00 1560.00 420.00 1800.00 3110.00	10110.00 9800.00 10600.00 11110.00 11300.00 12580.00 12500.00 9500.00 9900.00 9500.00 9500.00 9500.00

Garden refuse (mixed)	Jan – Feb	0.00	1.00	2955880.00	9776650.00
	Feb – Mar	0.00	1.00	1713340.00	6579430.00
	Mar – Apr	0.33	0.67	1260900.00	5307240.00
	Apr – May	0.67	0.33	164760.00	8354090.00
	May – Jun	0.50	0.50	1242900.00	3560770.00
	Jun – Jul	0.67	0.33	2130900.00	19342879.00
	Jul – Aug	0.00	1.00	2000440.00	90013050.00
	Aug – Sep	0.00	1.00	1975960.00	78986020.00
	Sep – Oct	0.67	0.33	1860860.00	69406120.00
	Oct – Nov	0.67	0.33	2999800.00	62765619.00
	Nov – Dec	0.33	0.67	4010760.00	59829669.00
	Dec - Jan	0.33	0.67	3018000.00	52988378.00
Illegal dumping	Jan – Feb	0.00	1.00	1090840.00	5403660.00
	Feb – Mar	0.00	1.00	772840.00	3377681.00
	Mar – Apr	0.67	0.33	444240.00	2428578.00
	Apr – May	0.67	0.33	28040.00	3191260.00
	May – Jun	1.00	0.00	389250.00	1529820.00
	Jun – Jul	1.00	0.00	1580240.00	3719974.00
	Jul – Aug	0.67	0.33	1750080.00	28459806.00
	Aug – Sep	0.00	1.00	2084340.00	26800456.00
	Sep – Oct	0.33	0.67	1532440.00	25671666.00
	Oct – Nov	0.00	1.00	2536420.00	25057636.00
	Nov – Dec	0.00	1.00	2087280.00	24892515.00
	Dec - Jan	0.00	1.00	1277700.00	23949735.00
Market	Jan – Feb	0.33	0.67	1220.00	3820808.00
	Feb – Mar	0.33	0.67	27770.00	2588560.00
	Mar – Apr	1.00	0.00	5060.00	1610950.00
	Apr – May	1.00	0.00	51980.00	2025310.00
	May – Jun	1.00	0.00	65440.00	100890.00
	Jun – Jul	0.67	0.33	131600.00	2090760.00
	Jul – Aug	0.33	0.67	120800.00	16001958.00
	Aug – Sep	0.00	1.00	149320.00	15717118.00
	Sep – Oct	0.00	1.00	110090.00	15532868.00
	Oct – Nov	0.00	1.00	94660.00	15326818.00
	Nov – Dec	0.33	0.67	52800.00	15233438.00
	Dec - Jan	0.00	1.00	25570.00	14902808.00
Round collected refuse	Jan – Feb	0.00	1.00	11361680.00	21705950.00
	Feb – Mar	0.00	1.00	8500570.00	20986540.00
	Mar – Apr	0.33	0.67	5073500.00	20305850.00
	Apr – May	1.00	0.00	587020.00	18579500.00
	May – Jun	0.50	0.50	8121841.00	19777430.00
	Jun – Jul	0.67	0.33	19728090.00	58504424.00
	Jul – Aug	0.00	1.00	17959900.00	188639834.00
	Aug – Sep	0.00	1.00	17472540.00	154406154.00
	Sep – Oct	0.33	0.67	13926880.00	131313034.00
	Oct – Nov	0.33	0.67	23101020.00	113421743.00
	Nov – Dec	0.00	1.00	24500300.00	106759532.00
	Dec - Jan	0.00	1.00	14111120.00	92726392.00

Street cleaning	Jan – Feb	0.00	1.00	925080.00	3427868.00
	Feb – Mar	0.33	0.67	505040.00	2079200.00
	Mar – Apr	0.33	0.67	286370.00	1721009.00
	Apr – May	0.67	0.33	23980.00	2729526.00
	May – Jun	1.00	0.00	217210.00	990230.00
	Jun – Jul	0.67	0.33	993320.00	3862926.00
	Jul – Aug	0.33	0.67	797840.00	22893303.00
	Aug – Sep	0.00	1.00	999620.00	21207163.00
	Sep – Oct	0.33	0.67	960460.00	19648393.00
	Oct – Nov	0.00	1.00	1556560.00	18881723.00
	Nov – Dec	0.00	1.00	1309820.00	18495043.00
	Dec - Jan	0.33	0.67	903940.00	17057417.00
Uncompacted – Non solid waste	Jan – Feb	0.33	0.67	1694240.00	9811397.00
	Feb – Mar	0.33	0.67	1217180.00	7720730.00
	Mar – Apr	0.33	0.67	1062980.00	8235398.00
	Apr – May	1.00	0.00	168320.00	10473453.00
	May – Jun	0.50	0.50	1197140.00	7560450.00
	Jun – Jul	0.67	0.33	3999600.00	11055428.00
	Jul – Aug	0.00	1.00	3602740.00	77406027.00
	Aug – Sep	0.00	1.00	3273720.00	72156757.00
	Sep – Oct	0.33	0.67	2880400.00	67791407.00
	Oct – Nov	0.33	0.67	4678358.00	64595007.00
	Nov – Dec	0.00	1.00	5128620.00	63104697.00
	Dec - Jan	0.00	1.00	2297040.00	57902754.00
Destruction foodstuff/non Pikitup	Jan – Feb	0.00	0.33	12000.00	15460.00
	Feb – Mar	0.00	0.33	11006.00	15460.00
	Mar – Apr	0.33	0.00	10020.00	15460.00
	Apr – May	0.33	0.00	10100.00	15460.00
	May – Jun	0.00	0.00	11500.00	15460.00
	Jun – Jul	0.33	0.33	11010.00	15460.00
	Jul – Aug	0.33	0.00	11500.00	12000.00
	Aug – Sep	0.00	0.33	11500.00	12000.00
	Sep – Oct	0.00	0.33	11500.00	12000.00
	Oct – Nov	0.67	0.00	9500.00	12000.00
	Nov – Dec	0.00	0.33	12000.00	15460.00
	Dec - Jan	0.00	0.33	12000.00	15460.00

APPENDIX: C

Code Listing:

```
Imports Excel = Microsoft.Office.Interop.Excel
Imports System.IO
Imports System.Text.Encoding
Imports System.Text

Public Class Form1

    Private Structure pageDetails
        Dim columns As Integer
        Dim rows As Integer
        Dim startCol As Integer
        Dim startRow As Integer
    End Structure
    ''' <summary>
    ''' dictionary to hold printed page details, with index key
    ''' </summary>
    ''' <remarks></remarks>
    Private pages As Dictionary(Of Integer, pageDetails)

    Dim maxPagesWide As Integer
    Dim maxPagesTall As Integer

    Public Shared Function LoadCompleteData() As DataTable
        Dim dt As DataTable

        'read lookuptable
        dt = EXCEL_MANIPULATIONS.readDataFromExcel("c:\ope\data.xlsx", 1, 2, 37, 1, 16)

        Return dt
    End Function
    Public Shared Function LoadWorkingData() As DataTable
        Dim dt As DataTable

        'read lookuptable
        dt = EXCEL_MANIPULATIONS.readDataFromExcel_WithMonthSep("c:\ope\data.xlsx", 1, 2, 37,
1, 18)

        Return dt
    End Function
    Private Sub btnLoadData_Click(sender As Object, e As EventArgs) Handles btnLoadData.Click
        Me.DataGridView1.DataSource = LoadWorkingData()
    End Sub

    Private Sub btnComputePrbs_Click(sender As Object, e As EventArgs) Handles
btnComputePrbs.Click
        'set up names
        Dim allNames(20) As String
        allNames(3) = "After 12h00 Sat., Sun. and Public Holidays"
        allNames(4) = "Builders rubble (clean)"
        allNames(5) = "Builders rubble (mixed/rock)"
        allNames(6) = "Compacted refuse"
        allNames(7) = "Container service"
        allNames(8) = "Cover soil"
        allNames(9) = "Dailies"
        allNames(10) = "Dry Industrial Uncompacted Non SW"
```

```
        allNames(11) = "Garden refuse (Mixed)"
        allNames(12) = "Illegal Dumping"
        allNames(13) = "Market"
        allNames(14) = "Round collected refuse"
        allNames(15) = "Street cleaning"
        allNames(16) = "Uncompacted - non solid waste"
        allNames(17) = "Destruction foodstuff/non pikitup"


        Console.WriteLine("Learning Algorithm Results:")

        Dim rnd As New Random


        Dim mydata As DataTable
        mydata = EXCEL_MANIPULATIONS.readDataFromExcel_WithMonthSep("c:\ope\data.xlsx", 1, 2,
37, 1, 18)

        Dim dt_results As New Generic.List(Of DataTable)

        For cols As Integer = 3 To 17

            Dim learn As New Generic.List(Of Learner)
            Dim pattern As New Generic.List(Of Probailities)


            'iterate through months
            Dim first As Double = 0.0
            With mydata
                For rw As Integer = 0 To mydata.Rows.Count - 1
                    Dim diff As Double = 0
                    Dim second As Double = CDbl(mydata.Rows(rw).Item(cols).ToString)

                    Dim newLearner As New Learner

                    newLearner.thisPoint = first
                    newLearner.nextPoint = second

                    diff = second - first


                    If diff < 0 Then
                        newLearner.flunct = "d"
                    ElseIf diff > 0 Then
                        newLearner.flunct = "i"
                    Else
                        newLearner.flunct = "s"
                    End If

                    newLearner.rate = Math.Abs(diff)

                    'this learning starts from a backward month
                    Dim timeOfYear As Integer = 0

                    If rw = 0 Then
                        timeOfYear = 5
                    Else
                        timeOfYear = CInt(mydata.Rows(rw - 1).Item(1).ToString)
                    End If
```

```
            newLearner.TimeOfYear = timeOfYear

            learn.Add(newLearner)

            first = CDbl(mydata.Rows(rw).Item(cols).ToString)

        Next


    End With

    Dim totalIncrease(13) As Integer
    Dim totalDecrease(13) As Integer

    Dim minVal(13) As Double
    Dim maxVal(13) As Double

    Dim minRateVal(13) As Double
    Dim maxRateVal(13) As Double

    Dim totalDataPoints(13) As Integer
    Dim timeOfYr(13) As Integer

    Dim data_points(13) As Double

    'initialize min and max values
    For k As Integer = 1 To 12
        minVal(k) = 1000000000
        maxVal(k) = 0

        minRateVal(k) = 1000000000
        maxRateVal(k) = 0

        totalDecrease(k) = 0
        totalIncrease(k) = 0
        totalDataPoints(k) = 0
        data_points(k) = 0
    Next

    For Each dt In learn
        With dt
            data_points(.TimeOfYear) = dt.thisPoint

            'If .TimeOfYear = 1 Then
            totalDataPoints(.TimeOfYear) += 1

            'assume this is the lowest val
            If dt.thisPoint < minVal(.TimeOfYear) Then
                minVal(.TimeOfYear) = dt.thisPoint
            Else
                'do nothing
            End If

            'handle max value
            If dt.thisPoint > maxVal(.TimeOfYear) Then
                maxVal(.TimeOfYear) = dt.thisPoint
            Else
                'do nothing
            End If
```

```
            'compute fluntuation prbs
            If dt.rate < minRateVal(.TimeOfYear) Then
                minRateVal(.TimeOfYear) = dt.rate
            Else
                'do nothing
            End If

            If dt.rate > maxRateVal(.TimeOfYear) Then
                maxRateVal(.TimeOfYear) = dt.rate
            Else
                'do nothing
            End If

            'count total increases/decreases
            If dt.flunct = "i" Then
                totalIncrease(.TimeOfYear) += 1
            ElseIf dt.flunct = "d" Then
                totalDecrease(.TimeOfYear) += 1
            End If
            'End If


        End With
    Next

    'displaying values
    Dim rw_count As Integer = 1
    For futureYears As Integer = 2015 To 2022 'for time of the year i
        Dim p As New DataTable

        With p
            .Columns.Add("SN")
            .Columns.Add("MTHYR")

            .Columns.Add("C" & cols.ToString)

        End With


        'create array here that can hold C3 to C17 for year i

        Dim aPrb As New Probailities

        For i As Integer = 1 To 12
            aPrb.TimeOfYear = i
            aPrb.prb_of_increase = totalIncrease(i) / totalDataPoints(i)
            aPrb.prb_of_decrease = totalDecrease(i) / totalDataPoints(i)

            aPrb.forecasted_value = rnd.Next(minVal(i), maxVal(i))
            aPrb.maxVal = maxVal(i)
            aPrb.minVal = minVal(i)


            'determine if it increases or  not

            'project future 5 values ---------------------
            Dim forecast As Double = 0

            Dim i_or_d As String = riseOrFall(aPrb.prb_of_increase)
```

```
                    'get a random rate
                    Dim aRate As Double
                    aRate = rnd.Next(CInt(minRateVal(i)), CInt(maxRateVal(i) + 1))

                    'dim get a random value with min and max
                    Dim aRandValue As Double
                    aRandValue = rnd.Next(minVal(i), maxVal(i) + 1)

                    If i_or_d = "i" Then
                        forecast = aRandValue + aRate
                    ElseIf i_or_d = "d" Then
                        forecast = aRandValue - aRate
                    End If

                    'check if forecast in negative or zero, if so, use random value between
range as forecast
                    If forecast <= 0 Then
                        'this forecast is a worst case scenario, where the random rate is huge
and reduces the random value beyond threshold
                        'so, use random value as forecast

                        forecast = aRandValue
                    End If
                    p.Rows.Add(rw_count, MonthName(i).ToString & ", " & futureYears.ToString,
forecast)
                    rw_count += 1
                    'MsgBox("Future Year " & futureYears.ToString & ", for: " & MonthName(i) &
" Last value was: " & data_points(i) & ", and the forecast is: " & forecast)
                    aPrb.forecasted_value = forecast
                    pattern.Add(aPrb)

                    'now reset this year's value to the forecasted one
                    data_points(i) = forecast

                Next

                p.PrimaryKey = New DataColumn() {p.Columns("SN")}
                dt_results.Add(p)
            Next


        Next

        'create display data table
        Dim display_DT As New DataTable

        Dim rw_kount As Integer = 1

        With display_DT
            'add preceding coloumns
            .Columns.Add("SN")
            .Columns.Add("MTHYR")

            For k As Integer = 3 To 17
                .Columns.Add("C" & k.ToString)
            Next
        End With

        Dim store(20) As Double
```

```
        'initialize store
        For kkkount As Integer = 1 To 20
            store(kkkount) = 0
        Next

        'Dim yr_watch As Integer = 2015
        For yyr As Integer = 2015 To 2022

            For mmth As Integer = 1 To 12
                Dim sstart As Integer = 3
                For j As Integer = 3 To 17
                    Dim thiscolstr As String = "C" & sstart.ToString

                    For Each dtt In dt_results

                        If (dtt.Columns(2).ColumnName = thiscolstr) And (dtt.Rows(mmth -
1).Item(1).ToString = MonthName(mmth) & ", " & yyr.ToString) Then
                            'we are merging this col
                            store(sstart) = dtt.Rows(mmth - 1).Item(2)
                            sstart += 1
                        End If
                    Next
                Next
                'add new roww here
                display_DT.Rows.Add(rw_kount, MonthName(mmth).ToString & ", " & yyr.ToString,
store(3), store(4), store(5), _
                store(6), store(7), store(8), store(9), store(10), store(11), store(12),
store(13), store(14), _
                 store(15), store(16), store(17))
                rw_kount += 1

                're-initialize store
                'maybe?
            Next

        Next
        DataGridView1.DataSource = display_DT
        For rwk As Integer = 1 To DataGridView1.Rows.Count
            DataGridView1.Rows(rwk - 1).HeaderCell.Value = rwk.ToString
        Next
        DataGridView1.RowHeadersWidth = CInt(DataGridView1.RowHeadersWidth * 1.35)
        display_DT.PrimaryKey = New DataColumn() {display_DT.Columns("SN")}
        MsgBox("DONE!")

    End Sub
    Private Sub DATAGRIDVIEW_TO_EXCEL(ByVal DGV As DataGridView)
        Try
            Dim DTB = New DataTable, RWS As Integer, CLS As Integer

            For CLS = 0 To DGV.ColumnCount - 1 ' COLUMNS OF DTB
                DTB.Columns.Add(DGV.Columns(CLS).Name.ToString)
            Next

            Dim DRW As DataRow

            For RWS = 0 To DGV.Rows.Count - 1 ' FILL DTB WITH DATAGRIDVIEW
                DRW = DTB.NewRow

                For CLS = 0 To DGV.ColumnCount - 1
                    Try
```

```
                        DRW(DTB.Columns(CLS).ColumnName.ToString) =
DGV.Rows(RWS).Cells(CLS).Value.ToString
                    Catch ex As Exception

                    End Try
                Next

                DTB.Rows.Add(DRW)
            Next

            DTB.AcceptChanges()

            Dim DST As New DataSet
            DST.Tables.Add(DTB)
            Dim FLE As String = "C:\Ope\XML.xml" ' PATH AND FILE NAME WHERE THE XML WIL BE
CREATED (EXEMPLE: C:\REPS\XML.xml)
            DTB.WriteXml(FLE)
            Dim EXL As String = "C:\Program Files (x86)\Microsoft Office\Office12\" ' PATH OF/
EXCEL.EXE IN YOUR MICROSOFT OFFICE
            Shell(Chr(34) & EXL & Chr(34) & " " & Chr(34) & FLE & Chr(34), vbNormalFocus) '
OPEN XML WITH EXCEL

        Catch ex As Exception
            MsgBox(ex.ToString)
        End Try

    End Sub
```

APPENDIX: D

Table D1: The 3 years dataset

Month/Year	After 12h00 Sat.,Sun. and Pub holidays	Builder rubble (Clean)	Builder rubble (mixed/rock)	Compacted refuse	Container service	Cover soil	Dailies	Dry Industrial uncompacted Non-SW	Garden refuse - mixed	Illegal dumping	Market	Round collected refuse	Street cleaning	Uncompacted non solid waste	Destruction foodstuff/ Non-Pikitup
June, 2012	4,110,010	50,800	20,540	677,850	2,959,590	5,186,630	585,500	12,000	2,130,900	2,650,300	2,090,760	39,115,257	1,600,789	7,608,500	11,010
July, 2012	5,890,520	4,970,560	3,800,750	2,775,480	9,625,200	10,030,214	1,225,470	12,500	2,580,910	15,555,950	9,700,650	40,340,880	3,870,980	12,900,345	11,560
August, 2012	3,501,180	4,379,550	3,650,980	2,530,800	7,400,123	8,920,788	1,340,770	9,500	2,510,890	16,597,800	8,900,610	39,560,770	3,330,442	11,390,690	12,000
September, 2012	3,333,200	4,112,980	3,555,900	2,256,700	5,760,040	9,070,654	1,300,890	9,900	2,390,780	14,700,670	8,580,770	30,320,865	3,210,678	8,567,200	11,900
October, 2012	3,211,150	3,890,600	3,200,980	2,487,090	5,000,762	4,000,780	1,109,021	5,080	2,999,800	12,907,320	4,122,070	28,212,000	2,470,808	7,772,345	9,500
November, 2012	3,009,120	3,459,090	2,100,865	1,998,760	3,970,080	3,290,220	808,444	4,320	4,010,760	7,800,430	3,111,456	26,900,910	2,310,050	7,400,230	15,400
December, 2012	2,918,200	1,100,230	1,000,860	1,210,440	2,566,100	1,111,829	556,700	3,110	4,220,800	4,000,990	3,798,010	25,800,730	2,109,880	7,123,890	14,500
January, 2013	2,634,470	38,260	7,180	456,520	1,366,150	248,800	144,300	3,007	4,325,499	2,430,519	132,280	21,705,950	1,557,230	6,804,470	12,250
February, 2013	2,410,080	130,800	9,760	500,930	1,470,870	330,620	305,209	2,060	4,110,911	2,007,340	57,890	20,986,540	1,480,920	7,720,730	11,006
March, 2013	1,748,850	6,680	12,900	591,100	1,556,560	388,610	408,420	1,525	4,040,840	1,652,580	5,060	20,305,850	1,524,850	8,235,398	10,020
April, 2013	2,125,390	98,960	15,670	508,160	1,086,010	489,420	304,980	540	3,803,600	1,670,870	78,500	18,579,500	1,059,030	7,425,340	10,100
May, 2013	2,280,900	157,202	26,980	545,788	1,200,650	501,230	298,060	2,000	3,560,770	1,529,820	100,890	19,777,430	990,230	7,560,450	11,500
June, 2013	2,425,460	3,330,400	11,280	64,480	894,460	10,266,660	368,580	5,000	2,913,260	1,580,240	131,600	19,728,090	993,320	3,999,600	
July, 2013	2,723,400	4,000,180	5,214,820	317,500	610,580	12,174,080	106,840	6,200	2,000,440	1,750,080	120,800	17,959,900	797,840	3,602,740	
August, 2013	1,630,140	3,500,160	7,001,420	405,280	552,540	11,329,740	200,700	3,040	1,975,960	2,084,340	149,320	17,472,540	999,620	3,273,720	
September, 2013	1,141,860	3,110,070	726,300	264,440	714,420	13,073,320	244,440	1,560	1,860,860	1,532,440	110,090	13,926,880	960,460	2,880,400	
October, 2013	2,885,940	2,692,680	2,016,680	371,740	1,056,160	16,053,140	371,140	420	3,461,420	2,536,420	94,660	23,101,020	1,556,560	4,678,358	

November, 2013	1,614,200	6,867,480	963,880	417,120	831,720	21,373,480	322,560	1,800	4,087,640	2,087,280	52,800	24,500,300	1,309,820	5,128,620	15,460
December, 2013	1,588,700	2,777,160	338,420	194,460	610,340	2,578,100	218,660	5,540	3,018,000	1,277,700	25,570	14,111,120	903,940	2,297,040	
January, 2014	1,545,300	1,004,660	140,100	152,560	591,480	1,675,315	166,020	7,120	2,955,880	1,090,840	1,220	11,361,680	925,080	1,694,240	
February, 2014	1,345,280	333,200	17,560	102,720	423,131	159,980	58,120	8,180	1,713,340	772,840	27,770	8,500,570	505,040	1,217,180	
March, 2014	383,040	144,520	68,340	49,960	380,920	14,020	39,900	9,120	1,260,900	444,240	44,940	5,073,500	286,370	1,062,980	
April, 2014	319,049	264,780	15,980	150,700	80,200	79,240	7,320	9,910	164,760	28,040	51,980	587,020	23,980	168,320	
May, 2014	583,440	167,330	32,640	235,560	410,360	20,600	42,180	11,300	1,242,900	389,250	65,440	8,121,841	217,210	1,197,140	
June, 2014	10,431,606	817,080	465,170	1,291,230	5,024,736	106,600	804,530	12,580	19,342,879	3,719,974	1,270,940	58,504,424	3,862,926	11,055,428	
January, 2015	3,249,193	304,160	43,620	301,100	6,254,809	237,260	447,020	10,110	9,776,650	5,403,660	3,820,808	17,488,243	3,427,868	9,811,397	
February, 2015	1,498,310	774,458	133,430	377,540	2,983,920	700,638	224,070	9,800	6,579,430	3,377,681	2,588,560	9,741,525	2,079,200	7,575,164	
March, 2015	769,170	1,909,808	123,103	345,570	2,852,220	1,533,940	162,320	10,600	5,307,240	2,428,578	1,610,950	9,165,530	1,721,009	6,488,934	
April, 2015	2,941,315	5,182,345	386,908	467,970	5,490,160	1,123,160	108,900	11,110	8,354,090	3,191,260	2,025,310	15,159,371	2,729,526	10,473,453	
May, 2015	2,683,550	2,577,330	397,640	560,870	6,120,800	1,250,800	142,180	11,300	9,080,900	4,110,080	2,700,980	18,970,560	3,117,330	11,197,600	

Table D2: forecasted waste data

Month/Year	After 12h00 Sat.,Sun. and Pub holidays	Builder rubble (Clean)	Builder rubble (mixed/rock)	Compacted refuse	Container service	Cover soil	Dailies	Dry Industrial uncompacted Non-SW	Garden refuse - mixed	Illegal dumping	Market	Round collected refuse	Street cleaning	Uncompacted non solid waste	Destruction foodstuff/Non-Pikitup
January, 2015	2025041	792944	164761	466086	3276709	2612608	109102	3900	887266	710502	1616891	15997731	2385148	6791451	11891
February, 2015	742750	372604	72924	257060	2823417	863128	225418	9139	1765770	319606	1411009	9062923	940261	6335947	11500
March, 2015	1729439	3215987	255245	489979	761548	420025	146670	3794	495511	1874239	547498	10506763	501520	835720	13040
April, 2015	1111997	4690772	274024	556234	1586956	459507	193523	9800	1918421	3064637	809076	10506121	2681490	3643955	10415
May, 2015	1181225	2338442	252488	910327	1740367	4673483	858861	11863	18863721	1295851	1218384	41675058	1958303	8196530	8319
June, 2015	12238699	11114825	1878243	3604278	7301277	11748709	1690992	13262	28230926	20219033	15281705	115087459	7896619	11887804	12554
July, 2015	1641563	9090589	1735003	2589300	20895276	10812627	425903	6592	14905431	15115788	251417	123690417	5892669	25500661	11310
August, 2015	3497015	8778916	3285333	3852031	23874698	7983474	743995	3316	38892691	17761349	6036276	33278059	5626605	24424027	11814
September, 2015	18961107	9973626	1001539	2307182	26999228	8690522	1087733	9349	66301954	4975437	7907203	45237010	12893366	26302579	11689
October, 2015	7115330	1063406	2164864	453714	24004240	4561790	535668	6276	14827506	13001911	2326856	107098132	16738670	28500362	10751
November, 2015	11401031	13293444	1516772	2298095	18162655	3508304	563199	7138	25630365	13882930	2085085	83626420	3842292	12057534	14823
December, 2015	9765591	7818546	704789	481566	10299468	1064647	50991	7926	8214526	1065741	11107322	19749220	12886511	15504478	12153
January, 2016	1438038	1037410	225186	371057	297430	1701767	82708	8548	4551426	1122414	228114	10745698	12956	7255181	13301
February, 2016	1048948	269643	104272	181719	1507797	457264	88754	4931	1552205	2133995	1528575	8300891	410427	5723115	13649
March, 2016	1835368	3707989	351573	369867	1325012	1488343	211401	6114	3035120	1102029	1224510	5941088	885205	857702	15016
April, 2016	1796709	1861062	186211	281311	664050	212397	295984	10847	2715608	2568182	2114050	17433953	1340984	8875652	11852
May, 2016	8938025	1319691	219654	814547	5365043	8093708	310160	10949	18477715	2542652	404109	59225497	1831624	8556014	1468
June, 2016	20665133	10666368	2959703	2006694	5623501	10408777	1422108	12701	31899051	11798639	14687342	126948958	13283712	23763255	14341

July, 2016	23333659	3457526	1057677	540493	23274513	11369274	343209	8752	45364233	13639397	9896371	128767983	11237054	62205563	11359
August, 2016	16266578	4127661	3277565	2725216	15974206	8085659	775137	5195	68264900	10760175	4703752	33721121	15051206	62460733	11888
Septembe r, 2016	19238792	1476372 6	2319899	3138940	22800453	6677537	1051062	1614	21344559	20957112	4478178	110796185	13950070	14000817	11449
October, 2016	8543786	1226752 3	1920225	2079165	22951578	8953541	669484	7052	39773494	15461628	3205583	97678864	11860170	39070061	12987
November , 2016	2854759	5399613	1195827	509717	18269255	7364152	292345	4090	36935132	20722958	4926066	90017148	5775485	39821473	12361
December , 2016	4030803	1703257	473899	67462	13115219	2494155	297208	5962	23005186	11831831	2763828	30616553	5472865	22029659	13953
January, 2017	1799862	934883	78925	282975	3147635	2260886	39896	5973	2988618	3869571	561199	14158981	1513424	4741282	14533
February, 2017	490277	177167	140841	90114	795036	837358	239271	3265	4215983	2271486	773158	5398666	1351975	1999423	11565
March, 2017	2218185	1388959	319956	692126	1003579	285038	51881	7224	1425018	1500228	1549022	12788643	78162	5915524	14415
April, 2017	1707458	127042	185463	241721	3724832	929650	273256	6500	1690048	2644438	1544566	6982065	1774727	8012553	10769
May, 2017	10273346	1856059	394390	1064811	5211247	9932478	294436	7282	14318448	1722861	838862	49309339	1066220	7871031	1809
June, 2017	15012700	1444110 5	4253416	3893689	11179191	4124577	2084550	8001	42203652	19525016	8673646	114574174	4523734	55035780	10525
July, 2017	11708292	1368493 4	1899199	1185294	27747000	10666311	1708637	10872	8279894	15868991	1836716	114934971	1486211	62940552	11573
August, 2017	17348802	4869153	2705214	3747477	16361747	11039286	497340	6628	14594056	1485461	870475	140611111	15785200	8600352	11934
Septembe r, 2017	16682541	3503026	1265817	2574490	29531447	10263901	1222917	3078	45097642	7984525	4090683	97075225	18210195	34577218	10746
October, 2017	2761154	5456523	2495339	96704	23445539	7926198	805744	5024	46308652	12806514	1607522	75061275	18091228	37657914	13721
November , 2017	2997149	1025766 1	414304	622944	30312281	2854657	441148	5046	31748937	4610312	8094359	55322700	14115031	35674756	13960
December , 2017	7729235	176464	462026	1959428	2520579	2519961	133340	9056	3803554	20131339	9391309	59125647	8267634	38875385	13565
January, 2018	1265036	379144	58061	456376	1822249	1739120	83561	7773	3133663	2417392	379099	15262729	1146596	3985702	12051
February, 2018	1051129	169537	105884	149653	1446736	942883	82686	8808	1511764	1036052	1156598	13497897	287312	3708846	13963
March, 2018	3175291	3239864	236862	478586	1454821	1595153	349728	6104	578365	891218	1449221	9518100	696734	3578694	10103
April, 2018	2078859	2554081	307924	526586	4017541	285233	278669	8111	1745779	1315473	929957	11698188	3040047	6493645	14018
May, 2018	9802498	2528904	305427	1062478	4173204	7522169	1003335	20604	4583687	1624569	1073757	15834048	1219069	5007679	419
June, 2018	9988657	1537712 6	1379977	2031223	17656551	6700014	1462739	13421	61012091	8879889	10040525	81263233	8974732	42819344	8106

July, 2018	22888093	10214259	3939960	3320052	17175333	11461317	1366182	5401	2792062	8282094	11412113	49450029	5793741	5238964	11774
August, 2018	5024040	9602312	2878053	3194435	3816648	6428250	1331161	7478	1961429	17735103	15196769	94534808	15970920	10311331	11451
Septembe r. 2018	19818329	4645038	1524158	1833317	11581018	9598900	1152394	2601	29294861	18082978	11759720	67728789	5314875	20261590	9938
October. 2018	12156678	3466715	1125689	698149	23837930	3825712	337586	1595	4425389	4434988	8064168	106959974	6380329	26442857	11401
November , 2018	10328167	6631900	427942	822307	11680469	7411698	499801	2473	34259531	20138252	7333478	51246434	14140797	8948490	14537
December , 2018	7277760	5394769	466138	276670	5111050	3206103	583994	8574	3276115	6118538	1092780	37409839	10287685	4822943	10357
January, 2019	678467	872832	107123	292187	1281086	851683	243632	3960	6228582	1738698	739008	12600429	2208011	5956089	12263
February, 2019	620602	166029	111276	111560	516128	630096	117305	5687	3111193	2681057	571741	9766148	1954795	4050181	14265
March, 2019	1532623	2368762	166572	237696	839	591324	293446	4990	1652636	1788314	1042559	10328188	167358	1280674	13329
April, 2019	1903672	776337	371973	542186	2502831	172904	85295	5634	8276884	3747580	1575893	5631112	1386146	1002871	10323
May, 2019	10573225	2322639	48246	1508796	5414571	6654443	1013269	19104	1679842	3560878	1885364	19296279	3461401	15140358	7088
June, 2019	11808533	17078461	2787722	4628514	25324611	6362542	1979274	8489	15830839	20503030	7173086	108776363	10969947	37134606	9658
July, 2019	14132880	5354145	3799164	3279033	30737394	10301640	1373993	6044	10737719	4879351	12466011	130865918	5263860	48230785	11703
August, 2019	6442163	12285058	5349167	2385851	32080825	6451742	1500912	3437	26077837	24202943	13705074	84019563	7249109	63881240	11924
Septembe r, 2019	15942707	6106083	1180341	3008186	4651451	4427252	304006	4347	50423652	10373099	6458766	41569963	5398650	27816824	10372
October, 2019	7844923	7918818	2768548	1260403	25254220	6575200	716226	8735	11277982	2323659	4354943	34605270	10793200	37613339	11871
November , 2019	3822791	6453956	1143166	239800	5405005	11164923	854867	3661	33436809	18574117	7367743	68016691	13797120	42120862	12490
December , 2019	5480157	7678271	621608	582518	2970030	1070773	387367	6350	10822086	1694135	9885475	52716438	12229713	21287901	11229
January, 2020	595404	717731	55277	516382	541125	1645183	162955	8897	6624391	3750986	55550	12304080	945535	4395628	13693
February, 2020	1133122	347761	29033	128680	1774419	493379	238533	9978	4687622	843302	11273	9368051	1644003	443666	12027
March, 2020	1257344	4860384	327085	572023	451774	1505233	190876	3843	1196520	1507244	1414042	2537144	389143	1491482	14894
April, 2020	1018430	2353932	110021	269617	2247425	215431	68123	4094	1098119	3562648	1984779	15307119	1030964	7342540	14804
May, 2020	6914960	1760561	68675	859418	4455894	4968153	112292	13196	11103943	1599565	444115	62116081	3524442	11036352	5443
June. 2020	20655154	18234354	2295479	4330523	32530269	11782549	1813774	12068	36616744	6411080	3491840	132845150	4052579	45582047	13995

July, 2020	13133320	4260796	155010	3431795	21312916	6753830	539552	8233	26628399	10564874	9845737	4302674	7307516	5790466	11676
August, 2020	10729430	15167184	3904125	2685813	256347	8360030	1291513	6970	14037917	4323863	2944804	55310426	6015053	39886069	11498
September, 2020	3524237	10372282	170424	2907007	15634333	10298896	991460	2063	66916856	14159221	6212252	16349032	12377284	44809532	10363
October, 2020	13770639	11759919	186720	933917	15104300	11263982	1125076	82	49436474	3573662	2543287	20171137	8550165	32786781	13216
November, 2020	16943979	4687635	1445899	2475898	3869792	12362628	598593	6558	25072857	18125801	13813629	23018463	13060183	33022123	13080
December, 2020	7721014	10004400	341488	2161214	7155603	1695037	358275	9564	3872506	7941801	5936144	51038754	5934626	15408000	13161
January, 2021	2077408	287891	160433	473265	4550618	2491579	175806	5670	7659571	1104744	719652	10946909	1480760	5231467	12639
February, 2021	1084116	343794	45155	216666	405880	1328720	2997	7415	5100175	1316800	699275	14263225	710344	876238	14553
March, 2021	1045045	3810865	207052	337567	755083	508778	352882	6313	2828110	1975023	341698	1115630	340853	1251877	11895
April, 2021	2062198	1969133	107965	253253	2458294	951215	105959	7216	3293863	2793310	1501018	15710796	2003925	1272885	10607
May, 2021	11484127	2597547	337625	1077106	3974615	9104573	686059	15347	8993876	3480790	2077277	40160447	2639509	6502210	4580
June, 2021	8384140	8271531	1966187	2214672	32341937	11906632	1322628	8717	52295425	21435769	9175807	130205614	3478432	51545159	12308
July, 2021	18938991	8665255	270781	4085776	1478611	10238785	2340018	8582	58887962	13937343	9916398	169724939	20911329	75115354	11626
August, 2021	5096512	10034468	1110173	364855	6584914	6849749	314157	7085	59419293	22999931	15212253	23976086	5432280	61832722	11611
September, 2021	20071398	8089585	2454983	4060058	6823957	11040820	997058	7728	70246742	18056456	11204162	30876824	862707	15635283	10178
October, 2021	6321232	10833787	327425	2288524	5544546	10782900	280785	9296	5506469	8511579	8734298	100587429	9552225	36485310	14118
November, 2021	12653347	2611711	538489	782130	26808925	6569697	624504	6490	55354284	18432789	7287180	62873812	13925134	29437689	11377
December, 2021	3440001	11499539	401690	787703	20396900	1846546	154937	5079	14718610	16235297	8512419	16536691	7485740	23445658	13416
January, 2022	1516281	956132	104072	375379	4265117	696905	148713	8939	7741083	1840949	638465	10247541	1781289	709806	13027
February, 2022	1550445	211065	53128	210154	594122	900890	182963	9400	4382217	2509729	823097	7419406	726907	2074846	12143
March, 2022	3138009	2784002	91293	539927	1701088	476437	189176	4830	4252568	1250867	1551770	2542970	714238	2169616	11421
April, 2022	889525	1455739	138122	540674	1839280	917535	228202	5745	4768841	3768139	985221	19112708	661960	5123903	9399
May, 2022	2875630	352708	39801	890939	2074671	1033946	393885	11463	11577155	2377026	529847	51182467	4254279	14418391	4644
June, 2022	16818406	2783618	5280381	1415531	2764259	9094412	1815042	10379	17201037	21224224	11335041	83912448	16469495	49182373	11744

July, 2022	3941943	8847181	3007036	2972153	25956686	7885952	2104278	8983	78710643	20586867	9257501	151853221	14908927	51534687	11623
August, 2022	2307155	1114429 7	2228352	2967811	12317447	10448266	699264	6542	60693862	11379016	8618921	34227898	19009605	8212213	11943
Septembe r, 2022	4383273	4893565	2380211	810231	15647091	11056074	215352	4249	13858241	2089936	12968231	17429162	11409737	63799688	10881
October, 2022	17591402	2678651	1988863	1925163	29962426	5606171	832013	997	11734379	14044717	12415309	52876045	7828488	4377205	11134
November , 2022	15566068	1145396 1	1057767	1126063	15807621	10559004	841094	5580	19391704	18101403	12450428	82901349	1955544	11929179	14098
December , 2022	11430011	5320742	707845	650248	16618713	1399897	656374	9411	14251133	13804295	8844244	32479094	11118936	5661165	12094

Table D3: Waste Characterization – Field data findings

Day of site visit	Number of trucks analyzed	Route of trucks	Composition (and volume of waste in relative comparison to socio-economic status)
6th of April, 2015	3	Southern Suburbs (Poor communities)	Food waste, garden waste, old textile materials, shoes, napkins, slippers, undefined-volume incombustibles, stones and sands, broken glass materials, glass cups and bottles (Volume of waste is relatively low in recyclable materials compared to the waste from middle and high income communities. It is ≤ 5 tonnes)
		Peripheries of the far north (Poor communities and informal settlements)	Food waste, garden waste, old textile materials, shoes, napkins, slippers, undefined-volume incombustibles, stones and sands, broken glass materials, glass cups and bottles (Volume of waste is relatively low in recyclable materials compared to the waste from middle and high income communities. It is ≤ 5 tonnes)
		Construction and demolition sites	Broken bricks, crushed concrete, dried up cement, broken ceramic, and steel mesh