

**Developing an Institutional GIS Database of Waste
Management in the North West Province,
South Africa**

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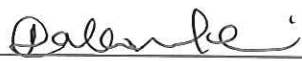
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Declaration

I, Refilwe Matsie, hereby declare that the dissertation for the Masters in Environmental Science and Management at North-West University hereby submitted, has not previously been submitted by me for a degree at this or any other university, that it is my own work in design and execution and that all material contained herein has been duly acknowledged.

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Abstract

Municipal Solid Waste Management (MSWM) is rapidly becoming a severe environmental problem worldwide. Geographic Information System (GIS) has proven to be powerful tools with potentials for several practical applications in waste management. The North West Province (NWP), like the other eight provinces in South Africa, is faced with poor MSWM due to lack of reliable data. Hence, the study is aimed at addressing this challenge through the creation of an institutional GIS database that would provide necessary quantitative data for an efficient integrated waste management system.

This study made use of a quantitative research design built around field observations, measurement of elements of the waste cycle and GIS. Both primary and secondary data were used to build a GIS database. The results showed that household waste generated high volumes of organic waste constituting 29.4% followed by paper and plastic with 18.7% and 14.7% respectively. While commercial areas mostly gave rise to paper and plastic waste making up 31.7% and 21.1%, of the total waste, respectively.

The study revealed that in most cases, the landfill sites were located relatively close to the buy-back centres. In the North West Province, the study also found that there is only one buy-back centre which processes recyclables while the rest of the buyback centres transport the collected recyclables out of the province. In addition, an estimate of 82% of the landfill sites were non-compliant.

Keywords: Municipal Solid Waste Management (MSWM), Integrated waste management, Geographic Information System (GIS), database, waste classification, household waste, commercial waste.

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Chapter 1

INTRODUCTION AND PROBLEM STATEMENT

1.1. Background

Waste management for municipal waste is an essential public service that provides citizens with a systematic structure for disposing of their waste in an environmentally friendly and economically feasible manner (Beigl et al., 2008). However, as the population grows and cities undergo urbanization, Municipal Solid Waste Management (MSWM) is becoming a severe environmental problem worldwide. Developing countries such as those in Africa are the most affected since they experience relatively high rates of urbanization and the majority of them have inadequate resources in place to cope with the situation (Mwanthi, 1997). The problem is that the quality and availability of data on solid-waste generation and management in Africa is scanty and hence delays the development of programs that will promote efficient use of solid waste in Africa (Simelane and Mohee, 2012). South Africa is no exception to the problem of improper MSWM, since most, if not all, of the municipalities within the country face challenges with regards to urban solid waste management.

As towns grow and develop, it becomes imperative for appropriate MSWM procedures to be implemented, due to the increasing magnitude and complexity of the waste generated as well as the scarcity of land for disposal (Verma and Bhonde, 2014). The result of inadequate waste management processes include disease transmission, fire hazards, odor nuisance, atmospheric and water pollution, aesthetic nuisance and economic losses (Basagaoglu, 1997). In South Africa, most municipal authorities are not equipped with the necessary skills and knowledge to use the present data to implement a more efficient system of managing waste. Hence, it is imperative that a broader understanding of the types of solid waste that are generated by the towns is developed and that research is done to establish how the different types of waste can be used to advance development in the form of recycling and energy generation (Simelane and Mohee, 2012). Therefore, there is an urgent need to address the lack of waste management strategies as it has negative social, environmental and economic impacts (Simelane and Mohee, 2012).

Geographical Information System (GIS) has emerged as a very powerful technology, which allows geographers to integrate data and methods in ways that support geographical analysis,

modelling as well as database management (Malczewski, 2004). Waste management in South Africa is structured in such a way that it is inter-linked. Therefore, a system as effective as GIS becomes a necessary requirement for all municipalities to help facilitate coherence between the different components that make up this Integrated Waste Management (IWM) system. GIS has several practical applications in waste management, which include; landfill site selection, planning routes for vehicles transporting the waste, establishing optimal locations for waste collection and maintaining the account data of the municipality's customers (Sumathi et al., 2008). Integrating database management within the waste management directorate in the municipalities of the North West Province will serve as a powerful tool that can be used for strategic waste management decision-making.

The overall waste management system consists of four distinct processes namely; (i) generation, (ii) collection and transportation, (iii) sorting, treatment and recovery, (iv) final disposal (UNEP). The created GIS database is mainly focused on the last two processes in the waste management system as it contains data on the quantity of waste that has been sorted as well as the locations of final disposal. This kind of data is very important since the Department of Environmental Affairs requires all municipalities to keep a record of waste disposal facilities that are under their area of jurisdiction (DEA, 2012). Records should indicate the size of their waste disposal facilities; the predicted lifespan and/or available airspace as well as the types and quantities of waste disposed. In addition, municipalities should also indicate the status of these waste disposal facilities with regards to whether they are licensed or not and should specify the type of waste they can handle i.e. hazardous, domestic or construction waste. Therefore, a spatial GIS database is required to capture the various locations and concomitant attributes. The GIS database has the ability to capture, manipulate and display data which can be used to establish strategies that can cater to the specific needs of a particular municipality.

1.2. Problem Statement

Waste management is one of the challenges facing cities and municipalities across the world (Guerrero et al., 2013). This is due to lack of financial resources, skilled human resource in waste management, lack of project continuity and information about waste management (Sujauddin et al., 2008). Studies show that lack of information about waste management by authorities is a major factor affecting waste management in cities and municipalities (Chung, 2008). The difficulties faced by municipalities are mainly due to lack of organization,

complexity and system multi-dimensionality (Burntley, 2007). Solid waste management in municipalities of North West of South Africa is also facing challenges such as lack of financial and human resources (PIWMP, 2017). However, this is also compounded by estimates of waste that are not accounted for as well as lack of specific information about waste management in the province (DEA, 2012). South Africa has a few waste characterization studies that have been done (Silbernagl, 2012), hence there is a need for more studies that would provide such information. Therefore a spatial database with potential for handling geometric and thematic data about waste generated in the provincial municipalities is required to address this information gap.

1.3. Research Aims and Objectives

Aim

The aim of this study was to create a spatial database for waste management using GIS that could be used as an integral component of the North West Province Integrated Waste Management Plan.

Specific Objectives

1. Collection and compilation of waste data from sampled municipalities.
2. Creation of GIS database for waste recycling in the province.

1.4. Justification of the Study

Most provinces, including the North West Province, do not collect information on waste characterisation, volumes generated as well as recycling and treatment (PIWMP, 2008). Developing a GIS database will allow municipalities to store, query and manipulate waste data at different levels of the waste chain with relative ease. In addition, an institutional database will facilitate the sharing of such information and creating awareness about waste, will enable all stakeholders, including communities, to gain a better understanding of the relationship between pollution, waste management and the quality of life (National Waste Management Strategy Implementation South Africa, 2006). The database will provide the municipalities with data that is necessary for the development of programs that will promote

efficient waste management strategies relevant for the specific demographics of the different municipalities within the four districts of the NW province.

1.5. Study Area

This study was conducted in selected municipalities across the North West Province, South Africa. Figure 1.1 shows the selected municipalities that were sampled.

1.5.1. Location

The North West Province borders the Limpopo Province to the North, Gauteng to the east, the Free State to the east and South, the Northern Cape to the South and Botswana to the West and North. The altitude ranges between one to two thousand meters above sea level.

1.5.2. Area

The province extends over a total land area of 116 320 square kilometers, which makes up 9.5% of the total area of South Africa. The Province is divided into four district municipalities (the Bophirima, Central, Southern and Bojanala Platinum) and 21 local municipalities.

1.5.3. Population

The provincial population is currently at 3.5 million people and is likely to increase to 3.9 or 4 million by 2030 (SSA, 2011). This population comprises of approximately 1.06 million households, which on average, consist of 3.3 people (NWPDP, 2012).

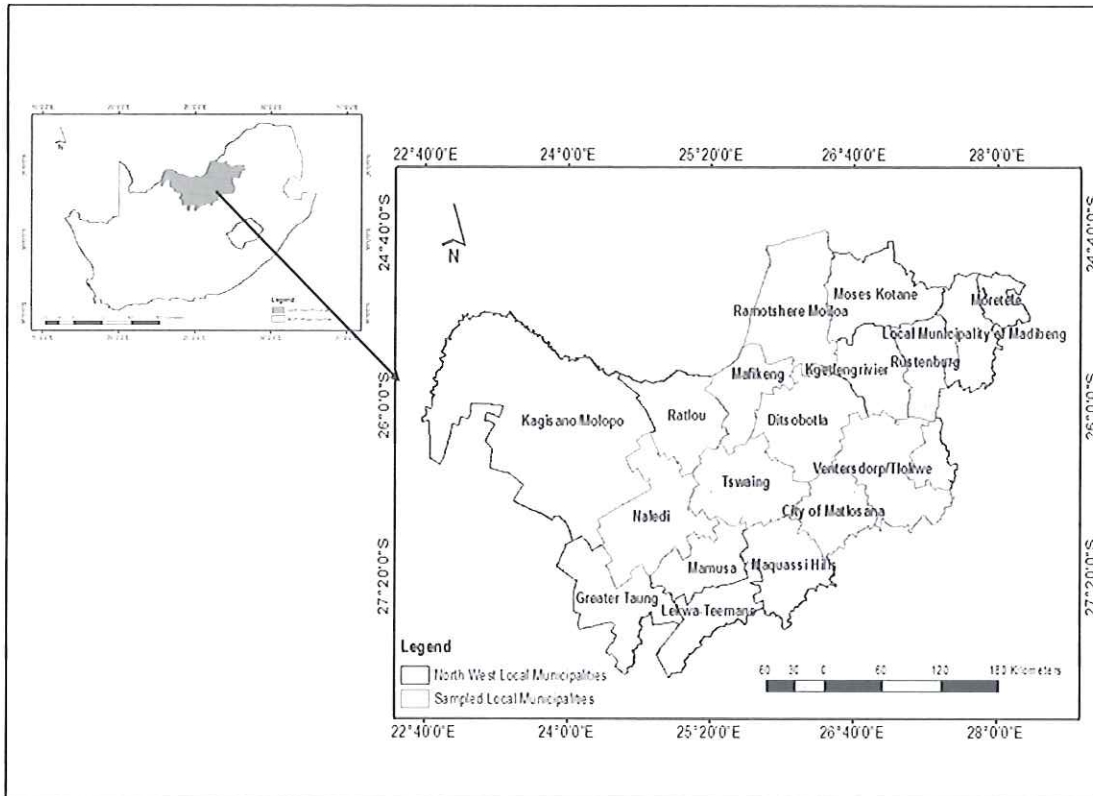


Figure 1.1: Map of the study area

1.4.4. Climate and rainfall

The provincial climate is characterised by distinct seasons of hot summers and cool sunny winters. The climate and rainfall varies from the more mountainous and wetter eastern region to the drier, semi-desert plains of the Kalahari in the west (NW DACE, 2012). The rainy season usually occurs from October to March.

1.4.5. Topography and Soil

The predominant veld types in the west are the Kalahari Thornveld and the shrub bushveld, with the central being predominated by the sour and sourish mixed bush veld (NWPDP, 2012). The east consists of a mixture of the other turf thornveld and mixed bush veld (NWPDP, 2012). The major soil characteristics are the red-yellow apedal soils (low clay) particularly in the western parts of the province, followed by the plinthic catena (ideal crop production soils) and the glenrosa and mispah (predominantly shallow and rocky) forms (NWPDP, 2012).

1.4.6. Existing Land Use

The North West Province is largely rural, i.e. 65% rural and 35% urban, hence is largely dominated by agricultural activities (NW DACE, 2002). The total potential arable land is 28.3%, grazing land is 56.8%, conserved land (the bulk of being comprised of game reserves) is 6.4% while 8.5% land is put into other uses such as housing (Department of Economic Affairs – NWPG, 2002).

1.4.7. Waste Management

In recent years, the North West province has had positive net migration rates that is to say; more people are migrating to the province than from the province. Thus has led to greater levels of urbanisation in larger towns and cities, which then leads to mounting pressure to provide sustainable waste management services and facilities. However, the Province has been facing several challenges that have made it very difficult to meet these demands. Challenges include the lack of available or current waste information, illegal dumping sites, resource recovery at waste disposal facilities, and the use of unpermitted landfills by municipalities and limited environmentally accepted landfill airspace. In addition, inadequate waste collection services, insufficient levels of recycling, waste minimisation, lack of waste databases, lack of regulation and enforcement of legislation (Fiehn and Ball, 2005).

1.5. Definition of Terms

The following terms have the following meanings throughout the document:

- **Waste:** Any substance; solid, liquid or gaseous, which is ‘discharged, emitted or deposited in the environment in such a volume, constituency or manner as to cause an alteration to the environment’ (PIWMP, 2008).
- **Integrated Waste Management (IWM):** A tool used for analysing and optimising the existing waste management system (PIWMP, 2008). IWM is based on the inter-linked nature of the waste management system in which changes in one aspect of the system invariably affects other areas of the system.
- **Municipal Solid Waste (MSW):** Includes the non-hazardous waste generated within the administrative boundary of a municipal authority. This waste is generated by households, commercial establishments, institutions, and light industrial wastes; it excludes industrial

process wastes, agricultural wastes, mining wastes and sewage sludge (Tchobanoglous, 2003).

- **Recycling:** Involves processing waste through the conversion of parts or all of the waste into other useful materials or to recover the original raw matter (Clark, 2002).
- **Composting:** The controlled biological decomposition of organic solid waste under aerobic (in the presence of oxygen) conditions. Organic waste materials are transformed into soil amendments such as humus or mulch (Tchobanoglous, 2003).
- **Commercial Waste:** Solid waste generated by stores, offices, institutions, restaurants, warehouses, and the non-manufacturing activities at industrial facilities (Tchobanoglous, 2003).
- **Residential Waste:** Refers to waste generated within the urban and rural settlements (PIWMP, 2008).

1.6. Structure of the Dissertation

This dissertation contains five chapters whereby Chapter One introduces the topic and outlines the problem statement as well as the aims and objectives of the research. Chapter Two examines the work done by other authors with regards to waste management globally, regionally as well as locally in the form of a literature review. This Literature Review encompasses the theoretical frameworks and methods carried out in waste management. Chapter Three details the techniques that were carried out in accomplishing this research project. Chapter Four presents and discusses the results obtained from the detailed processes that were carried out in the previous chapter. Chapter Five presents the conclusions and recommendations.

Chapter 2

LITERATURE REVIEW

2.1. Introduction

This chapter examines literature on the complex nature of integrated waste management in municipalities. The chapter first explored the challenges of waste management in developing countries, such as South Africa, and revealed the concomitant implications that arose from those challenges. Secondly, the responsibilities of the various spheres of government i.e. national, provincial, district and local levels, were outlined. Thirdly, the most prominent waste attributes were defined and these included waste categories, sources, composition, generation rates and recycling. Fourthly, an examination of literature on waste treatment and recovery methods such as landfill, thermal and biochemical conversion was conducted. The chapter further engaged literature on the waste characterisation methods and lastly, on how GIS and databases could improve waste management.

2.2. Waste Management in Developing Countries

Waste management is a pressing issue in most developing countries, which urges them to develop and implement effective, necessary and integrated management plans for waste generation prediction (Seadon, 2006; Batinic et al., 2011). Developing countries are characterised by increasing population levels, a growing economy, rapid urbanization and a rise in community living standards. These factors have greatly influenced the municipal solid waste generation rate in developing countries (Minghua et al., 2009). Rapidly increasing population growth compounded by urbanisation results in a drastic increase in municipal solid waste generation and varying patterns of waste composition. Literature has revealed that by 2007, for the first time in human history, more people in the world occupied cities and towns than rural areas and by 2017, it has been predicted that the developing world is likely to become more urban in character as opposed to rural (United Nations, 2004). This growth in population and urbanisation rates has also contributed to the rapid and unplanned expansion of low-income settlements (squatter camps) on the outskirts of many large cities, which have occurred without the accompanying public services and facilities such as suitable sewage waste facilities and solid waste collection services (Cohen, 2006; Sakay et al., 2011).

2.2.1. Population Growth and Urbanisation

According to the UNDESA/PD (2012), cities in Africa are likely to experience significant growth at average annual rates of between 1.93% and 6.13% by 2025. Instead of this being an opportunity for economic, social and environmental advancement, it is viewed as posing a threat to limited resources such as land and increased urban poverty (Boadi et al., 2005). Buenrostro and Bocco (2003), describe waste management in developing countries as being very rudimentary whereas Onu (2000) noted that it is characterised by incompetent waste collection practices, variable and insufficient levels of service due to limited resources. South Africa, as a developing country, also faces the afore-mentioned challenges.

Between 1950 and 2000, the urbanisation level in developing countries increased from 18% to 40%, with the level expected to exceed 50% by 2020 and 64% in 2050 (UNDESA/PD, 2012). Urbanization has always been considered to be in conflict with development in colonial and post-colonial Africa (Njoh, 2003). For instance, in South Africa during the apartheid era, the government established legislation to restrict the rural-to-urban movement of native or indigenous Africans. In other parts of Africa, government attempts at controlling urban growth and urbanization involved legislation that evicted homeless newcomers, banished sidewalk traders, and controlled urban land use, amongst others (Njoh, 2003). Three factors remain dominant in the debate on the causes of urbanisation in Africa: natural population growth, rural–urban migration, and re-classification of rural settlements as urban (McGranahan et al., 2009; Turok, 2012). However, it is important to note that these factors are not mutually exclusive.

2.2.2 Implications of Population and Urbanisation to Waste Management

The implications of increased population growth and urbanisation in relation to waste management include: pressure on the country's limited resources, which then leads to inequality of municipal services between urban and rural areas (DEA, 2012a). The disparity in service coverage between different communities in the same area is a characteristic of waste management practices in South Africa (Matete and Trois, 2008). 'Urban bias' policies date back to the colonial era, in which residents in urban areas have access to municipal services whereas the rural residents receive sub-standard services or nothing at all. Literature has suggested that in such cases, engineers and town planners need to collaborate in order to establish innovative and cost-effective methods of waste collection, while maintaining a

standard that is acceptable to both the community and the environment (CSIR, 2011; DEA, 2012).

Another important consequence of urbanisation that impacts waste management, is reduced family size as it impacts living standards in the sub-Saharan Africa. Reduced family size follows as a result of delayed marriages - this phenomenon being 'more likely (to take place) in urban areas than in rural areas' (Smith, 1983). A reduction in the family size translates to a decrease in the number of dependents to feed - accompanied by increased economic opportunities and incomes, hence the family tends to enjoy an improved quality of life. This point is emphasised by Bradshaw and Noonan (1997), who interpret the inequalities between urban and rural areas as an increase in the standard of living for urban residents. A reduction in family size has an influence on the level of waste generation (Senzige et al., 2014) and the increased standard of living results in an increase in waste complexity (DEA, 2012).

2.3. Waste Management and Legislature in South Africa

The 1996 Constitution of South Africa, Section 24 states that: *everyone has the right to an environment that is not harmful to their health or well-being; and the right to have the environment protected, for the benefit of the present and future generations, through reasonable legislative and other measures that prevent pollution and ecological degradation; promote conservation and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.* This unequivocally lists the State's responsibility to ensuring that all citizens live in an environment that is clean, healthy and sustainable. Waste management is one of the critical elements of sustainable development primarily because comprehensive waste management practices contribute to sustainability (DEA, 2012).

2.3.1. National Responsibilities

In South Africa, all spheres of government are legally responsible for waste management and a detailed outline of the specific roles of all those spheres of government can be found in the 2011 Municipal Waste Sector Plan. Waste management in South Africa is based on the principles of the White Paper on Integrated Pollution and Waste Management (IP and WM), the National Waste Management Strategy (NWMS), and also the New National Environmental Management Waste Act (2008) (Muzenda, 2012). In using the aforementioned strategies, it means that South Africa supports a waste hierarchy through

promoting cleaner production, waste minimisation, re-use, re-cycling and waste treatment. Disposal and remediation have been regarded as the last options in waste management as of 2010 (Figure 2.1). This waste management hierarchy has been developed to improve the management of waste and reduce its associated impacts.

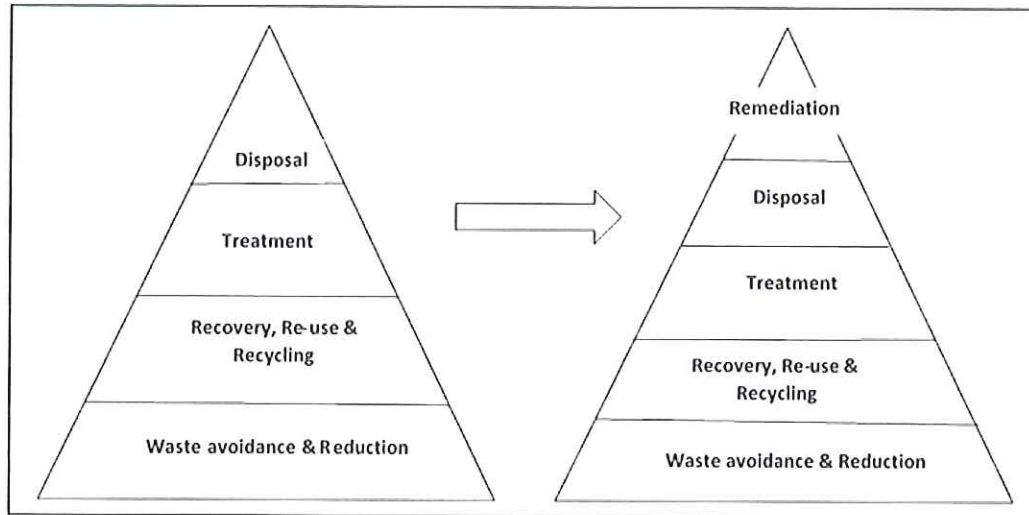


Figure 2.1: Waste Hierarchy, NWMS 1999 and 2010, (Savage, 2009).

The NEM:WA (National Environmental Management: Waste Act) prescribes several mandatory and optional services that the Department of Environmental Affairs (DEA) must fulfil. In terms of mandatory services, the DEA is responsible for:

- Establishing the National Waste Management Strategy (NWMS);
- Setting national norms and standards;
- Establishing and maintaining a National Contaminated Land Register;
- Establishing and maintaining a National Waste Information System; and,
- Preparing and implementing a National IWMP. (DEA, 2016)

It is the responsibility of the Minister of the DEA to licence authority for hazardous waste activities. The DEA is also responsible for promoting and ensuring the implementation of the NWMS and national norms and standards. As the key agent for waste management-related functions, the DEA is also responsible for:

- Development of policy, strategy and legislation;
- Co-ordination, enforcement and dissemination of information;
- Participation in appeals (against government decisions, authorizations, etc.);

- Monitoring, auditing and review;
- Capacity building. (DEA, 2016)

2.3.2 Provincial Responsibilities

The provincial government has been tasked with responsibilities such as developing the provincial environmental implementation plans; reviewing the first-generation IWMPs received from the municipalities and if required, assisting with the drafting of these (DEA, 2016). The provincial DEA also monitors compliance with provincial implementation plans and intervention may occur if necessary (DEA, 2016). In addition, provincial responsibilities include developing provincial guidelines and standards as well as enforcing provincial regulations in terms of general waste collection, and supporting the local government in the implementation of waste collection services (DEA, 2016). The provincial department also acts on environmental hazards as required and ensures that all industries have access to appropriate waste disposal facilities.

Quality assurance of the Waste Information System is also conducted at the provincial level along with the implementation and enforcement of waste minimization and recycling initiatives (DEA, 2016). The provincial government plays a significant role in promoting the development of voluntary partnerships with industry. Other functions include: registration and certification of hazardous waste transporters, the waste manifest system and the establishment and control of hazardous waste collection facilities. Finally, the province supports the DEA in terms of planning for a system of medical waste treatment facilities, and investigating the feasibility of centralized (regional) waste treatment facilities (DEA, 2016).

The North West Province operates on the Integrated Waste Management (IWM) strategy in compliance with the stipulated legislation. The IWM is a tool based on the concept that all aspects of waste management are inter-linked, hence a change in one aspect leads to a change in another aspect (PIWMP, 2008). The overall objective of the Integrated Waste Management is: “To integrate and optimise waste management, in order to maximise efficiency and minimise the associated environmental impacts and financial costs, and to improve the quality of life of all South Africans” (NEMA, 2008).

2.3.2. District and Local Responsibilities

The Constitution allocates the tasks of refuse removal, refuse dumps and solid waste disposal to local governments. According to the CSIR report (2011) on municipal waste management, good practices and the roles of district and local municipalities in waste management are summarised in Table 2.1.

Table 2.1: District vs Local roles and responsibilities.

District	Local
Ensuring integrated development planning for the whole district including development of a framework for IDPs and ensuring that IWMPs inform the IDP process.	Compiling and implementing IWMPs and integrating the IDPs. Conducting public awareness campaigns across all communities.
Promoting bulk infrastructure development and services for the whole district.	Collecting data and reporting to the Waste Information System.
Building local municipality capacity and to assist if a local municipality fails to perform its management functions	Providing waste management services, including waste removal, waste storage and waste disposal services.
Promoting the equitable distribution of resources between the local municipalities in its area	Implementing and enforcing waste minimization and recycling

2.4. The Various Attributes of Waste

Waste is said to be “a mirror of the society” since waste generation and disposal reflect a range of aspects of the society, such as its economic, historical, cultural, and environmental components (Sakurai, 2000). However, in many developing countries, the distinction of waste is not clear hence the definition/distinction of the waste varies depending on countries and cities. For instance, the European Court of Justice in the European Union legislation,

defines waste as 'discard'. However, in South Africa, there is presently more than one legal definitions of waste. This causes complications amongst industry and government with regards to waste management issues and disturbs the successful application of the waste hierarchy (Muzenda et al., 2012). For the purposes of this study, waste will be defined as any substance whether solid, liquid or gaseous, which is 'discharged, emitted or deposited in the environment in such a volume, constituency or manner as to cause an alteration to the environment' (PIWMP, 2008).

2.4.1. Waste Categories and Their Sources

The foundation to successful planning of a waste management program heavily depends on the availability of reliable information concerning the quantity and the type of waste generated (Guerrero et al., 2013). MSW composition studies provide crucial information that can be used to estimate material recovery potential, to identify sources of component generation, to facilitate design of processing equipment, to estimate physical, chemical, and thermal properties of the waste as well as to maintain compliance with the prescribed legislative frameworks (Gidarakos et al., 2005). However, these fundamental statistics are lacking in many developing countries (Buenrostro et al., 2001) and in instances where they are available, they are unreliable since they come from various sources, which cannot be validated and are sometimes based on assumptions and not necessarily on scientific measurements (Couth and Trois, 2011; Ranjith, 2012).

The production and consumption patterns of human settlements are responsible for the generation of various waste products (SOER, 2008). The term 'waste categories' is used to classify the various wastes generated. There are many categories that can be applied to waste, however, in the Provincial Integrated Waste Management Plan (PIWMP), the following categories are used: residential, commercial, industrial and hazardous. Residential waste refers to the general type of waste generated by people in urban and rural areas. Commercial waste is generated in business districts and often includes office and retail waste. Industrial waste refers to the non-hazardous portion of waste produced. In general, large-scale industries dispose the hazardous fraction of their waste through their on-site facilities or by transporting it to the relevant disposal sites. Hazardous waste on the other hand refers to the kind of waste which is toxic, explosive, corrosive, or possesses other characteristics that can cause danger to health or the environment (LaGrega et al., 2001).

2.4.2. Waste Composition and Waste Generation Rates

As the economies of developing countries expand, so do the waste streams, particularly in terms of volume and complexity. There are various factors that influence composition of the generated waste such as seasonality, lifestyle, demography, geography, and legislation (AbdAlqader and Hamad, 2012). These variations make the defining and measuring of the composition of waste more difficult and at the same time, more essential. There are several studies that explore the link between waste generation, its composition and socioeconomic factors (Philippe and Culot; 2009 Kayode and Omole, 2011; Monavari et al., 2012; Zia et al, 2017; Jouhara et al, 2017). Findings from these studies revealed that the waste composition of households is directly associated with the increase in income, which then results in changed composition and quantities of the household waste (Ogwueleka, 2013). In addition, individuals from the higher income level tend to consume more industrialized products and as a result, their garbage contains more recyclable materials than that of individuals from the lower income level (Medina, 1997).

In general, the waste characteristics of developing countries are characterised by (1) high waste densities, (2) high moisture contents, (3) large organic fraction, and (4) cities with sweeping services that give rise to large amounts of dust and dirt (Chandrappa and Das, 2017).

2.4.3. Waste Recycling



In South Africa, the majority of commercial waste recycling initiatives have been developed on a temporary basis and have been sustained by the private sector, with little or no financial support from government (DEA, 2009). Government has tried to stimulate waste recycling by introducing waste buy-back centres, garden waste drop-off centres, separation of different waste streams, such as glass, paper/cardboard, cans, scrap metal, plastics and garden waste, however, these efforts have so far been relatively ineffective (DEA, 2009). This is evident in the large quantities of recyclable materials that end up at landfill sites.

In the context of the North West province, recycling and re-use initiatives are still in their early stages and are very few. There was a recycling project carried out by a municipality in Leeudoringstad, a small town in the province, in 1999 but the project failed due to mismanagement. As a result, literature has shown that it is better to have the private and informal sector conducting most of the recycling initiatives. The private sector, which has

responded to recycling as a business opportunity, has been a lot more effective in increasing the rates of recovery and recycling of certain waste streams (DEA, 2016). Other initiatives such as composting have also not yet been firmly established in the province. However, in the Rustenburg Local Municipality, pilot projects have been initiated in order to establish the feasibility of composting (PIWMP, 2008).

2.5 Waste Treatment and Recovery Methods

A variety of waste management practises have been studied and developed. These include source reduction, collection, recycling, composting, incineration (burning), landfilling and simply dumping (Hoornweg and Bhada-Tata, 2012). In most countries, municipal waste management services depend on landfills as the main method of waste treatment. In South Africa, over 90 per cent of all South Africa's waste is disposed of at landfill sites (DEA 2011). However, many of these landfill sites are non-compliant with licence conditions, resulting in poor levels of operation and negative impacts on the environment. AfriForum (2015) audited 56 landfill sites across South Africa and found that only six of them could comply with the national standards. Due to these appalling outcomes, AfriForum is planning on directing letters to local as well as district municipalities to take immediate action with regard to the state of the landfill sites, failing which, criminal charges will be brought against the parties involved (Venter, 2017).

Waste recycling assists in transforming discarded materials into resources and in so doing helps reduce the environmental impact by reducing the amount of waste disposed at landfills whilst creating employment opportunities (DEA, 2016). Traditionally, unsanitary landfill procedures such as open dumping and open incineration methods were commonly used (Tozlu et al., 2016). However, studies have exposed the waste's energy potential and as result, are exploring the various complex methods of taking advantage of this energy. These methods are referred to as waste-to-energy (WTE) technologies. WTE technologies have been proposed to provide a viable solution, especially for the developing countries (Moya et al., 2017). There are three major types of WTE technologies namely; thermal conversion, biochemical conversion and landfill (Tozlu et al., 2016).

2.5.1. Thermal Conversion

Thermal conversion methods encompass incineration, pyrolysis and gasification, with incineration being the most frequently used. The main purpose of these methods is to reduce

the waste volume while converting the waste to energy that is hidden within the waste in the form of heat, steam, electrical energy or combustible material. Using the incineration method, an estimate of about 70% of the total waste mass can be reduced and in turn, approximately 90% of the total volume is reduced (Kumar, 2000).

The incineration process is carried out in three stages; the initial stage is combustion of solid waste chemical elements; carbon (C), hydrogen (H₂) and sulfur (S) in an oxygen-rich environment, which usually occurs at temperatures between 750 and 1000 °C (Tozlu et al., 2016). This is followed by energy recovery in which the typical amount of net energy that can be produced per ton of domestic waste is approximately 0.7 MWh of electricity and 2 MWh of district heating (Moustakas & Loizidou, 2010). The final stage is air pollution, which involves the emission of CO₂, SO₂, NO, NO₂ and HCl which are harmful to human health.

‘Pyrolysis’ involves the use of indirect, external heat and occurs at temperatures ranging between 450 to 750°C (Tozlu et al., 2016). This process takes place in the absence or almost complete absence of free oxygen, which eradicates the volatile portions of the organic materials, to give rise to a syngas composed primarily of H₂, CO, CO₂, CH₄ and complex hydrocarbons (Golomeova et al., 2013). The three types of pyrolysis methods are conventional pyrolysis (550–900 K), fast pyrolysis (850–1250 K), and flash pyrolysis (1050–1300 K) (Tozlu et al., 2016).

In the ‘gasification’ process, MSW is converted into CO₂, CO and H₂O, which occurs by reacting MSW at high temperatures of about 4700°C. The process occurs without combustion but with a controlled amount of oxygen and/or steam (Kalyani and Pandey, 2014). Although gasification and combustion processes transform carbonaceous material to gases, gasification is different from an incineration process. The difference lies in that gasification operates in the absence of oxygen or with a limited amount of oxygen, whereas combustion processes operate with excess oxygen (Moustakas & Loizidou, 2010).

2.5.2. Biochemical Conversion

Biochemical conversion can be regarded as the most eco-friendly method from the three major WTE technologies. This method is centred on the biological reaction undertaken by microorganism enzymes. There are two kinds of biochemical conversion methods, namely; anaerobic digestion and composting (Kalyani and Pandey, 2014). In terms of the anaerobic

digestion, the MSW is assembled in an environment that is free of oxygen. The MSW undergoes a series of biological processes, where microorganisms breakdown the wastes to biodegradable material. Such a process usually takes place at around 65 °C and decreases the amount of waste to produce biogas for combined heat and power or as a transport fuel (Tozlu et al., 2016). Composting refers to a biological decomposition of biodegradable solid waste under conditions that are mainly aerobic. This natural process of recycling decomposed organic materials into a rich soil is known as compost (Kalyani and Pandey, 2014).

2.5.3. Landfill

The landfill method is soil-based and makes use of engineering principles that confine solid waste to the smallest area possible and decrease it to the lowest allowable volume in a sanitary landfill (Tozlu et al., 2016). Landfill is the most commonly used waste treatment technique in the world however; developed countries prefer to reduce their MSW by using the incineration technology due to a reduction of approximately 70% of the total waste mass and thus 90% of the total volume (This preferred method has negative implications for the environment, such as air pollution where is the closing bracket.

2.6 Waste Characterisation Methods

Waste characterisation is a vital element in any municipal waste management organisation (MWM) of the urban solid waste in a city yet, such data are not commonly compiled in cities across Africa (Guadalupe et al., 2009). Waste characterization refers to methods used to determine the various types of materials discarded in a waste stream and in what ratio (National League of Cities, 2013). However, characterization of solid waste is usually a difficult task because of the heterogeneity of the waste and its spatial and temporal variations (Lagerkvist et al., 2011). Waste characterisation data involves information on the various categories and amounts of materials (paper, food waste, glass, yard waste, etc.) in the waste stream. Many factors influence waste characterisation, these include habits, cultural tradition, socioeconomic and climatic conditions. It varies not only from city to city but even within the same city (Gawaika, 2004).

Different locations generate various types of waste depending on many factors, amongst these factors being socioeconomic variables. Housing types, and the sizes and main activities of commercial establishments were hypothesized as the key determinants contributing to the spatial variability of solid waste generation (Purcell & Magette, 2009). Due to limited

resources that are available for waste characterization, it is important to highlight aspects that make up the representative nature of the characterization process. These aspects include spatial and temporal variation as well as uncertainty.

The two most widely used methods for waste characterization are the materials flow method and site-specific sampling via sorting and weighing refuse by category (Staley and Barlaz, 2009). On the one hand, the materials flow method makes use of industry data on the production and import and export of goods to estimate waste generation and is best applied at the national level. Nevertheless, the materials flow approach cannot account for seasonal, geographic, and socioeconomic differences at regional or local levels. On the other hand, the site-specific sampling includes picking analysis/quantifying material fractions as identifiable items, particle size distribution, moisture content and densities (Lagerkvist et al., 2011).

In the waste characterization process, the area and period needs to be defined and evaluated for significant variations, which can be categorised or represented as an average. Although spatial and temporal representations may be properly addressed, the heterogeneity of waste is still significant and any characterization will be associated with substantial uncertainty (Lagerkvist et al., 2011). Other steps in the process of waste characterization include sampling and sample preparation. Due to the heterogeneous nature of the waste, there is always a compromise between practicality and heterogeneity. Therefore, the more heterogeneous the waste is, the larger the sample must be in order to represent the components that appear less frequently (Lagerkvist et al., 2011).

Characterization procedures for waste materials can be classified into three categories namely; physical analyses, chemical analyses and performance testing. Physical analyses refers to analysing/quantifying material fractions as identifiable items, particle size distribution, moisture content and densities (Lagerkvist et al., 2011); whereas chemical analyses involves measurements of pH and alkalinity, organic matter, inorganics and heating value/calorific value. Leaching tests determine the aqueous leachability of substances and respiration tests measure how degradable the waste is. Biochemical methane potentials measure the amount of methane that can be generated from the organic waste under optimal conditions. Performance tests include compressibility tests, which are performed to gain knowledge about waste densities as a function of the pressure or forces compressing the waste (Lagerkvist et al., 2011).

2.7 Application of GIS in Waste Management

A geographic information system (GIS) is a system that enables users to visualize, question, analyse, and interpret geographically referenced data in order to understand relationships, patterns, and trends. GIS makes use of spatial data such as maps, aerial photographs, satellite images along with other qualitative, quantitative and descriptive information databases. Several studies reveal that the most advanced methodology used to automate the process of waste planning and management is the design and construction of integrated systems based on GIS environments (Karadimas and Loumos, 2008). The selection of appropriate landfill sites is a common application of GIS and remote sensing tools (Choudhury and Das, 2012, Ebistu and Minale, 2013, Suresh and Sivasankar, 2014). Other applications include selection of the location of recycling drop-off stations (Chang et al., 2000); municipalities can obtain the precise estimations of solid waste generation using the local population density and income group distribution (Vijay et al., 2005); information which can be used to conduct waste generation forecasting (Dyson and Chang, 2005).

A study of the relationship between an area's socio-economic standing and the quantities of waste generated was carried out in South Wales by Emery et al. (2003). The results showed that residents living in semi-detached properties generated the greatest quantities of waste followed by the council areas and finally, the terraced areas (Emery et al., 2003). The semi-detached households had the highest amounts of the kitchen putrescible waste whereas council and terraced house dwellings varied quite widely from one part of the country to another. In general, the trends showed that areas of greater economic wealth purchased larger quantities of food stuffs and hence disposed of larger quantities of waste (Emery et al., 2003). Similarly, GIS was applied to econometric models to generate disaggregate predictions of residential waste loads (Javaheri et al., 2006). Another study conducted by Ahluwalia and Nema (2006) aimed at tackling issues involved in the planning and designing of a computer-based waste management system in an integrated manner in Delhi. The model is based on an integer linear programming method with the objective of minimizing environmental risk as well as cost (Ahluwalia and Nema, 2006).

2.7.1 Database Models

There are various types of databases such as hierarchic, network, relational, and object oriented database development approaches.

The first generation of databases were navigational in that applications accessed data through record pointers from one record to another. These databases inspired the formation of hierarchic and network data models. The hierarchic data model stores data in a hierarchic structure, synonymous to a tree. All the nodes of the 'tree' represent one record-type. There is a so called 'parent-child' relation between the data (Garcia-Molina, 2008). A parent is the table that stores the primary key whereas child is any table that references the parent with a foreign key (Pratt and Adamski, 2011). Each datum can have as many 'descendants' (children, grandchildren...) as possible but can have only one 'ancestor' (parent, grandparent...). Its main advantage is being easily describable and easy to create however, it is no longer relevant today. The further development of the hierarchic model gave rise to the network data model (Elmasri and Navathe, 2016). In this model it is possible to create a system of multiple relations between the data i.e. datum can have many ancestors as possible (Coronel et al., 2013). The model's key disadvantages are its complex relations and demand for storage place as it appears in the environment of computers with a great capacity (Garcia-Molina, 2008).

Relational database

The most commonly used model is the relational model which arranges data into tables, also known as relations which consists of columns and rows (Pratt and Adamski, 2011). In a multi-table database the relationships between each table must be defined in order to link those tables correctly. Each column, also known as a field, lists an attribute whilst each row, called a tuple, holds data about a specific instance of the entity in question (Elmasri and Navathe, 2016). A specific attribute or a combination of attributes is chosen as a primary key that can be referred to in other tables. A primary key is chosen to uniquely identify a single row in a table. Tables within the same database can be related to each other using foreign keys. A foreign key is a field (or a collection of fields) in one table that refers to the primary key in another table (Elmasri and Navathe, 2016). Although relational database models are easy to use, flexible and secure the object data model provides a richer set of semantics than the relational model (Hoffer, 2011).

Relational databases allow the storage of physical location and shape of geometric objects inside tables which gives rise to spatial databases. The spatial data option within databases make storage, retrieval, and manipulation of spatial data easier and more natural to users, benefiting of all the power of the relational databases (Quantum, 2013). There are two ways

of managing spatial data with relational technology, firstly by putting all the data that is spatial and non-spatial in the relational database which is dubbed the integrated approach and secondly by separating the spatial from the non-spatial data also known as the hybrid approach (Worboys and Duckham, 2004). Since relational databases have limitations in the case of spatial data, the most effective way proves to be the use of object-relational databases (Huibing, 2008).

Object databases

The primary components of an object-based model are its objects or entities (Worboys and Duckham, 2004). A crucial feature of object databases is that it gives the designer authority to specify both the structure of complex objects and the operations that can be applied to these objects. Object databases are designed so they can be seamlessly integrated with software that is developed using object-oriented programming languages (Elmasri and Navathe, 2016). However, with object-based spatial databases the location is stored as objects. The object-based spatial database models the world as a surface that has several typical objects that exist independent of their locations (Blaschke, 2008). Objects can be simple as polygons and lines, or be more complex depending on the prescribed requirements.

Object- relational databases

Most of the main database vendors are enhancing the relational model to include some of the mechanisms available in Object databases (Pratt and Adamski, 2011). These extended Relational databases are often called Object-Relational. Therefore the Object data model can be seen as an enhancement of the Relational model to provide a wider range of modelling capabilities (Coronel et al., 2013). Although many experimental prototypes and commercial object-oriented database systems have been created, they have not found widespread use because of the popularity of relational and object-relational systems.

2.7.2 Databases in Municipalities

The South African Waste Information System (SAWIS) is a system used by the government and industry to capture routine data on the tonnages of waste generated, recycled and disposed of in South Africa on a monthly and annual basis. The SAWIS was established in terms of Section 60 of the National Environmental Management: Waste Act (Act 59 of 2008). Godfrey and Scott (2010) carried to gauge the likely impact of collecting data for the

SAWIS. Findings of such as a study showed that the private waste companies were more successful at collecting data as compared to the public companies. In addition, the study revealed that financial support and/or reporting to an international holding company were the main driving force behind data collection of the waste.

Factors that limit data collection include lack of equipment in terms of information technology (IT) and capacity (Godfrey and Scott, 2010). Many municipalities across South Africa do not have weighbridges at the landfill sites and hence crucial information is not collected. In some cases where the data is collected, it is not analysed to extract meaningful information for effective decision making.

2.8 Summary

This chapter revealed challenges in the management of municipal solid waste in developing countries such as South Africa and the possible solutions that these countries can implement to overcome the challenges. The literature reviewed, explored one of the solutions towards the challenge: creation of a GIS database. Of noteworthy, is that most municipalities in the developing countries are characterised by limited resources in terms of finances, equipment and capacity. These challenges hinder the efficiency of waste management and as such, obtaining reliable data on waste is an even more challenging task with some municipalities not collecting any waste data at all. Therefore, many developing countries do not have waste data and in cases where they are available, they can be considered to be unreliable since they come from different sources, which cannot be validated or they are established on erroneous assumptions and not necessarily scientific methods.

The chapter also explored the various types of databases in terms of their strengths and weaknesses. Literature revealed that the integration of spatial data into object-relational databases was a necessary characteristic for GIS users. The South African Waste Information System (SAWIS) was briefly explained as well as the importance of continuous collection of waste data. The next chapter outlines the data collection process that was undertaken in carrying out this study.

Chapter 3

METHODOLOGY

3.1 Introduction

This study was conducted to develop an understanding of the quantity and type of waste generated in the North West Province and to make this information available to all the municipalities, private recycling organisations and other relevant stakeholders. The chapter outlines the processes, which were undertaken in acquiring the results obtained within this study.

3.2 Sampling Process

Sampling is the process of selecting a portion of the entire process as an approximate representative of the population, which permits statistical generalization. Statistical generalization refers to the process where conclusions are based on the observation of a limited number of cases, and extended to cover all the other unobserved cases that fit in the same category (Watt and Van den Berg, 2002). This section describes the sampling procedures that were followed in establishing the sample population.

3.2.1. Study Area Sampling

For this study, local municipalities were used as study cases in which the population size of the respective local municipalities was used as the sampling frame. The 21 municipalities of the North West Province were classified into three categories as per population size, using the 2011 population census. The range of the population sizes of the municipalities was determined by subtracting the lowest population size from the largest. The range was then divided into three and used as the interval for establishing the three categories. The categories are A denoting high population (range 384,000-550,000); B = medium (217,000- 383,000) and C = low (50,000- 216,000).

A stratified random sample was then employed to include each category of the population and a table of random digits was then used to select the local municipalities that were included in the study (Table 3.1). The sample size was proportional to the actual number of municipalities falling within each of the categories.

Table 3.1: The Sampled Local Municipalities.

Name of District	Local Municipality	Population*	Category
Ngaka Modiri Molema	Mafikeng	291,527	Medium
	Tswaing	124,218	Low
	Zeerust	150,713	Low
Kenneth Kaunda	Ventersdorp	56,702	Low
	Tlokwe	162,762	Low
	City of Matlosana	398,676	High
Dr Ruth Mompati	Naledi	66,781	Low
Bojanala	Rustenburg	549,575	High

*Source: Statistics South Africa, 2011

3.2.2. Site Interviews Sampling

This study sampled two main waste generators namely, residential and commercial establishments.

Household Sampling

The areas surveyed covered high, medium and low income residential areas, representing high (HIRA), medium (MIRA) and low income (LIRA) groups. From each income level, 3 houses were sampled due to time and financial constraints. For the entire study area, data was collected from 72 houses. The underlying assumption was that all houses within the same income group generated similar types and quantities of waste (Table 3.2). The following waste types were used for classification; Paper, Plastic, Organic, Soil, Textile, E-waste, Glass, Metal and Mixed contaminated.

Table 2.2: Number of Houses Sampled per Income Group for Each Municipality.

Sampled residential Areas (Income levels)	High	Medium	Low
No. of households sampled	3	3	3
Total number of households sampled per municipality			9

Commercial Sampling

In selecting the commercial establishments, the following categories were outlined; schools, food outlets, service providers, retailers, recreational, and auto/electronics (Table 3.3). This list is not exhaustive as there are other establishments that were not sampled due to time constraints. For each commercial category, 3 establishments were sampled with the assumption that the same establishments in the different municipalities generated similar types of waste. The total number of establishments sampled was 144.

Table 3.3: Number of Sampled Commercial Establishments

Sampled commercial establishments	Schools	Food outlets	Service providers	Retailers	Recreational	Auto/electricals
No. of establishments sampled	3	3	3	3	3	3
Total number of commercial establishments sampled per municipality						18
Total number of commercial establishments for the study (18*8)						144

3.3 Research Design

A quantitative research design was used in which numeric data was collected, analysed and interpreted through waste classification methods and interviews using structured questionnaires (Leedy, 1993). The data in quantitative research are measurable and can be acquired by various methods or collected from various *primary* and *secondary* sources (Poate and Daplyn, 1993).

3.3.1 Data Sources

This study made use of both the primary and secondary data sources in which measurements obtained in the field comprised the primary data and data from literature and interviews conducted made up the secondary data. Data collected in quantitative research may be cross-sectional, time series or pooled (Bryman, 1988).

3.3.2 Data Collection

Fieldwork was conducted during the months of June and July 2017, in which data was collected once-off and hence the data collection type implemented was cross-sectional. The detailed methodologies used to achieve each objective are provided below.

3.4 Collection and compilation of waste data from sampled municipalities.

3.4.1. Fieldwork

The key waste generators were defined and their relevant data acquired. Fieldwork was conducted in which the municipalities were visited and observations were made and recorded on the observation schedule (Appendix 1). The purpose of the fieldwork in this objective was to identify and compile the key waste generators in the study area. Visits and observations at the buy-back centres and the landfills were used to establish the sources of the different wastes. The sources of waste were an indication of the generator of a particular type of waste.

3.4.2. Secondary Data

Reports from the respective sample municipalities and relevant literature were obtained from the internet and analysed for data on the key waste generators.

Data analysis: Captured data was tabulated and subjected to frequency computations using descriptive statistics. The outputs are presented in the form of applicable graphics to highlight the key waste generators in the study area.

3.4.3. Waste classification

The waste classification process was conducted using protective clothing and masks. The classified waste was obtained from the identified key waste generators namely, residential and commercial.

Residential Data

The waste collection schedules of the sampled municipalities were collected and used to arrange a schedule for fieldwork to be done. On collection days, waste was readily available on the kerbside. Upon arrival, the total weight of the waste was measured, and the weight of

the refuse bag was considered to be negligible. In cases where the waste was placed in wheelie bins or cardboard boxes without a refuse bag, it was transferred into a refuse bag in order for the total weight to be measured. The waste was removed from the main refuse bag and placed into smaller plastic bags according to a specific waste type. The waste was separated according to the following waste types: Paper/Cardboard, Plastic, Organic, Soil/Ash, Textile/Leather, E-waste, Glass, Metal and Mixed contaminated. Using a portable spring balance, the mass of the sorted waste in the smaller plastic bags was measured and recorded (Figure 3.1).



Figure 3.1: Separating paper/cardboard waste type (A) .Weighing of separated waste (B).

Commercial Business Data

For commercial sampling, on-site sampling was coupled with interviews with the identified waste generator and analysed quantitatively. The interviews were conducted to establish the average waste produced per day, the questions in interview schedule were close-ended (Appendix 2). Due to the high volumes of waste generated by most commercial establishments, approximately 10% of the total population of waste samples was classified and used to represent the characteristics of the total waste load on site (Figure 3.2). The ‘mixed contamination’ waste type was excluded due to health reasons and time constraints.

Skips that are used by large scale commercial businesses were visited to establish the classes of waste that is dumped there. The total number of plastics that can be accommodated by the skip in question was established and estimates were made based on that approximation.



Figure 3.2: Weighing waste at a commercial site (A). Skips used by large scale commercial businesses (B).

3.4.4. Mapping Waste Management Sites in the Province

According to the waste cycle, the final destination of waste is either incineration, recovery plant (buy-back centre) or disposal site (landfill). Since there are no incineration plants in the North West, maps illustrating the recovery plants and disposal sites were generated.

Information from literature and municipal reports were used to establish the waste management sites (transfer stations and landfill sites). Once the sites were identified, a field excursion was conducted and the coordinates of the identified sites were recorded using a Garmin Global positioning System at ± 6 m accuracy.

Map Creation

The coordinates recorded during the field excursion were entered into Microsoft Excel. Subsequently, the generated spreadsheet was imported into ArcMap 10.3.1 software program as input data, which was then used to create a map.

3.5 Creation of GIS database for waste recycling in the province.

A GIS database was created to store data collective in objective 1. A relational database system was selected because of its efficient ad hoc query ability as well as its user-friendly nature

Conceptual Schema

As an initial step, the conceptual schema was designed and attention was paid to minimizing redundancy of data without losing data. An Entity Relationship Diagram (ERD) was generated, which showed the main entities involved (Figure 3.3). Based on the Entity Relationship Diagram (ERD), the major entities identified are: Waste sites, Municipality, Property, and Waste.

Logical Schema

A logical schema was then created based on the conceptual schema and is given in Figure 3.4. The logical schema was also checked for normalization and it was found to be in the third normal form also known as 3NF. Normalisation is the process of arranging a database in order to reduce redundancy and improve data integrity. This process is achieved by restructuring relational databases in accordance with a series of normal forms. The main purpose of normalisation is to optimise speed, accuracy, and efficiency. The first normal form, sometimes called 1NF, states that each attribute or column value must be atomic. That is, each attribute must contain a single value, not a set of values or another database row. First Normal Form Rules are:

1. Eliminate repeating groups in individual tables.
2. Create a separate table for each set of related data.
3. Identify each set of related data with a primary key.

All the rules were observed in which repeating groups were removed, separate tables for all related data and a primary key was identified.

A schema is said to be in second normal form (also called 2NF) if all attributes that are not part of the primary key are fully functionally dependent on the primary key, and the schema is already in first normal form (Beynon-Davies, 2004). For instance if the primary key is

made up of multiple columns, every other attribute in the table must be dependent on the combination of these columns. This procedure was done for all the tables.

The third normal form (3NF) requires that a table must be in second normal form and that all columns in the table must relate only to the primary key and not to each other (Beynon-Davies, 2004). This rule further emphasizes the idea that there should be a separate table for each entity in the data set. This procedure was carried out in establishing the tables for the study's data sets. Implementing the rules of normalisation usually gives rise to the creation of multiple tables in a database. The relationships between the tables should also be considered in order to ensure that any new tables are linked to at least one other table in the database using a foreign-key, primary-key pair.

Physical Schema

The logical schema was then converted to its corresponding physical schema as shown in Figure 3.5. This schema also indicates which field is either a primary or foreign key. Firstly, the tables hold Number data fields specified for the 'area' field which occurs only once, in the Municipality table. Then there is Point data fields in the form of GPS coordinates which occurs in three out of the four tables, namely: Municipality, Property and Waste site. Finally, the rest of the data fields are variable characters which usually take the form of names, descriptions, and classifications. These variable characters occur in all the tables.

Skeleton tables

The skeleton schema portrayed in figure 3.6 shows the sample data that could be entered into the logical schema. The *Municipal* data table holds data about the municipality in which the municipality ID is the primary key since none of the sampled municipalities had duplicate names.

The *Property* table describes the property of interest which could either be a household or a business in a specific location. The primary key, Property_ID was created from the first letter of the Municipality name, the property type, and order of sampling eg NHS 1 means the sampled waste was located in Naledi municipality, it is a household and was the first house to be sampled in that area. Another example is; RBS 10 which means the sampled waste was located in Rustenburg municipality and it is the 10th business that was sampled in that area.

The Waste table outlines all the classes of waste that were considered in the study. The Waste Generated by Property table holds quantitative data about the classes of waste that were outlined for the purposes of this study.

Waste sites table contains data about the waste sites i.e. landfills and buy-back centres. Lastly, the waste site composition holds data on the kind of waste that can be found at the specified waste sites.

System Architecture

The spatial database system was implemented using the Drupal application. The system architecture is depicted in Figure 3.7 in which data was stored in MySQL database and the Drupal engine was used to access and display data in the web interface. The engine was also used to render maps from Google Maps based on the coordinates supplied

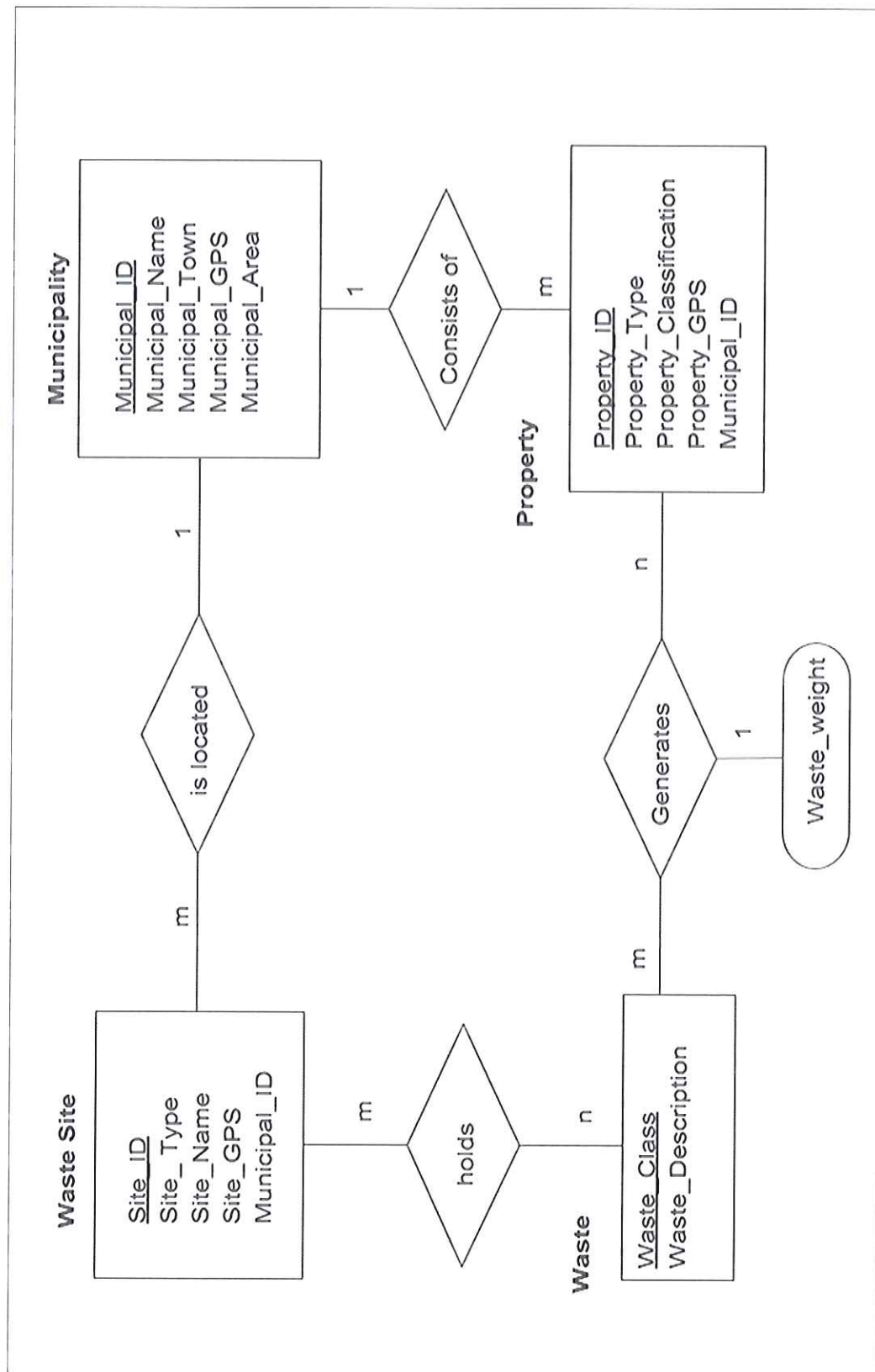


Figure 3.3: ER diagram (Conceptual schema) indicating the various entities involved in the database.

Municipality

<u>Municipal_ID</u>	Municipal_Name	Municipal_Town	Municipal_Area	Municipal_GPS
---------------------	----------------	----------------	----------------	---------------

Primary key: Municipal_ID

Property

<u>Property_ID</u>	Property_Type	Property_Classification	Property_GPS	Municipal_ID
--------------------	---------------	-------------------------	--------------	--------------

Primary key: Municipal_ID

Foreign key: Municipal_ID references Municipality

Waste

<u>Waste_Class</u>	Description
--------------------	-------------

Primary key: Waste_Class

Waste_Generated_by_Property

<u>Property_ID</u>	Waste_Class	Waste_weight
--------------------	-------------	--------------

Primary key :{ Property_ID, Waste_Class} and Property_ID reference Property and Waste_Class

Waste_Sites

<u>Site_ID</u>	Site GPS	Site Type	Site Name	Municipal_ID
----------------	----------	-----------	-----------	--------------

Primary key: Site_ID

Waste_Site_Composition

<u>Site_ID</u>	Waste_Class
----------------	-------------

Primary key: {Site_ID, Waste_Class}

Foreign key: Municipal_ID references Municipality

Figure 3.4: Logical schema for the GIS spatial database.

Municipality

Municipal_ID: VARCHAR(30), PRIMARY KEY

Municipal_Name: VARCHAR(30)

Municipal_Town: VARCHAR(30)

Municipal_Area: NUMBER(10)

Municipal_GPS: POINT

Property

Property_ID: VARCHAR(30), PRIMARY KEY

Property_Type: VARCHAR(20)

Property_Classification: VARCHAR(20)

Property_GPS: POINT

Municipal_ID: VARCHAR(30), FOREIGN KEY

Waste

Waste_Class: VARCHAR(20), PRIMARY KEY

Waste_Description: VARCHAR(50)

Waste site

Site_ID: VARCHAR(20), PRIMARY KEY

Site_Type: VARCHAR(20)

Site_Name: VARCHAR(30)

Site_GPS: POINT

Municipal_ID: VARCHAR(30), FOREIGN KEY

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Figure 3.5: Physical schema for the GIS spatial database.

Municipal

Municipal_ID	Municipal_Name	Municipal_Town	Municipal_Area	Municipal_GPS
Zeerust	Moiloa Ramotshere	Zeerust	7192.86	-25.495; 25.986

Property

<u>Property_ID</u>	Property_Type	Property_Classification	Property_GPS	Municipal_ID
NHS 1	House	Low	-26.9707; 24.7463	Naledi
RBS 10	Business	Retailer	-25.66656; 27.2395	Rustenburg

Waste_Generated_by_Property

<u>Property_ID</u>	Waste_Class	Waste_weight
ZHS 9	Metals	0.5

Waste

<u>Waste Classes</u>	Description
Paper	White paper, Card box

Waste site

<u>Site_ID</u>	Site_GPS	Site_Type	Site_Name	Municipal_ID
Ventersdorp LF	-26.299; 26.779	Landfill	Ventersdorp Landfill	Ventersdorp

Waste_Site_composition

<u>Site_ID</u>	Waste_Class
Ventersdorp LF	Glass

Figure 3.6: Skeleton tables for the GIS spatial database.

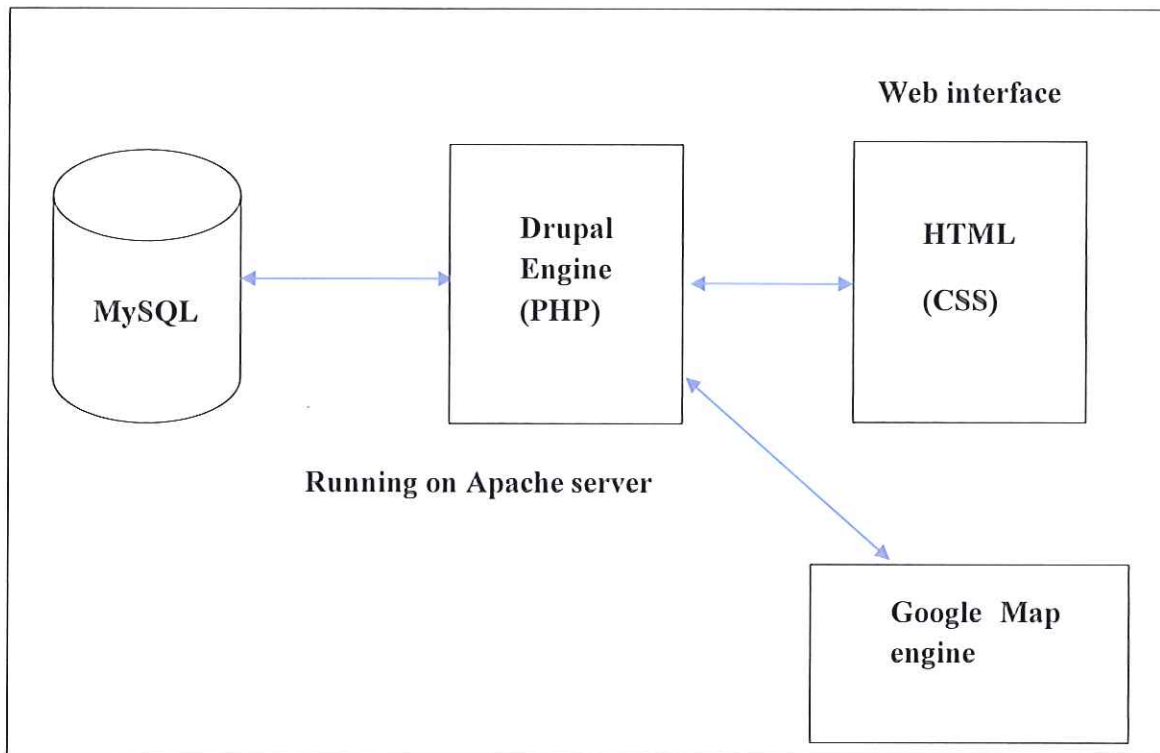


Figure 3.7: System architecture of the spatial database application.

3.6 Summary

The study followed a quantitative design in which numeric data was collected and analysed to fulfil the outlined objectives. Data on the key waste generators was obtained through the primary and secondary data sources. Extensive fieldwork was conducted in order to characterise the residential and commercial waste. A map of the waste sites i.e. buy-back centres and landfill sites was created using ArcGIS. A GIS database incorporating all the data collected was also created in fulfilment of the aim of the study. The next chapter presents the obtained results and discusses the implications of those results.

Chapter 4

RESULTS and DISCUSSION

4.1 Introduction

This chapter presents and discusses the results obtained in this study. Information on service provision to the key waste generators is outlined along with the amount and composition of the solid waste they generate. A map of the waste sites within the province is illustrated and discussed. Finally, the resultant database and its functions are presented.

4.2. Service Provision to Key Waste Generators within the Province

The study found that the main key waste generators are from: households, commercial areas, hazardous facilities (such as medical, mining and chemical) and small scale industries (PIWMP, 2008). However, in this study, primary data was collected for the first two key generators namely: households and commercial areas.

This study revealed that provision of services in terms of waste management depends on the socio-economic set-up of particular households. Various residential areas receive different services based on income. There were also variations in terms of the volume of wastes generated. There are variations in terms of waste generated, corroborating the study by Chandrappa and Das (2012) and these include (1) differences in the consumption pattern (for instance people in lower income areas consume less), (2) differences in the levels of recycling/reuse at source of generation and (3) differences in culture.

In this study, it has been observed that residents in the low income residential areas (LIRA) receive inadequate MSW services. This could be attributed to high population densities compared to the other income areas. The situation is compounded by the population's inability to pay the municipal rates as most of these communities are characterised by high unemployment rates. This then leads to high levels of illegal dumping within such income areas. The middle income residential areas (MIRA) and high income residential areas (HIRA) usually receive adequate services as they are, in most cases, able to pay the municipal rates. However, there are cases in which the municipality is under-resourced and is unable to carry out its duties diligently and in such instances, the municipality will procure services from

other private waste service providers. Table 4.1 summarises the socio-economic characteristics of the municipalities.

Table 4.1: Characteristics of Municipalities.

Municipal name	Municipal Area* (km ²)	Population Per municipality [#] (2016)	No of households per municipality*	No. of Landfills
City of Matlosana	3561.46	417 282	135 894	2
Mahikeng	3698.44	314 394	103 333	1
Moiloa Ramotshere	7192.86	157 690	48 070	1
Naledi	6941.2	68 803	20 692	2
Rustenburg	3423.26	626 522	262 576	4
Tlokwe City Council	2673.68	243 527 (after the merger)	52537	1
Ventersdorp	3764.05		14 562	1
Tswaing	5966.25	129 052	35 300	4

*Source: <https://census2011.adrianfrith.com/>

[#]Source: <https://municipalities.co.za/locals/view/193/>

On average, waste is collected once a week in households and once on a daily basis from commercial businesses. Some commercial businesses alluded that their waste was not collected as scheduled even though they paid their municipal utility bills. This creates additional costs for them as they have to secure the services from the other external waste service providers.

4.3 Classification of the Various Classes of Waste Generated

The fieldwork conducted covered a total of 24 households and 144 commercial institutions in 8 municipalities across the North West province. Table 4.2 provides an overall view of the composition of waste classes generated by all the households from the three income areas over a period of 7 days. As expected of the MSW, all income strata consists of organic, paper, and plastic waste as the highest constituent (Pharino, 2017).

Table 4.2: Waste Generated per Waste Class from all Income Areas per Week.

Waste classes	Proportion of waste generated from total generated in 7 days (%)
Organic	29.4
Paper	18.7
Plastic	14.7
Mixed contamination	9.7
Metal	8.4
Glass	6.7
Textile	5.7
E-waste	3.3
Soil	3.3

4.3.1. Household Waste Composition

Organic Waste

Table 4.2 shows that the organic waste class constituted the highest portion of the generated waste from all the waste classes, with 29.4%. Figure 4.1 illustrates that the highest portion of the organic waste class emerged from the HIRA (38%), followed by the MIRA (33%) and LIRA (30%). The results obtained are similar to those of a study by Zia et al., (2017) in which it was found that a low income group has the lowest average annual waste generation and the maximum waste was generated in the high income group. However, it is important to note that income level is not the only factor that influences waste composition and generation. Seasonality and the number of persons in a household also have a significant influence. A study conducted in Islamabad, Pakistan revealed that from the three socio-economic groups (low, medium and high income) during the four seasons of the year, more food waste and less paper was generated during the spring/summer as compared to winter/autumn seasons (Zia et al., 2017). This could be due the fact that low temperatures reduce the consumption of fresh foods and drinks (Kamran, 2015).

In another study conducted in Grahamstown - South Africa, 96 houses across three specified income areas had their waste classified using the 'sort' and 'weigh' technique (Nkoana et al., 2014). The results showed that the high-income areas had significantly fewer persons per household than the medium and low-income study sites (Nkoana et al., 2014). In addition, the ANOVA test revealed that houses in the high-income areas generated significantly less waste

than the medium-income or low-income site ($P<0.01$) (Nkoana et al., 2014). However, there was no statistically significant difference observed between the amount of waste produced in the medium-income and low-income sites ($P>0.05$). Therefore, the larger the household, the less waste produced per capita, however the larger the community, the more waste generated per capita (Karak et al., 2012; Pitchel, 2014). However, for the current study, seasonality and number of person per household was outside the scope. Yet, an observation on seasonality was made in which the organic content from the HIRA was mainly from the leaves that had fallen during the data collection period as it was conducted during the autumn season.

Paper Waste

Table 4.2 shows that paper is the second highest generated waste class following the organic waste. This outcome is similar to a study conducted by Ramachandra et al. (2018) in India, which revealed that paper waste represents the second common household solid waste. According to Figure 4.1, paper waste is highest in the MIRA (38%) followed by the LIRA (36%) and the lowest portion is from the HIRA (27%). These findings are inconsistent with literature such as Ilyas et al. (2017) and Hoornweg and Bhada-Tata (2012), which showed that the high income areas generate high portions of paper wastes. The current study found that the HIRA resulted in the lowest portion of paper waste as compared to the other income areas. Literature shows that income and household size are the most significant factors affecting the quantity of solid waste from household waste (Richardson and Havelick, 1978). Therefore, in the current study, the household size could have had heavily influenced the results of the various income areas. A sentence to justify that in the HIRA, there are fewer people per household than in the other groups. Similarly, the study by Nkoana et al. (2014) revealed that the average number of persons per household was statistically significant ($P<0.01$) between the high-income and low-income sites in which the high-income site had the lowest average number of people per household.

The following section discusses the implications of the obtained results for each of the waste classes covering all the income areas.

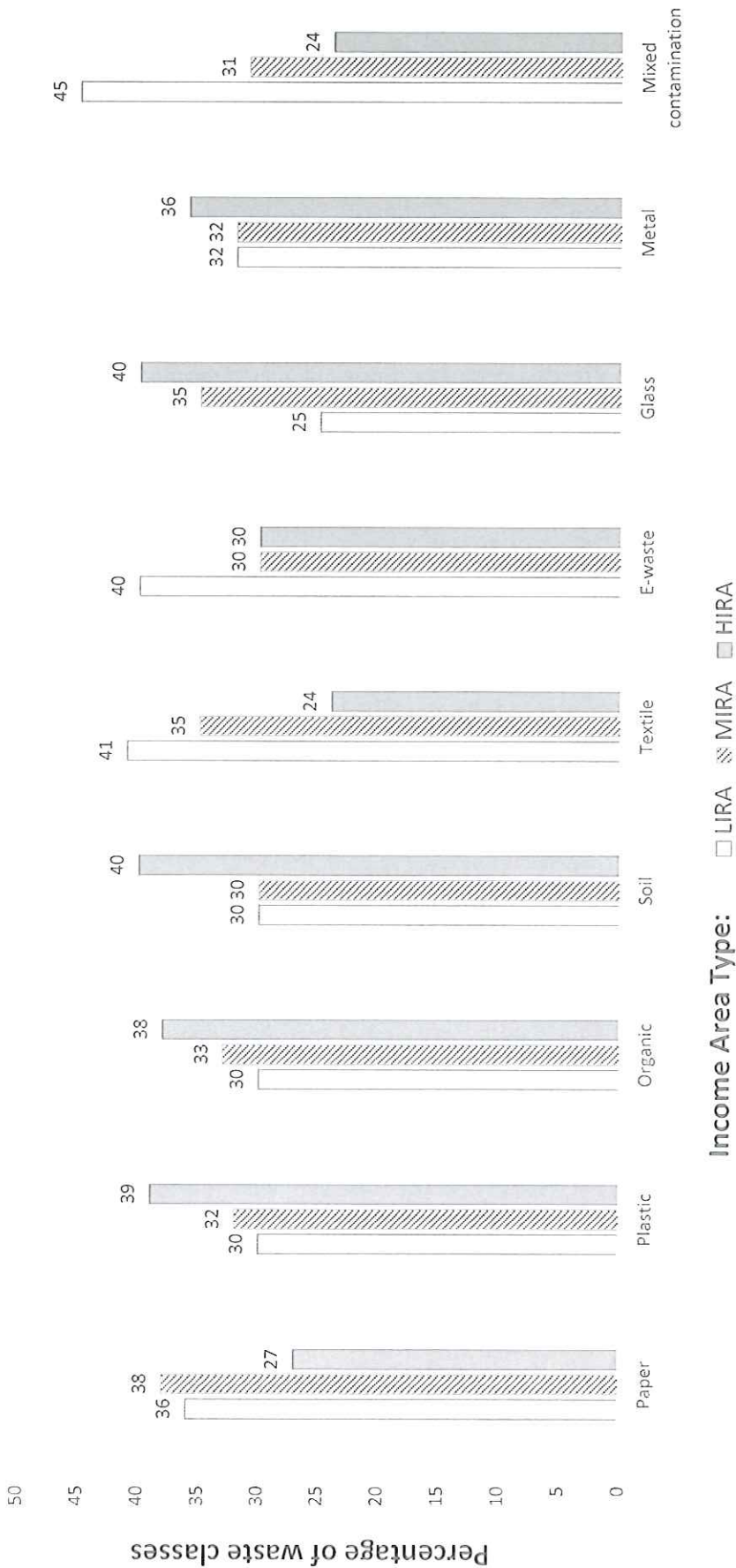


Figure 4.1: Waste classes generated per week across the different income area.

Plastic Waste

The highest plastic waste was derived from the HIRA, making up to 39% of the total plastic waste, followed by the MIRA with 32% and then the LIRA 30% as is illustrated in Figure 4.1. A similar study conducted on 96 houses in Grahamstown, revealed that the high-income households tend to produce more packaging waste such as paper and plastic (Nkoana et al., 2014). The same results were also reiterated in a study by Dhamija (2006), who found that the wealthier localities generated more paper and plastic waste while the low-income localities generated more soil and glass waste. Due to the low income level, buying of plastic papers would mean an extra cost to the already stretched monetary budgets. In line with the World Bank's report of 2012, plastic is the third highest generated waste class (after organic and paper) in most cities of the world including the study area (Table 4.2).

Mixed Contamination Waste

Mixed contamination waste in the form of disposable diapers (nappies), bandages, sanitary towels and other sanitary waste was mostly generated by the LIRA (45%) whilst the HIRA and MIRA contributed 31% and 24% respectively, to the total mixed contaminated waste generated (Figure 4.1). The LIRA had the highest percentage of mixed contamination in the form of disposable nappies however, there is limited literature and information regarding policies on diaper disposal or how diapers are actually handled (Reese et al., 2015). Similarly, a study by Zia et al., (2017) revealed that textile and diapers were highest in the lowest income group. A plausible explanation for the high volumes of mixed contaminated waste from the LIRA could be due to the high household size as evidenced from the high population densities that usually characterise the LIRA (SSA, 2011).

Metal Waste

The metal waste class was highest in the HIRA with 36% whilst in the MIRA and LIRA, it was 32%. Metals occupied 5% as is shown in Figure 4.1, and included aluminium cans, scrap metals, tin/steel, non-ferrous metals and other composite metals (Ayeleru, 2016). Metal waste from the MIRA and LIRA is lowest since it is recycled or segregated at household level, especially by the LIRA (Batool et al., 2008). This outcome is emphasised by Late and Mule (2012) who assert that the low values of metal waste in the waste streams are essentially due to the large scale recycling of this constituent. Observations during the study revealed that there are several buy-back centres, which provide ample opportunities for the low income

residents (who are usually unemployed) to engage in informal trading of the recyclables such as metals, as a form of income generation.

Glass Waste

Glass waste was high in the HIRA with 40%, followed by the MIRA (35%) and the lowest generated was by the LIRA with 25% (Figure 4.1). These trends are similar to a study by Chatsiwa (2015) in which glass, particularly, glass bottle waste, was high in the HIRA because most of the high income earners can afford to buy many soft drinks and wines, whose empty containers end up in the waste stream. Another study examining the relationship between the level of income and pro-environmental behaviour, found that the more people earn, the more they consume, which in turn results in high disposal behaviours (Kozar and Connel, 2015). In the LIRA, bottles and glasses are exchanged for other items with vendors and re-used for other purposes in the houses, hence only a small portion constitutes part of the disposable waste.

E-waste Waste

The current study revealed that the LIRA generated the most e-waste (40%) whereas the MIRA and HIRA generated the same quantity of e-waste (30%) as is illustrated in Figure 4.1. The high portion contributed by the LIRA could be due to the low cost of mass produced electrical equipment of low quality and mostly afforded by the LIRA residents. However, such items cost more to fix and as a result, residents throw them away. Residents of the MIRA and HIRA are able to buy electrical equipment of higher quality and as a result, they last longer and the price of fixing the equipment is relatively low compared to the cost price. A study by An et al. (2015) in China uncovered that the informal e-waste sector consists of sites that extract the valuable parts of the electronics. The same is true in South Africa, that e-waste appliances are stripped into their components (e.g.: plastic, copper wires and metals), which then get recycled individually as opposed to disposing of the whole electrical appliance or gadget.

Soil and Textile Waste

The current study showed that the HIRA (40%) generated the most soil waste, which consisted of soil, dust and ash (Figure 4.1). The remaining income areas, LIRA and MIRA, both generated 30% of the soil waste. The high soil waste generated by the HIRA could be

attributed to the garden waste that results from pruning and maintaining gardens. The LIRA and MIRA's waste comprised mostly of ash resulting from the burnt waste. This is echoed by Nshimirimana (2004), who revealed that in the low-income areas, ash and soil represents a large proportion of the waste stream since most households use biomass for energy.

In terms of textile waste, the highest volumes were generated from the LIRA (41%), followed by the MIRA (35%) and then the HIRA (24%). The observed trends could be attributed to the increasing rates of globalisation, which has made it possible to mass produce clothing at increasingly lower prices (Claudio, 2007). Therefore, disposing of clothes is becoming a common phenomenon as more and more youth purchase 'fast fashion'. The term 'fast fashion' refers to clothing whose cost is cheaper than the cost of recycling (Birtwistle and Moore, 2007). The LIRA produced the highest textile waste and this could be due to the purchasing clothing of low quality, which does not last. Therefore, such clothes are repeatedly disposed of as they require frequent replacement as compared to the HIRA. Consequently, clothing purchased by the HIRA is of a higher quality and hence do not need repetitive replacements. In addition, the HIRA has access to internet, which then makes it easier for them to conduct domestic re-sales online. It has become a common trend to sell clothing and other used goods directly to other individuals via an auction websites such as eBay (Claudio, 2007).

4.3.2. Commercial Businesses Waste Composition

Several studies highlight that waste from commercial sources (especially commercial zones with shopping centers and markets) mainly comprises of paper and non-recyclable plastic (Ilyas et al., 2017). This is because the major activity that relates to the commercial sector is buying and selling, which involves paper packaging as well as plastic bags, hence the exorbitant amounts of recyclable papers and non-recyclable plastics within the waste stream (Ilyas et al., 2017). In this study, a total of 144 commercial institutions in 8 municipalities across the North West province were sampled. This section provides an overview of the obtained results and discusses the implications thereof.

Schools

In this study, paper emerged as the highest generated waste class comprising of 30% of the total waste, followed by plastic with 21%. Organic waste made up of 19% of the total waste.

The low volumes of organic waste could be due to the recycling that takes place at the school before the waste is collected (Figure 4.2).

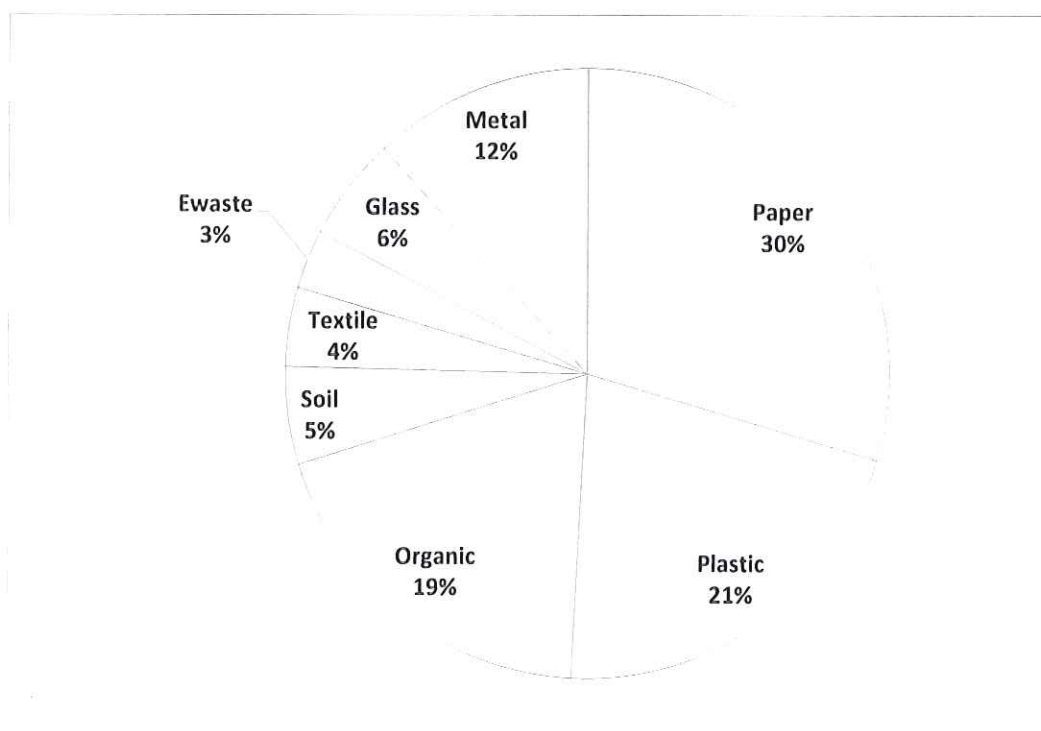


Figure 4.2: Average Amount of Waste Classes Generated in a School Daily.

Several schools across the country provide food to students as part of the South Africa's Primary School Feeding Scheme (PSFS), which was introduced by the former president under the "Presidential Lead Project" of the RDP in 1994 (Engelbrecht, 2005). Schools with feeding schemes usually reserve the peelings or rotten food waste for pig farmers, hence this waste does not make it to the landfill sites. In addition, most schools in the LIRA highlighted that the municipality does not collect their waste and as a result, they burn their waste, hence the total waste generated is not adequately represented.

The current study observed that primary schools generated more paper than high schools as their classroom activities involved drawing and snipping paper. The results obtained in this study are parallel to a previous study that was also conducted at a school in which paper and other paper waste got the highest percentage composition of the waste stream originating from the classrooms and school offices (Arazo, 2015).

In a case study of three schools in Florida (USA), the results showed that metal and glass comprised the smallest fraction of the waste stream (Wilkie et al., 2015). The same is true for

this study in which metal makes up only 12% and glass 6% of the total waste generated. This could possibly be because tuckshops at the schools prefer to sell their beverages in plastic bottles as opposed to cans and glass bottles. For instance, a study was carried out at some South African schools, which revealed the importance of reviewing school policies and practices that unintentionally perpetuated violence (Mthiyane, 2013). This was following an incident in which a 15-year old high school learner was recorded attacking a fellow pupil with a glass bottle on the school premises (Nzama, 2008). Therefore, incidents such as these influence the type of products that tuckshops on school premises stock. In so doing, this has a direct impact onto the resulting waste composition at schools.

Retails

In this study, paper waste comprised the highest waste class (37%) followed by plastic, which made up 27% of the waste stream. The most common plastics were consumables packaging from retail products (Figure 4.3). Due to the growing middle class as characterised by developing countries, there is an increase in consumer markets for plastic goods as well as the concomitant plastic packaging (Deloitte, 2003).

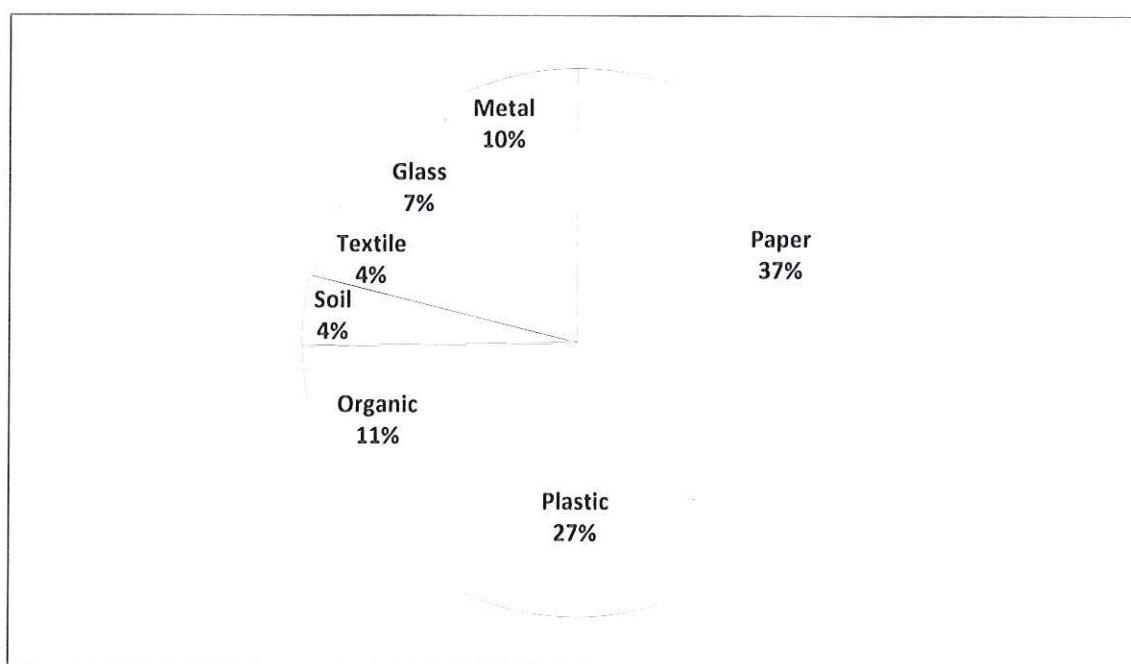


Figure 4.3: Average Amount of Waste Classes Generated in a Retail Daily

For the organic waste, 11% resulted primarily from the single serve take-out food, which was normally purchased by employees on duty. The obtained results are similar to a study, which

discovered that paper waste was the highest contributor of waste in retail stores compared to other waste classes (OQM, 2015). The subsequent waste classes produced in the OQM (2015) were plastic and organic, which are comparable to the current study.

The following waste classes i.e. glass and metal, made up 7% and 10% of the waste stream respectively. Glass and metal waste classes emerged as a result of either purchases by employees in the form of beverages i.e. aluminium cans or glass bottles; or as damaged goods, which formed part of a retail's trading inventory. Soil and textile waste classes both constituted 4% of the waste stream

More textiles were found in Clothing and Sports establishments, and more metals (primarily hangers) were found in the Other Retail category (OQM, 2015). The low level of soil quoted resulted from the dirt and dust emanating from sweeping the retail space. However, in this study, there was no e-waste identified in retail waste as most of them are taken for repairs or returned to the suppliers.

Service Providers

In this study, office based businesses such as banks, law firms, salons and insurance companies were surveyed and have been termed 'service providers'. The results found that highest waste produced is paper, making up 26% of the total waste stream as is shown in Figure 4.4. The outcome is similar to that of a study conducted by Aidoo (2005), which explored how people's activities in offices affect waste composition. It was found that the highest waste class generated was paper waste in the form of reports, print outs and junk mail (Aidoo, 2005). Similarly, in this study the sampled service providers generated paper in the same manner from their daily operations. However, despite paper being the highest waste produced in this sector, it is predicted to decrease as more and more service providers are going paperless in the advent of digital and online services.

This study had textile waste as the second highest generated waste, constituting 23% of the total generated waste from the "service providers." The high percentage of textile waste emanated from salons in the form of hair clippings and/or discarded hairpieces. The current study also observed worn out towels that are no longer used by salons in the waste. In some cases, depending on the length, Mills (2015) noted that hair clippings of a certain length could be used to make wigs while the rest can be used for composting. However, in the current study, all hair clipping and hair pieces are disposed of at the landfill.

The third type of waste generated from service providers was plastic (17%), which emerged in the form of packaging materials (i.e. plastic containing new cards for new bank users, shampoo and conditioner containers from salons and food packages for meals consumed by employees). Similarly, Aidoo (2005) observed that some of the plastics such as water bottles and cold drink bottles are recyclable plastics while others were non-recyclable plastics such as polystyrene foams, yoghurt pot, hot drink cups from vending machines and café, disposable drinking cups and cutlery. The remaining waste classes of glass, metal and organic make up 7%, 12% and 9% respectively. These waste classes are characteristic of meals that employees have at work. The soil waste class (6%) consists of the dust and dirt that is cleaned up from offices and the surrounding areas at the end of the day.

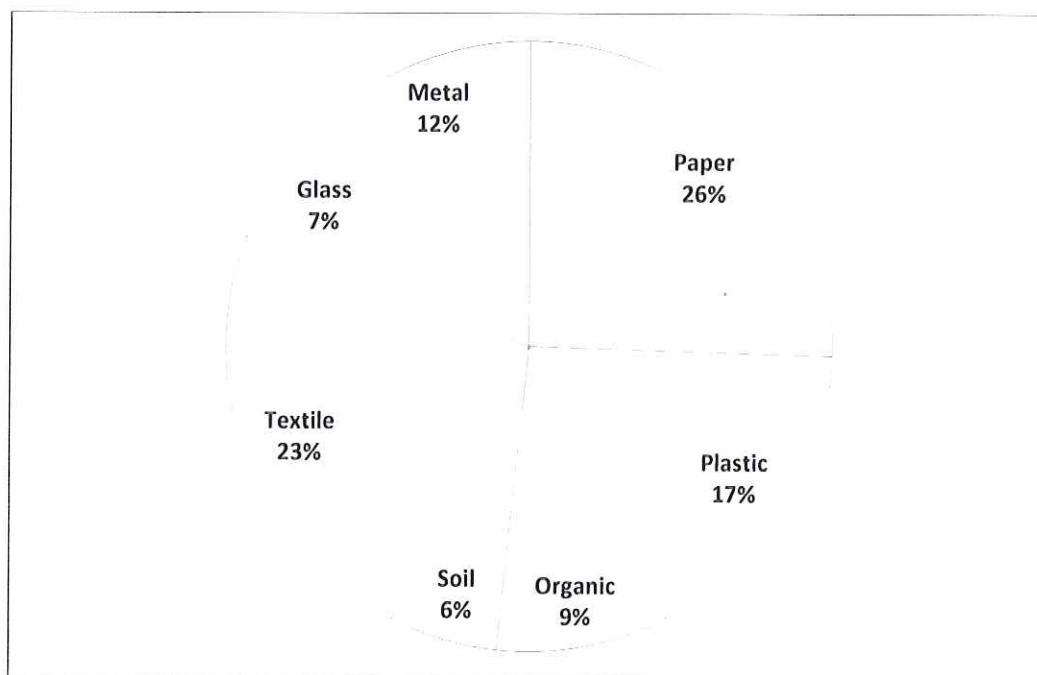


Figure 4.4: Average Amount of Waste Classes Generated from Service Providers.

Food outlets

The current study resulted in paper waste being the highest waste class generated, making up 27% of the total waste stream (Figure 4.5). Similarly, a study conducted in Austin (USA) on the waste composition of selected quick service (fast food) restaurants was carried out by the Austin Resource Recovery (ARR) (2012). The results showed that paper was the most generated waste class, with cardboard consisting a major part of the restaurants' waste stream (ARR, 2012). Therefore, paper waste constituted the largest portion of waste in food outlets, especially quick service restaurants as it is used as a packaging material. This was followed

by organic waste with 24%, then plastic and metal with 18% and 17% respectively (Figure 4.5).

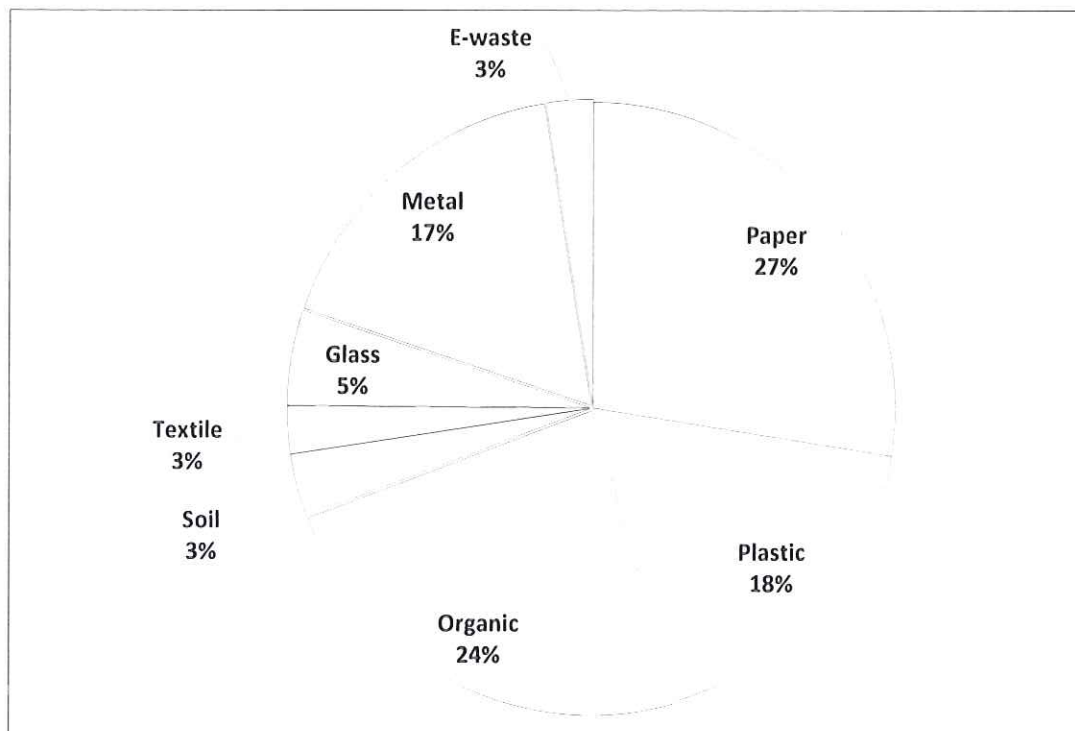


Figure 4.5: Average Amount of Waste Classes Generated in a Food Outlets.

The current study observed that organic waste constituted leftover food, vegetable peelings and used cooking oil. The same was observed in the ARR (2014) study, which indicated that fast food waste was made up of grease/grease trap waste as well as food scraps. However, during the study, it was noted that grease is either thrown out and ends up at the landfill or it is given to farmers or re-used by the food outlets.

Plastic waste comprised 18% of the total waste stream and includes items such as plastic bags for packaging, straws, disposable cups and cool drink bottles. Metal made up of 17% while glass made up 5%. Metals and glass result from the refreshments that are usually served with meals such as cool drink cans or juice/alcoholic beverages packaged in glass. From these results, it can be deduced that customers prefer their beverages in plastic bottles and cans more than in glass bottles. This is supported by a global survey in which industry players identified that plastics will continue replacing glass and metals; and flexible packaging will continue to replace rigid structures (Packaging World Magazine and DuPont Packaging and Industrial Polymers, 2012).

The remaining waste classes i.e. e-waste, textile and soil comprised of 3% each. E-waste and textile are not common waste items within food outlets however, there are some instances when there are found in the waste stream. This occurs especially when the bins can be accessed by the public or when employees dispose these waste classes at their workplace. In addition, literature has observed that restaurants display high generation levels on Sunday (Mongtoeun et al, 2014). This was also observed when sampling was conducted at selected food outlets on Monday mornings.

Recreational

Organic waste made up 28%, followed by paper waste with 24% and then plastic with 19% (Figure 4.6). The organic waste consists of food scraps and garden waste. The results can be likened to a study conducted by Chi (2005) in Vietnam, which showed that among the waste generated by the hotels, organic waste accounted for the largest percentage and consisted of leftover food followed by fruit waste, vegetable waste, and yard waste. In addition, studies show that factors that influence food waste in the hospitality industry, include: the amount of on-site food preparation, over-production of meals, menu choice and the extent to which consumers leave food uneaten (WRAP, 2013). The current study observed that paper waste emanates as a result of packaging materials and paper emanating from facilities that host conferences or workshops.

Plastic waste consisted of packaging material, bottles and disposable cutlery and plates. Metal made up 18%, while glass made up 5% and the remaining waste classes are textile and soil, which only make up a small percentage of 3% each. These results are similar to a study conducted by Trung and Kumar (2005) in a Vietnam hotel, which revealed that the highest waste emerged from food waste, followed by plastic/packaging then paper and lastly, aluminium cans.

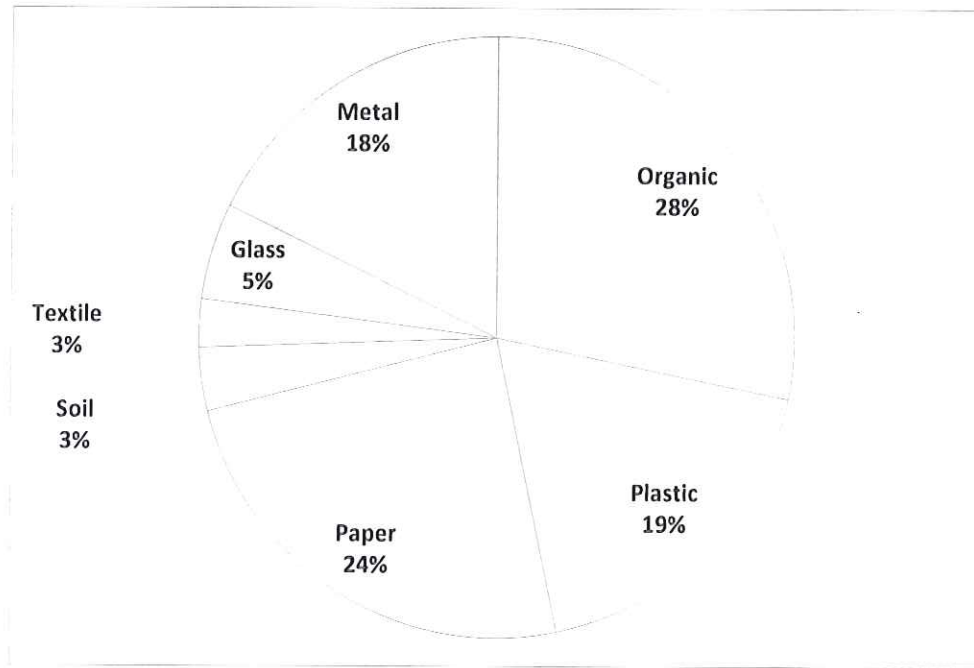


Figure 4.6: Average Amount of Waste Classes Generated in a Recreational Facility Daily.

Recreational places located in CBDs are usually busier than those that are in the outskirts of town. The frequency with which people book the place also determines the magnitude of waste that is generated since most recreational places can go for months without bookings, therefore, low waste generation can be expected during such times.

Auto and electronics

Auto and electronics denotes businesses that deal with cars and/or electronics. In the current study, the category 'auto' refers to businesses such as car dealerships, where cars are fixed and vehicle parts sold. Electronics refers to places where electrical items are fixed, bought, or sold. The current study revealed that paper (25%) and plastic (16%) comprised most of the waste as these are the materials used for packaging parts that may be required for repairs (Figure 4.7). The other waste classes generated from this category are glass and metals with 12% and 11% respectively. The metals arise from the small metal scraps generated during car repairs while the glass commonly emanates from broken windscreens. For the auto related waste, tyres made up most of the waste however, these tyres hardly make their way to the dumpsites. Initially, the Recycling and Economic Development Initiative of South Africa (REDISA) Waste Tyre Management used to collect tyres from various Auto Repairs but is currently no longer active. As a result, owners have now resorted to selling them to farmers or other stakeholders for recycling purposes. The remaining waste classes; organic (8%), soil

(6%) and e-waste (7%) are minimal, especially the e-waste since the majority of the parts are recycled.

In general, waste from these two categories is generally low because of the high rates of recycling that take place within these business entities. Studies have shown that the automobile manufacturers are using more environmentally friendly materials in manufacturing their cars, which then assists 'the End-of-life' vehicles to push the recycling process further. For instance, the currently recyclability is approximately 85% and recoverability 95% (Nawrocky et al., 2010; House et al., 2011; PRNewswire, 2015). In terms of electronics, surveys and literature estimate that about 80% of materials used can effectively be re-cycled (Moltó et al., 2011).

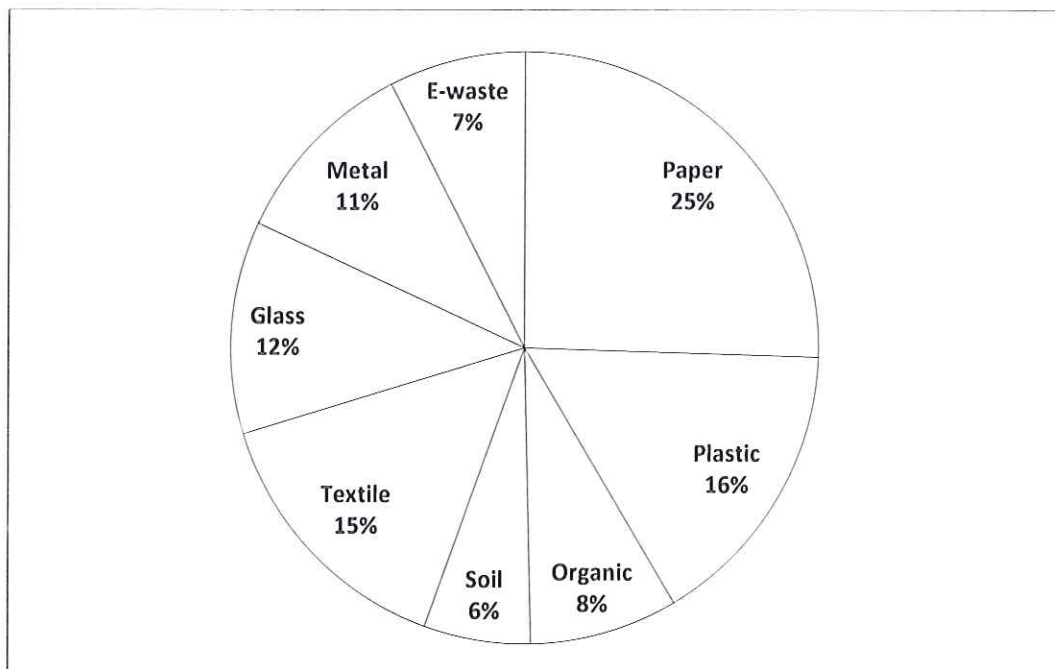


Figure 4.7: Average Waste Classes Generated in Auto and Electronics per day.

4.4. Waste treatment in the North West province



Waste management consists of several interrelated components that make up the waste cycle. These components, in broad terms, encompass the following: waste generation, on-site storage, collection, transfer stations/systems and either landfill, incineration or buy-back centres. In this study, the latter components of the waste cycle, where the waste is either disposed of at a landfill, incinerated or taken to a buy-back centre is termed 'waste treatment'. Landfill sites and buy-back centres were outlined in this study since they are

ubiquitous across the province, unlike incinerators. The waste treatment sites from the sampled municipalities were mapped in the GIS environment using ArcMap 10.2 software and the resultant map is illustrated in Figure 4.8. The map shows the locations of landfill sites in relation to the buy-back centres from the study area. However, it is important to note that the identified buy-back centres are not exhaustive as new ones emerge rapidly over a short period of time.

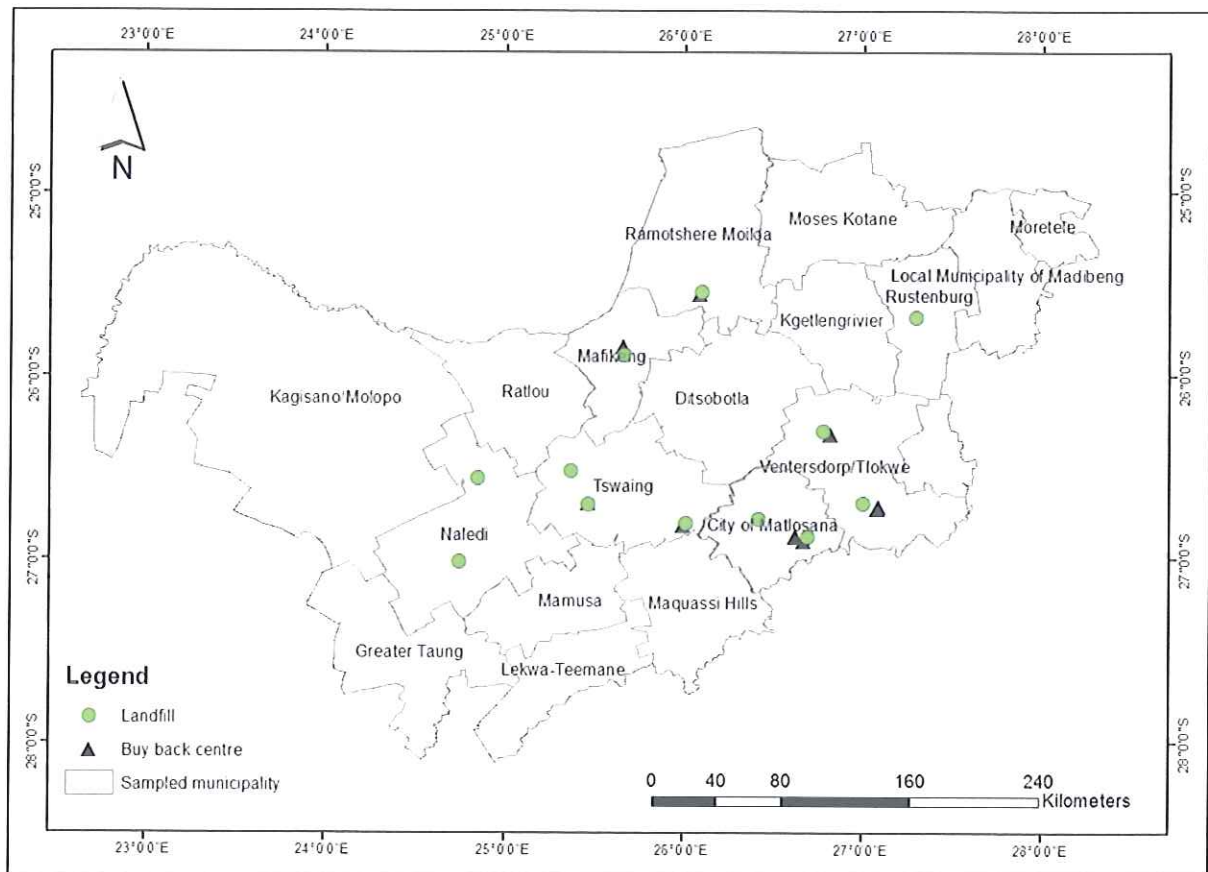


Figure 4.8: Waste Treatment Sites in the Sampled Municipalities.

4.4.1 Landfills

All municipalities have at least one landfill site. According to a report by AfriForum of 2015, it was revealed that only 1 landfill out of the 9 landfills that were audited, was compliant, namely the Vryburg Landfill (Naledi Municipality). The results of the report are summarised in Table 4.3.

According to Table 4.3, the Vryburg landfill complies with 92% of the minimum requirements and is considered to be the cleanest landfill site in the province. The worst

landfill site is that of Delareyville followed by Stella and Coligny. The bad conditions of these landfill sites are attributed to mismanagement, little to no law enforcement, corruption and a lack of training and competent employees. Out of the 83 landfill sites audited nationwide in 2016, 82% did not adhere to the minimum standards (Venter, 2017). Therefore, the state of the majority of landfill sites not only in the North West province but across South Africa, is not satisfactory and thus needs to be redressed.

Table 4.3: Comparison of best and worst landfills in North West province.

Best	Percentage	Worst	Percentage
Vryburg	92	Bloemhof	16
		Coligny	12
		Delareyville	8
		Klerksdorp	64
		Klerksdorp	68
		Stella	12
		Wolmaransstad	24
		Lichtenburg	20

*Source: AfriForum Annual landfill Report (2015) <https://www.afriforum.co.za/dirtiest-dumpsites-north-west/>

*The percentages represent the magnitude of compliance to conventions of Department of Environmental Affairs.

4.4.2 Buy-Back Centres

A buy-back centre refers to a facility, where individuals or groups bring recyclables in return for payment. All municipalities have at least one buy-back centre (Figure 4.8). The commonly recycled materials are paper, plastic, glass and metals. In most cases, these centres are usually located near the dumping site (Figure 4.8) as this minimises transport cost either for the centre or the re-claimers, who exchange recyclable materials for cash.

Buy-back centres, depending on their magnitude, process the recyclable materials for storage purposes before transporting them to Gauteng province, where the actual re-cycling takes place. Small scale centres have baler machinery whilst larger ones have grinding machinery, which reduce the volume of the re-cyclables and therefore, the maximum amount of the materials can be transported to the re-cycling companies (Figure 4.9). From the sampled municipalities in this study, only one buy-back centre located in Klerksdorp, re-cycled the materials to form new products.



Figure 4.9: (A) Machine Used To Granulate Recyclables - HD. (B) By-products of Granulating Process.

4.5. GIS database for waste in the province

A GIS database holds data that relates directly to location since it has geometry such as points, lines and polygons. The GIS database is similar to the The South African Waste Information System (SAWIS) system in that it also contains data on waste however, the major difference between the two is that the GIS database deals with data on a small scale. (SAWIS) is a system used by the government and industry to capture routine data on the tonnages of waste generated, recycled and disposed of in South Africa on a monthly and annual basis (NEMA, 2008). Whereas the GIS database collected waste data once-off as opposed to routinely as is the case with SAWIS. The waste data captured in the database emanates from the commercial sector as well as domestic households in the North West Province. The GIS database is advantageous because it also holds data about the locations of waste treatment facilities such as landfills and buy-back centres.

Geographic Information Systems (GIS) are powerful tools that assist in capturing, storing, manipulating, analysing and displaying spatial data (Chalkias and Lasaridi, 2011). Combining GIS with other related technologies such as Global Positioning System (GPS) and Remote Sensing (RS) allows recording of spatial data and direct use of these data for analysis as well as map creation. Therefore, GIS is relevant for waste management due to its ability to handle waste managements' complex nature. Several studies have shown that it has been acknowledged as one of the most favourable approaches to automate the process of waste management and planning (Ghose et al, 2006; Karadimas et al., 2007).

In the current study, the Drupal application was used to create a database and the resulting front-end layout of the database is depicted in Figure 4.10. After creating an account, a potential user can login into the database, in order to access the data. The tabs adjacent to the 'home' tab indicate the nature of data contained within the database. This data can be sorted by clicking on the name of the column that requires sorting. The data can also be imported to Microsoft Excel by clicking on the orange icon denoted 'XLS' at the bottom of the page

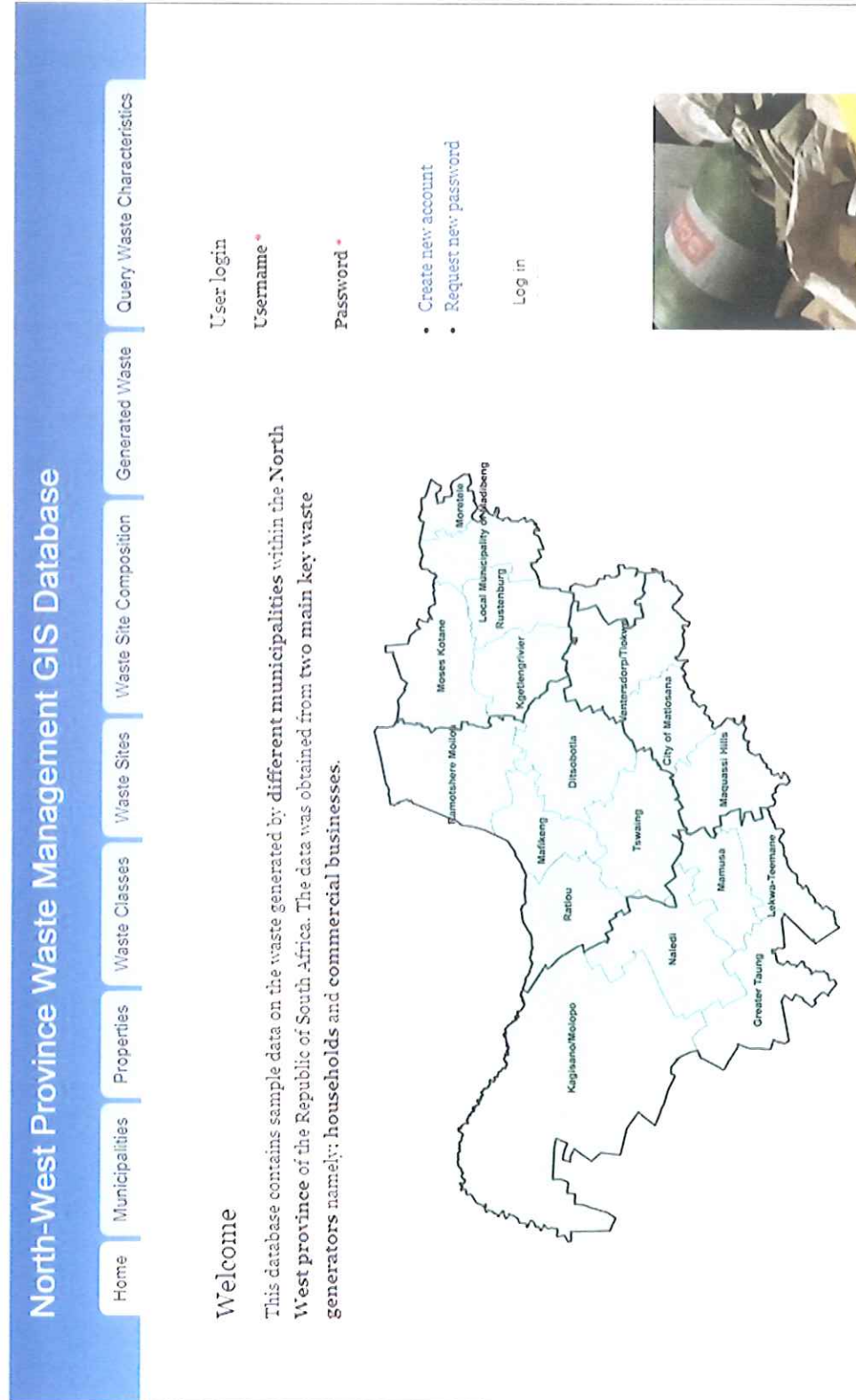
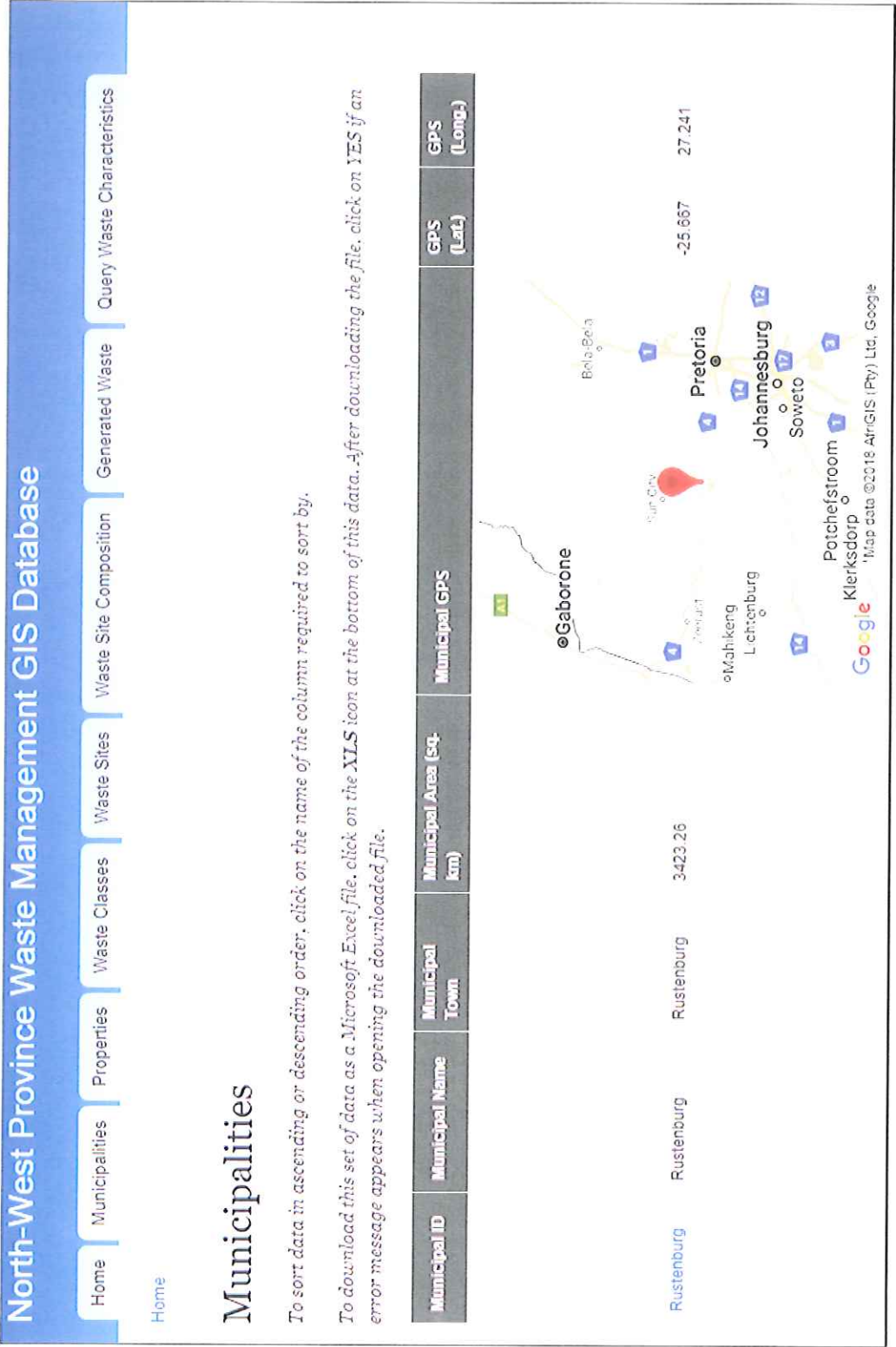


Figure 4.10: Home Page of the GIS Database

The first tab, *Municipality* (Figure 4.11) contains information about the municipalities that were sampled in this study to represent the North West province. The next tab is for *Properties* and it refers to the outlined waste generators described in section 4.2 of this dissertation i.e. households and businesses (Figure 4.12). The data can also be sorted or imported to Microsoft Excel for analysis. In this tab, Property ID entries are denoted according to the type i.e the households are denoted with the letter H whilst the businesses are denoted with B. For example, the households from Zeerust are labelled ZHS 1, ZHS 7 and businesses are denoted as ZBS 2, ZBS15 etc.



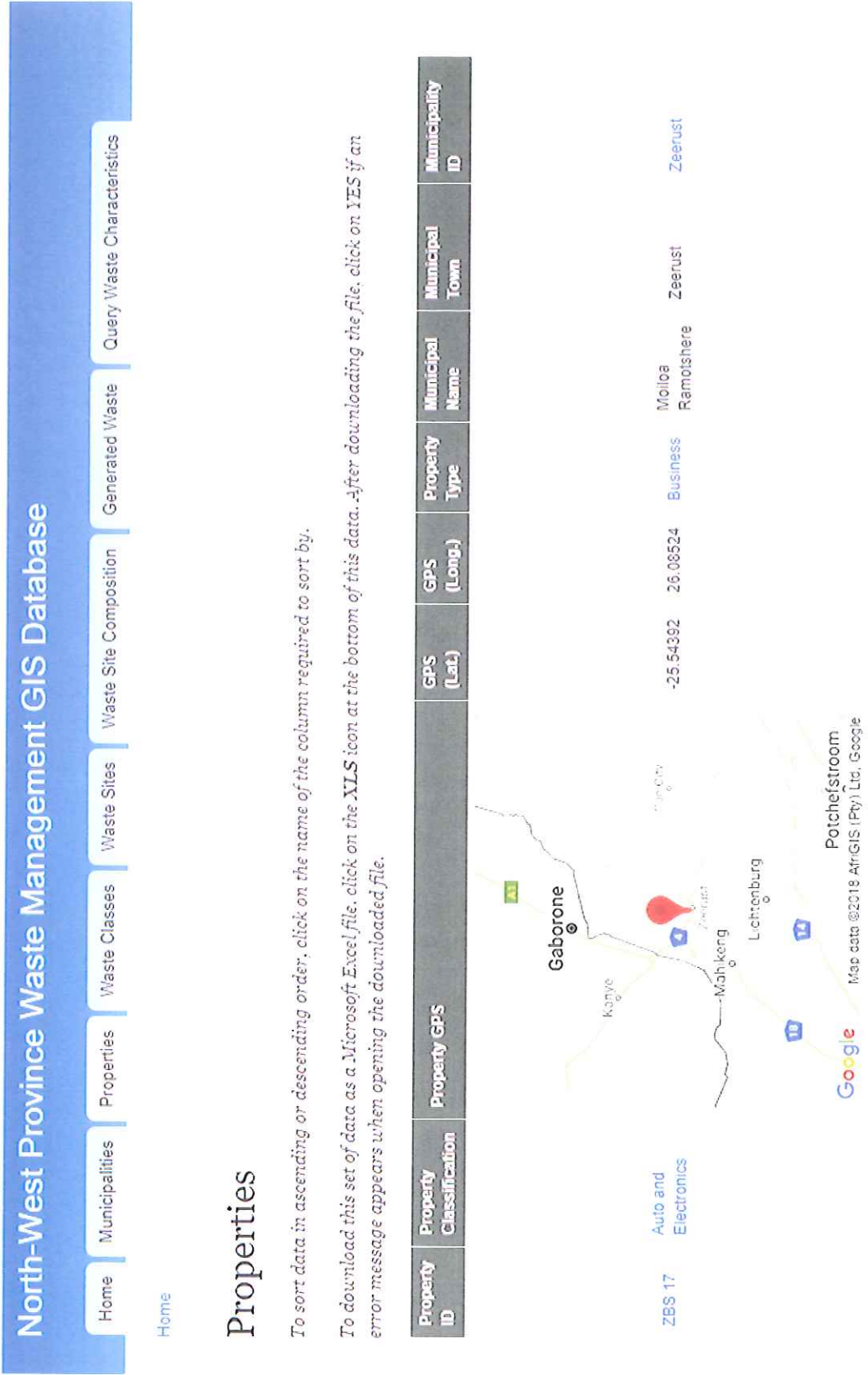


Figure 4.12: Tab showing data on the households and businesses, which are collectively termed ‘Properties’.

Waste Classes | North-West Province Waste Management GIS Database

[Home](#)
[Municipalities](#)
[Properties](#)
[Waste Classes](#)
[Waste Sites](#)
[Waste Site Composition](#)
[Generated Waste](#)
[Query Waste Characteristics](#)

Waste Classes

To sort data in ascending or descending order, click on the name of the column required to sort by.

To download this set of data as a Microsoft Excel file, click on the XLS icon at the bottom of this data. After downloading the file, click on YES if an error message appears when opening the downloaded file.

Waste Class	Description
Mixed contamination	Sanitary towels, bandages, disposable nappies
Glass	Glass bottles (broken)
E-waste	Electrical wires, cellphones, electrical appliances
Textile	Leather, clothing material, hair
Soil	Sandy material, ash, dust
Plastic	Polystyrene, plastic containers, bags, bottles
Metals	Aluminum, copper wires
Organic	Food, garden waste
Paper	White paper, card box

To download this set of data as a Microsoft Excel file, click on the XLS icon below. After downloading the file, click on YES if an error message appears when opening the downloaded file.

XLS

Figure 4.13: The *Waste Classes* tab gives a detailed description for the specified waste classes.

The *Waste sites* tab, Figure 4.14, presents data on the waste sites that have been outlined. A graphical representation of this data is in Figure 4.8. All the landfill sites contain all the waste classes, however, the buy-back centres do not contain all the waste classes. This is because it is not feasible to recycle all the waste classes. A summary of the waste classes, which can be found at the various waste sites is summarised in the *Waste Site composition* tab, Figure 4.15.

The *Generated waste* tab (Figure 4.16) contains data about the quantity of waste weighed at the different property locations. The *Query Waste Characteristics* tab (Figure 4.17) allows the user an opportunity to manipulate the Generated waste data for meaningful information. However, it is important to note that the household waste recorded is the estimated waste generated per week, whereas for businesses, it is recorded for daily waste.

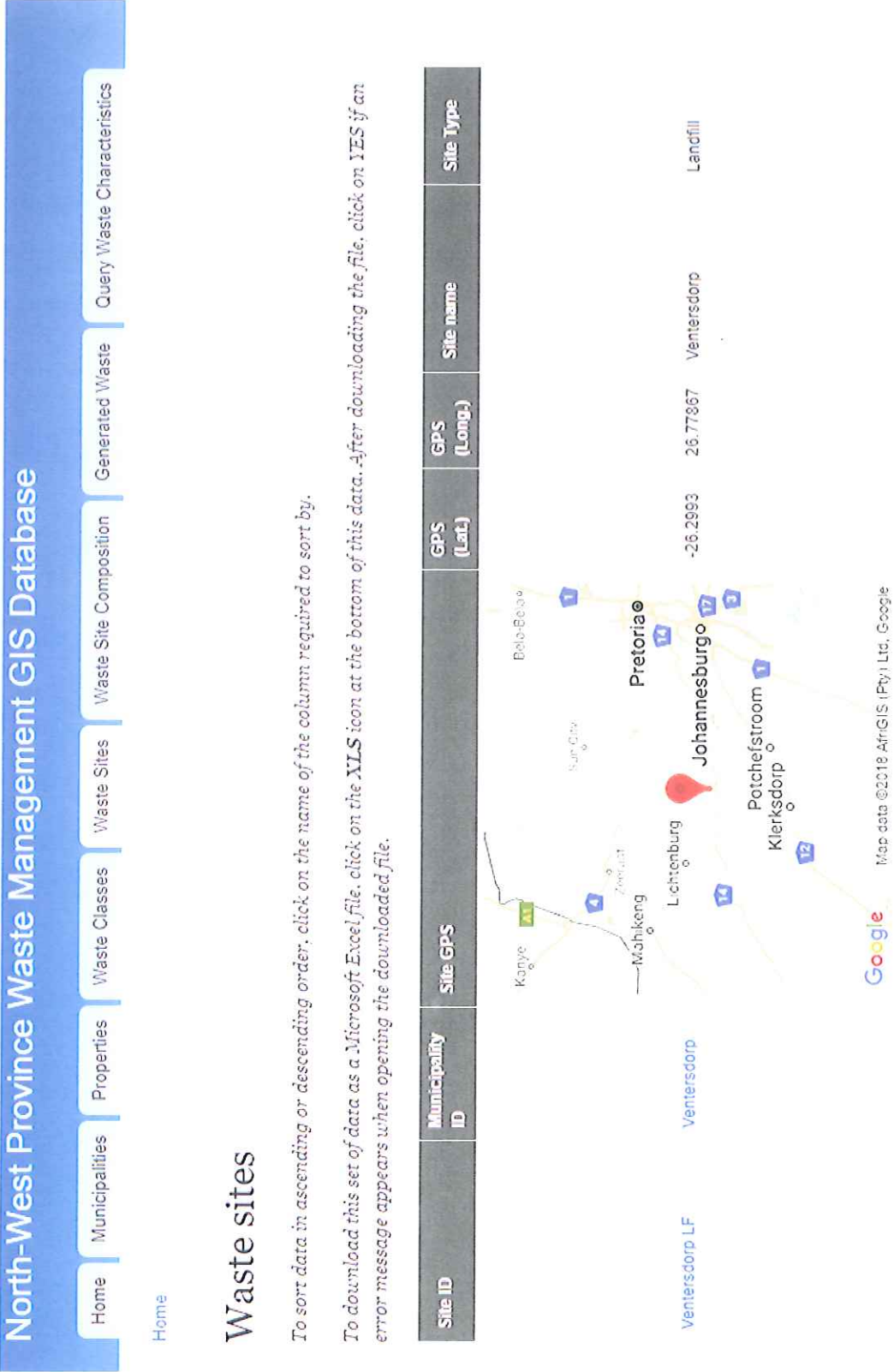


Figure 4.14: Waste Sites Tab

Waste Site Composition

[Home](#)
[Municipalities](#)
[Properties](#)
[Waste Classes](#)
[Waste Sites](#)
[Waste Site Composition](#)
[Generated Waste](#)
[Query Waste Characteristics](#)

Home

Waste Site Composition

To sort data in ascending or descending order, click on the name of the column required to sort by.

To download this set of data as a Microsoft Excel file, click on the **XLS** icon at the bottom of this data. After downloading the file, click on **YES** if an error message appears when opening the downloaded file.

Site name	Waste Type
Ventersdorp	Mixed contamination
Ventersdorp	Metallic
Ventersdorp	E-waste
Ventersdorp	Glass
Ventersdorp	Textile
Ventersdorp	Soil
Ventersdorp	Organic
Ventersdorp	Plastic
Ventersdorp	Paper
Waste Gang	Glass

123456789
next
last

To download this set of data as a Microsoft Excel file, click on the **XLS** icon at the bottom of this data. After downloading the file, click on **YES** if an error message appears when opening the downloaded file.

XLS

Figure 4.15: Waste Site Composition Tab

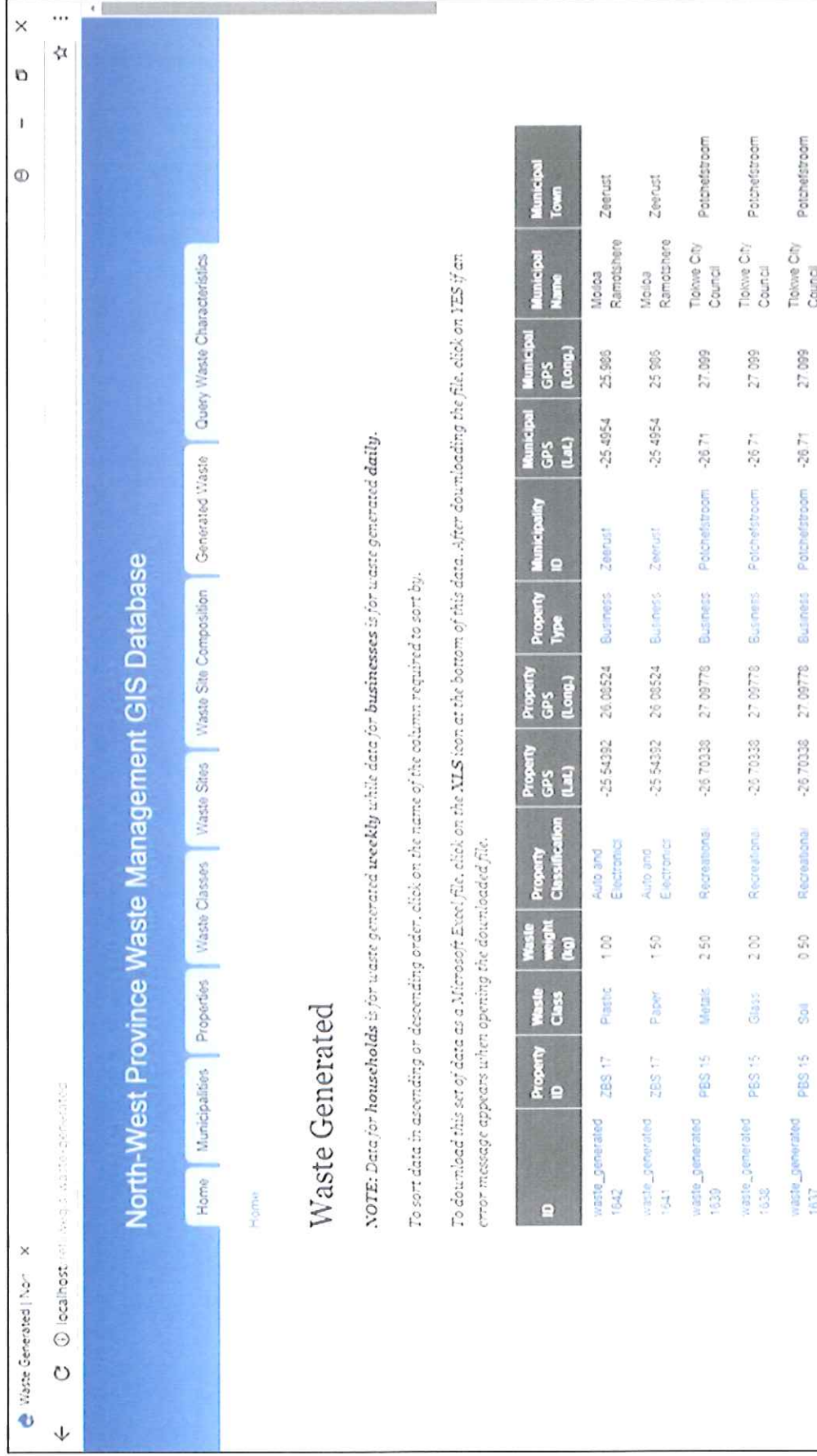


Figure 4.16: Generated Waste Tab

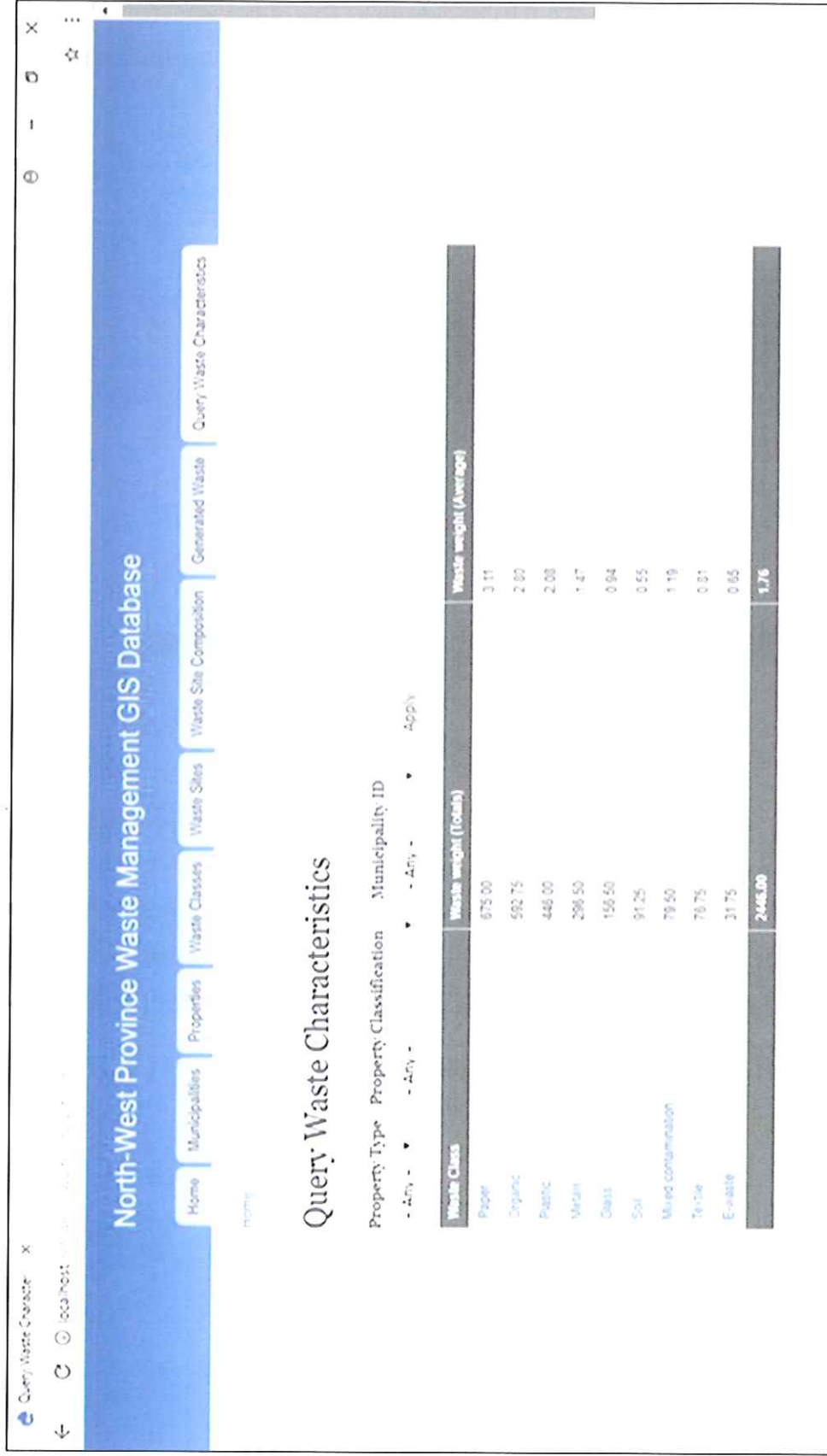
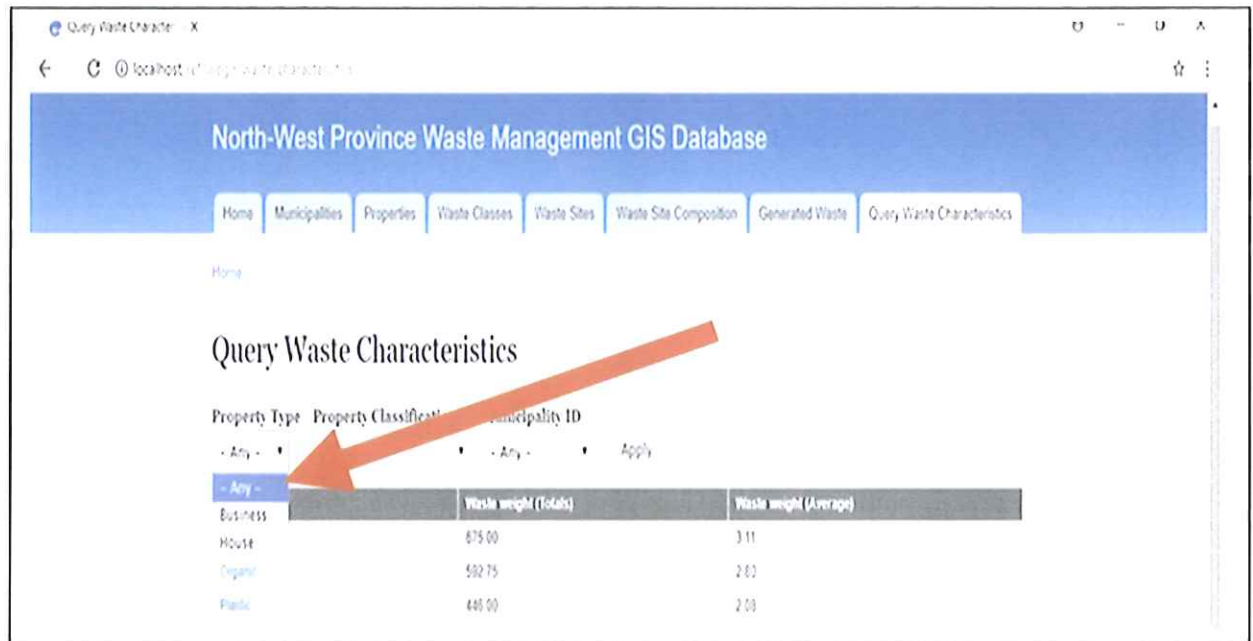


Figure 4.17: Query Waste Characteristics tab

Query building using the database

The process of building queries using the database involves five interactive steps in which various criteria can be selected depending on the desired data. The main data outcome is for the total waste and average waste and the data is presented in kilograms.

Step 1: Select the Property type of interest either House or Business.



North-West Province Waste Management GIS Database

Home Municipalities Properties Waste Classes Waste Sites Waste Site Composition Generated Waste Query Waste Characteristics

Home

Query Waste Characteristics

Property Type: Property Classification: Municipality ID: Apply

	Waste weight (Totals)	Waste weight (Average)
Business	875.00	3.11
House	592.75	2.83
Organic	440.00	2.09
Plastic		

Step 2: Once the property type has been specified, select the property classification that relates to the selected property type. For example, if the user selects 'House', they can then select either Low (A), Medium or High Income. However, if Business is selected (B), then the user can select either Auto/Electronics, Schools, Food Outlets, Recreational, Retail and Service providers. If the user selects 'Any', then it will automatically aggregate all the property types.

North-West Province Waste Management GIS Database

Home Municipalities Properties Waste Classes Waste Sites Waste Site Composition Generated Waste Query Waste Characteristics

Home

Query Waste Characteristics

Property Type: House Property Classification: - Any - Municipality ID: - Any - Apply

Waste Class	Weight (Totals)	Waste weight (Average)
Paper	32.75	3.11
Organic	149.00	2.82
Plastic	196.50	2.08
Metals	156.50	1.47
Glass	11.25	0.94
Soil and contaminant	19.50	0.55
Textile	78.75	0.81

Red arrow A points to the 'High Income House' row in the table. Red arrow B points to the 'Paper' row in the table.

Step 3: Following step 2, the user can select the municipality of interest, if 'Any' is selected, then all the municipalities will be taken into account.

North-West Province Waste Management GIS Database

Home Municipalities Properties Waste Classes Waste Sites Waste Site Composition Generated Waste Query Waste Characteristics

Home

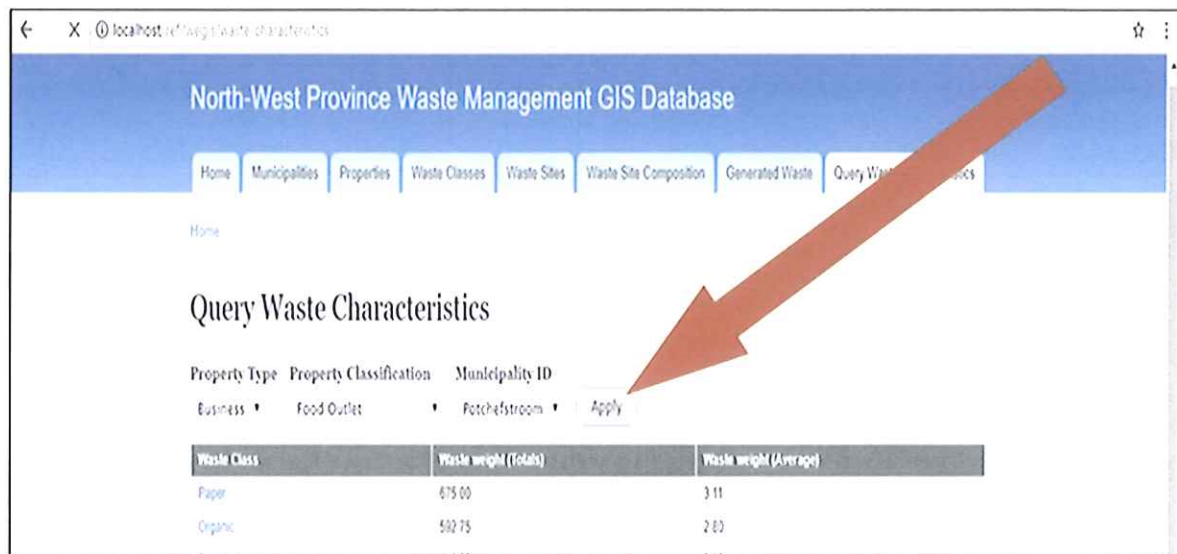
Query Waste Characteristics

Property Type: Business Property Classification: Food Outlet Municipality ID: - Any - Apply

Waste Class	Weight (Totals)	Waste weight (Average)
Paper	674	3.11
Organic	592	2.82
Plastic	449	2.08
Metals	296	1.47
Glass	155	0.94
Soil	91	0.55

Red arrow points to the 'Delareyville' row in the table.

Step 4: Once all the conditions have been set, the user can then click 'Apply'. The results obtained present the total quantity as well as the average weight of the various waste classes.



Example: If a user wants to query how much waste was generated by the 3 food outlets sampled in Potchefstroom, they would have to select Business for Property type followed by food outlet for Property classification and Potchefstroom for the municipality. The results are illustrated in Figure 4.18.

Waste Class	Waste weight (Totals)	Waste weight (Average)
Paper	22.00	7.33
Organic	15.00	5.00
Plastic	13.00	4.33
Metal	12.50	3.50
Glass	5.50	1.83
Soil	3.00	1.00
	69.00	3.83

Figure 4.18: Resultant Waste Characteristics for a Query on Waste Generated by Food Outlets in Potchefstroom.

Other User-cases:

The database can also be used for the following purposes:

- To locate schools (or any of the other business types) that generate a specific amount of waste per week.
- To approximate the average amount of waste generated by households per week in a specific location.
- To establish which class of households create the most waste in a specific location.
- To establish which recycling strategy would be best suited for a specific business or household type in a specific location.



4.6. Summary

From the household results, it can be denoted that organic waste was the highest waste class produced, which was in line with literature. This was followed by paper and plastic, which are the main materials used for packaging purposes. In addition, these materials have been predicted to continue replacing rigid structures such as metals and glass, which is why their percentage is minimal. In terms of commercial waste, paper consisted the highest percentage except for the recreational facilities. The study observed that the recreational facility trends were similar to households, hence organic waste was highest.

The state of landfill sites was examined and it was found that the majority of the landfill sites did not comply with the minimum requirements. In addition, the study found that the buy-back centres are usually located near landfill sites, which makes it easier for waste reclaimers to exchange their materials. With regards to the Buy Back Centres, there is only one centre that processes re-cycled materials to form new products, whereas the rest send their recycled materials to the Gauteng province for processing. The created GIS database demonstrated that the data can be manipulated by a user depending on their specifications. The following chapter will conclude on the study and provide recommendations on future studies emanating from the current study.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter recaps the aim and objectives of the study as explained in section 1.4.8 of Chapter 1, before continuing to highlight the major conclusions that were derived from the current study. In addition, this chapter also provides recommendations for future studies.

5.2 Limitations of the Study

All studies have limitations of some sort, and the same is true for this study. The limitations encountered in carrying out this study are highlighted in this section.

5.2.1 Labour Intensive Data Collection

One of the key limitations of the study was the fact that the data collection procedure was labour intensive and could not be carried out by the researcher alone; additional labour had to be appointed to assist in moving the waste around as well as in using the spring balance as this required strong individuals to lift the heavy volumes of waste. The appointed assistants were informed about the aims and objectives of the project and trained on how to classify waste. This made the classification process to proceed faster and hence the sample municipalities were covered timeously.

5.2.2 Factors Affecting Data Collection

The data collection process was during the months of June and July 2017, which is the winter season. Therefore, the data is biased towards a winter season as this is a cross-sectional study. The assumption here is that the data is representative of waste generated during any season of the year. However, the impact of seasonality on waste generation (seasonal variation) was outside the scope of this study.

5.2.3 Ethical issues

The collection of waste from the various waste generators was coupled with interviews. The interviewees were thoroughly informed of the research project, along with its aim and

objectives. The procedure for the interviews was clearly explained to interviewees before the interviews commenced. The location of the interview was up to the interviewees and alternatives were offered, either private or public. Confidentiality was observed as the interviewees were not named and permission to record (in writing) all the contributions made was sought from the interviewees before the interview. All questions were closed ended however, there were extra comments that were noted which helped with the statistical generalisation of the sampled data.

5.2.4 Waste Classification Procedure

During the fieldwork period, June - July 2017, the weather was characterised by windy conditions and as a result, the waste could not be emptied out onto a large layer of PVC or PP plastic (Figure 5.1) to allow mixing of the commercial waste as this would cause the waste to be dispersed by the wind. Instead, only one plastic bag was chosen for classification. This presented biased results in cases where the waste types were already classified.

In addition, the instrument used for weighing the waste had its limitations. The spring balance that was used for weighing the waste was an analogue one with 0.5 kg intervals, this means that all weights were rounded up or down to the nearest 0.5 kg as the arm used to read the measurements was dynamic, making it difficult to record accurate readings. Waste types which were below 0.5 kg were estimated by subtracting the already classified waste from the total mixed weight of the waste.



Figure 5.1: The Waste Characterization Procedure.

5.3 Conclusions

The aim of this study was to create a database for waste management using GIS so that it can be used as an integral component of the North West Province Integrated Waste Management Plan. The objectives were to collect and compile waste data from sampled municipalities followed by the creation of the GIS database for waste recycling in the province. Using these findings, the focus of the study was to create a GIS database for waste management in the province. The outlined methodologies were conducted and results obtained.

The study has led to the following conclusions against the aim and objectives:

1. The created GIS database provides data on the elements involved in the waste stream within a municipality. It provides data on the municipalities, the key waste generators, the waste classes generated by the waste generators as well as the associated quantities of the waste. It also provides data on the waste treatment sites and details the waste composition of the outlined waste sites. The database can also be used to manipulate data about the quantities of waste generated and the user can obtain the total quantities of waste sampled as well as the average waste generated per waste class, under pre-determined conditions. However, updating and uploading of new information remains the intellectual property of the creator.
2. The study revealed the following trends with regards to the waste data: from the households' results, organic waste was the highest waste class produced followed by paper and plastic, which are usually used for packaging purposes. Commercial waste mostly consisted of paper and plastic, which are commonly used for packaging purposes. However, recreational facilities, unlike the other commercial categories, followed trends similar to those of the household waste composition i.e. generated more organic waste than paper and plastic.
3. In mapping the waste treatment sites, landfills and buy-back centres, it was observed that in most cases, the landfill sites were located relatively close to the buy-back centres. This helps reduce transport costs for both the buy-back centres and reclaimers. In addition, there is only one buy-back centre that processes recycled materials to form new products. The study observed that many of the landfill sites did not satisfy the minimum requirements and the majority of the municipalities do not collect data for SAWIS.

5.4 Recommendations

In light of the study's findings, the following recommendations were made:

1. An integral GIS database should form a compulsory component of the integrated waste management plans as it can be an instrumental tool, if used effectively. The information that it provides can be useful in decision and policy making processes in all the municipalities, private recycling organisations and other relevant stakeholders.
2. Despite the present recycling initiatives in all the municipalities, more initiatives need to be established, particularly targeting malls, since they accommodate the majority of the different kinds of businesses, all under one roof i.e. retails, service providers and food outlets. Using information from the GIS database municipal officers can forecast waste generation over a certain period of time in a specific location. This can only be possible if the data is collected routinely as opposed to once-off as done in this study.
3. The North West government should consider setting up a buy-back centre that does recycling to form new products since there is only one that exists. This investment has the ability to pay off in the long run since most of the buy-back centres around the North West province will send recyclable material to the new built buy-back centre instead of Gauteng province, which is what is currently happening.
4. Future related research should consider the following:
 - A more sustained waste census in the form of a case-control type as opposed to the cross-sectional type, which was employed in this study.
 - Seasonal analysis should form part of the future related work to establish whether or not seasons influence the waste generation patterns across the municipalities.

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Appendix 1: Observation schedule

INFORMATION REQUIRED FROM LOCAL MUNICIPALITIES					
Local Municipality					
Contact Person					
1. Number of employees in the Waste Management Department					
Directors	Waste Managers	Supervisors	Casual Labourers	Landfill Supervisors	
2. Landfills					
Status	No. of Landfills	Names of Landfills			
Fenced					
Not fenced					
3. Waste Recycling					
		Names			
Number of buy back centres					

Number of Recycling centres					
4. Waste Information (Tick)					
Record					
Do not Record					
Send to SAWIS					
Do not send to SAWIS					
5. Vehicles					
Status	No. of Tractors	No. of compactors	No. of general trucks	No. of weighbridges	
Operation					
Non-operational					

Appendix 2: Interview schedule

DATE:

MUNICIPALITY NAME:

Name of business:										
Business type:	School	Food outlet	Service provider	Retailer	Recreational	Auto/electric				
GPS Coordinates										
Total weight of waste to be sampled										
Type	Plastic (bottles, containers...)	Paper/Card box	Organic(Food, garden waste)	E-waste	Glass	Metal	Textile	Soil/ash		
Weight										
Freq. of disposal	Once daily	Twice daily		Weekly		Monthly				
Approx size of waste disposed	Number of Plastic bags			Number of Bins			Number/ volume of card box			
Municipality/ Private	Municipality			Private						
Recycling	No	Yes:								
Comments:										