

THE IMPACT OF MUNICIPAL WASTE DISPOSAL FACILITIES ON WATER RESOURCES: A CASE STUDY OF THE UPPER VAAL WATER MANAGEMENT AREA IN SOUTH AFRICA

By

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DECLARATION OF INDEPENDENT WORK

I, HERBERT MALISE NOE, student number _____, hereby declare that this research project submitted to the Central University of Technology, Free State, for a Doctor of Philosophy in Environmental Health degree in Environmental Health is my own work and that it has not been submitted before to any institution by me or any other person in fulfilment of the requirements for the attainment of any qualification.

SIGNATURE OF STUDENT

17 July 2025
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SUMMARY

Solid waste management is a growing concern globally and features prominently in several Sustainable Development Goals (SDGs), including inclusive education (SDG 4), sustainable economic growth (SDG 8), sustainable cities (SDG 11), and responsible consumption and production (SDG 12). Yet, despite its relevance to sustainable development, South Africa continues to face a serious waste crisis. The country generated approximately 108 million tons of solid waste in 2012, with over 90% being landfilled. By 2017, waste volumes soared to 54.2 million tons per annum, including 66.9 million tons of hazardous waste. These figures highlight the troubling reality that South Africa's waste generation is rapidly increasing while landfilling remains the dominant yet unsustainable disposal method.

Municipalities across the country are struggling to cope with the sheer scale of the waste streams being produced, largely due to unprecedented population growth, urban extension, and the lack of infrastructure to establish new landfill sites. This has resulted in a dangerous reliance on unregulated and poorly managed landfilling practices. The consequences are far-reaching. Landfill leachates contaminate surface and groundwater sources, threatening both human health and biodiversity. Communities are increasingly exposed to polluted water, leading to the spread of diseases such as cholera, typhoid, and dysentery. Air pollution caused by dust, gas emissions, and chemical volatilization from landfill sites contributes to nearly 10% of adverse health effects, yet the threat is frequently overlooked in waste management practices and policy implementation.

The environmental toll is equally severe. Landfills are among the top emitters of greenhouse gases (GHGs) globally. In the United States (US) they account for 20% of total gaseous emissions, while in Malaysia landfills are responsible for a staggering 90% of the country's GHG emissions. These emissions are directly linked to six of the most pressing global challenges: climate change, biodiversity loss, poverty, population growth, deforestation, and water scarcity. Against this background, the continued use of landfilling in South Africa risks the reversal of critical human development gains. South Africa's waste management system currently experiences several challenges as

municipal solid waste is generated at levels that exceed the natural environment's ability to adapt to the waste streams dumped at landfills and other poorly managed sites. Yet, regardless of this dire condition, municipalities still dispose of waste by means of unregulated landfilling. Claims are that the cost of waste disposal on landfills is the cheapest when compared to other alternatives such as those that exist in the integrated waste management system hierarchy.

The current study uncovered severe deficiencies in landfill engineering, operations, and compliance. Many sites that were visited lacked basic structural safeguards, failed to report accurate waste data, and operated outside the regulatory frameworks outlined in the National Environmental Management: Waste Act (2008). This contradiction, where South Africa boasts one of the most progressive legal frameworks in Africa yet exhibits widespread non-compliance with waste management practices, points to deeper systemic issues such as inadequate funding, insufficient technical expertise, poor enforcement, and poor environmental awareness at local level.

Developed nations have successfully transitioned to more advanced **waste disposal technologies**. Japan incinerates 80% of its municipal waste, Sweden 50%, and Germany, where only 1% of waste goes to landfill, has embraced waste-to-energy solutions that generate heat and electricity while drastically reducing landfill use. South Africa, by comparison, lags behind due to infrastructural, financial, and policy-related challenges.

If South Africa is to meaningfully address its waste crisis and meet the SDG targets, urgent reforms are needed. This includes shifting towards a circular economy that encourages waste separation at household level, the prioritization of recycling, and a reduction of reliance on landfills. With escalating energy shortages due to Eskom's instability, investing in waste-to-energy technologies presents a dual opportunity to both manage waste and contribute to energy generation.

The aim of the study was to explore the reasons why municipalities do not comply with solid waste management regulations and to determine to what extent non-compliance occurs at water resources in South Africa. An objective of the study was to assess the

factors causing non-compliance by municipal-owned waste disposal facilities (also referred to as unregulated landfills) with available legislation and the impact of this oversight on water resources in the Vaal Water Management area. Four research questions were formulated to address the main objectives:

- What are the causes of municipal waste disposal facilities' failure to comply with legislative directives?
- What is the total cost incurred by waste disposal facilities in South Africa?
- What factors are associated with the prevalence of non-compliance by municipal-owned waste disposal facilities in South Africa?
- Which model or set of guidelines can be used to develop a cost-effective waste disposal strategy for municipalities in South Africa?

The development of a basic guideline for the planning and construction of small landfills in rural and developing areas is an outcome of the study (Appendix A).

Key findings revealed that inadequate service coverage, operational inefficiencies, limited utilization of recycling activities, poor management of hazardous waste, and inadequate landfill space limited effective waste management practices by municipalities regardless of sound policies.

From a financial perspective, municipalities may consider landfilling the cheapest waste disposal option. However, this is only true when external costs, environmental degradation, human health impacts, and biodiversity loss are ignored. In contrast, recycling and informal waste collection present a more sustainable and cost-effective alternative.

Guidelines that can be used for designing and operating landfills more efficiently in developing countries where other waste management practices are simply too costly are discussed. These guidelines propose a set of steps to design and operate successful landfill sites, including landfill site selection, the regular monitoring of geological and hydrological conditions, ensuring an efficient drainage system, considering site topography, and achieving mechanical stability. Managing landfills effectively is crucial because South Africa has limited water resources and leachate

generated by landfills pollutes groundwater resources. Generally, landfills in South Africa are inadequately operated. Proper operation of landfills requires meticulous measuring and record keeping, a procedure for unloading waste, waste compaction, cover material, leachate treatment, and landfill gas management.

This study examined the underlying reasons for municipal non-compliance with waste management legislation in the Upper Vaal Water Management area. A mixed-methods approach was employed using structured questionnaires. The findings are alarming. Daily waste volumes at the studied landfills ranged between 10.3 and 37.8 m³, reaching monthly volumes of over 1,100 m³. Despite nearly half of the landfills having projected lifespans of more than 16 years, poor waste management practices clearly accelerated their depletion.

Non-compliance by municipal-owned landfills in the Upper Vaal area were investigated and the impact of their practices on water resources in this region was determined. According to the results of the investigation, groundwater monitoring was either irregular or entirely absent in most municipalities, meaning that leachate contamination was undetected, and this endangered critical water resources in an already water-scarce area.

A key finding was that the distance between some residential dwellings and extensive, yet poorly managed, landfill sites was a mere one to two kilometres. In addition, 94% of the boreholes near these landfills still contained water Accessed on by residents. However, 58% of the municipalities did not conduct groundwater monitoring, while even those that did (42%) only monitored the groundwater quarterly or twice per annum. Moreover, compliance reports by municipalities were rarely submitted.

On a broader scale, the waste management policies and technologies utilised in South Africa were compared with those of developed countries. The implications of this investigation clearly showed that the commitment of all stakeholders, namely municipalities, residents (the community), businesses, and manufacturers is crucial if more sustainable household waste management practices are to be achieved.

Pertinent recommendations based on the findings pertaining to each research question are provided to conclude this thesis.

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CHAPTER ONE

INTRODUCTION AND BACKGROUND TO THE STUDY

1.1 Introduction

Rasmeni and Madyira (2019) iterate that municipal solid waste is a salient issue in many South African provinces. This is due to the lack of landfill capacity that has been caused by unprecedented population growth in both major cities and rural areas in conjunction with the lack of capacity to construct new landfill sites. In South Africa, waste management is experiencing several challenges, particularly as municipal solid waste is generated at levels that exceed the natural environment's ability to adapt to the impact of unprecedented waste disposal at landfills. It is unfortunate that, as a crisis management strategy, municipalities have continued to dispose of waste by engaging in unregulated landfilling practices (Tan *et al.*, 2015).

Bohm *et al.* (2010), who assessed the cost of municipal waste disposal and recycling, argue that landfilling it is the cheapest disposal strategy compared to other alternatives recommended as part of the integrated waste management system hierarchy. Various other authors agree with this notion, such as Talalaj (2013), Jerie and Tevera (2014), Scarlat *et al.* (2015), Tan *et al.* (2015) and Yazdani *et al.* (2015). Gworek *et al.* (2016) aver that 95% of the total municipal solid waste collected worldwide is disposed of on landfills. For example, approximately 98 million tonnes of total waste generated in South Africa per annum is disposed of on landfill sites (Department of Environmental Affairs, 2012). Therefore, there is clear evidence that landfill waste disposal remains the leading and most common method of waste disposal used by most South African municipalities.

The National Water Act of South Africa (Republic of South Africa, 1998) states that every South African citizen has the right to potable water. The minimum quantity is 25 litres per person per day, or 6 000 litres per household per month. Nyika, Onyari, Dinka and Bhardwaj (2021) confirm that improper waste disposal causes surface water runoff and groundwater pollution through leaching or infiltration. This means that affected sediments from surface runoff pollute open water bodies such as rivers, lakes, and

dams. Water contaminated by landfill leachate poses a major environmental risk to downstream users as they use this polluted water to meet their daily needs such as drinking it, using it for cooking, and washing themselves and their clothes in it. People who ingest contaminated water can contract waterborne diseases such as typhoid fever, cholera, and dysentery (Nyika, Onyari, Dinka and Bhardwaj, 2021). Water polluted by landfills also poses a threat to animals and aquatic life. Hence, if this situation remains unchecked, it will eventually contribute to the deterioration of the entire ecosystem.

Naruka (2012) observes that air pollution contributes to approximately 9.9% of adverse health effects. In addition, solid waste disposal causes air contamination through volatilisation, dust, and gas emissions. In light of the forgoing facts, it has been claimed that waste disposal through landfill may be the cheapest method only in terms of cost savings by municipalities as the cost to humans, animals, and the environment may be immeasurable in the long term. It is acknowledged that regulated landfills that apply full-cost accounting may not be the cheapest waste disposal method (Machete and Shale, 2015), but it is far more beneficial than the methods used irresponsibly. Tan *et al.* (2015) argue that recycling is less expensive than waste disposal by landfill at US\$90.25 per ton for waste disposal and US\$49.82 per ton for recycling. Moreover, it is estimated that waste pickers in South Africa save municipalities approximately R700 million per year in collection and disposal costs (Schenck *et al.*, 2019).

Scarlat *et al.* (2015) assert that landfill is a significant emitter of greenhouse gases (GHGs). For instance, 20% of the GHG emissions in the US comes from landfills (Birkenholz *et al.*, 2017). An earlier study also avers that about 90% of Malaysia's total greenhouse gas emissions originate from landfills (Tan *et al.*, 2015). These greenhouse gas emissions occur as a result of the high rate of waste disposal by landfill in Malaysia and pose a dire threat to the six significant global sustainability challenges, namely climate change, loss of biodiversity, population growth, poverty, deforestation, and scarcity of drinking water (Aja and Al-kayiem, 2014; Magazzino, Mele and Schneider, 2020; Paes, de Medeiros, Mancini, Gasol, Pons and Durany, 2020). Various authors have therefore argued that landfill waste disposal will ultimately have the undesirable consequences of lowering, and even reversing, human development gains (Schaltegger and Csutora, 2012; Colenbrander *et al.*, 2015; Messner, 2015). The notion that

landfilling is the cheapest way of waste disposal in the waste management hierarchy thus requires continued research and scientific scrutiny.

In developed countries, waste disposal has shifted from landfill to waste-to-energy technologies (Fedan *et al.*, 2015; Scarlat *et al.*, 2015; Tan *et al.*, 2015; Bundhoo *et al.*, 2016). For example, Japan incinerates 80% of its municipal solid waste, Germany 35%, Europe 24%, and Sweden 50%, while heat and other fuels are generated during this waste treatment process (Fedan *et al.*, 2015; Tan *et al.*, 2015). According to Tan *et al.* (2015), in Germany only about 1% of waste is disposed of on landfill sites. This country has thus demonstrated that there are benefits to disposing of waste using technologies other than landfill. However, waste disposal strategies in developing countries still differ vastly from those used in developed countries, to the detriment of the former.

Studies conducted in South Africa have affirmed that most municipal-owned landfills are unregulated (Worku, Snyman and Muchie, 2014). In addition, unregulated landfills that do not comply with statutory legislation result in environmental externalities and other societal risks emanating from soil, water, and air pollution (Vilas, 2015; Jingjing, 2014). According to Olukanni *et al.* (2014) and Yazdani *et al.* (2015), the non-compliance of municipal-owned landfills with statutory legislation may be attributed to the following: (1) the lack of technical knowledge; (2) poorly developed solid waste management guidelines; (3) lack of environmental consciousness; (4) insufficient resources (finances, equipment, poor and inefficient collection systems); (5) inadequate regulations; and (6) inadequate monitoring and penalties for contraventions. This is a puzzling dichotomy, as South Africa's legal framework for waste management is one of the most advanced in Africa as it clearly outlines the mandate of all government levels (national, provincial, and local) to adhere to non-maleficent waste management practices.

1.2 Research Objectives

The aim of the study was to explore the reasons why municipalities do not comply with solid waste management regulations and to determine to what extent this non-compliance impacts available water resources in the Upper Vaal water management area of South Africa. To achieve this aim, study objectives and questions were formulated. The first objective was to assess the factors that cause municipal-owned

waste disposal facilities, or unregulated landfill managers, to refrain from complying with available legislation, while another objective was to determine the impact of this non-compliance on water resources in South Africa. Previous studies (Tan *et al.*, 2015; Scarlat *et al.*, 2015; Fedan *et al.*, 2015; Bundhoo *et al.*, 2016) suggest that several factors cause non-compliance by municipal-owned unregulated landfills, but many of these factors were revealed by studies conducted abroad, and therefore the factors that elicit non-compliance in the South African context have remained relatively understudied and therefore unknown. To fill this gap, this research study addressed the following research questions:

- What are the causes of municipal waste disposal facilities' failure to comply with legislative directives?
- What is the total cost incurred by waste disposal facilities in South Africa?
- What factors are associated with the prevalence of non-compliance by municipal-owned waste disposal facilities in South Africa?
- Which model or set of guidelines can be used to develop a cost-effective waste disposal strategy for municipalities in South Africa? and
- What are the critical success factors that South Africa should adopt and implement for sustainable waste management?

1.3 Study Area

The Vaal Water Management area is divided into the upper, middle, and lower catchment areas. The map presented in Figure 1.1 provides a visual overview of the entire catchment area.

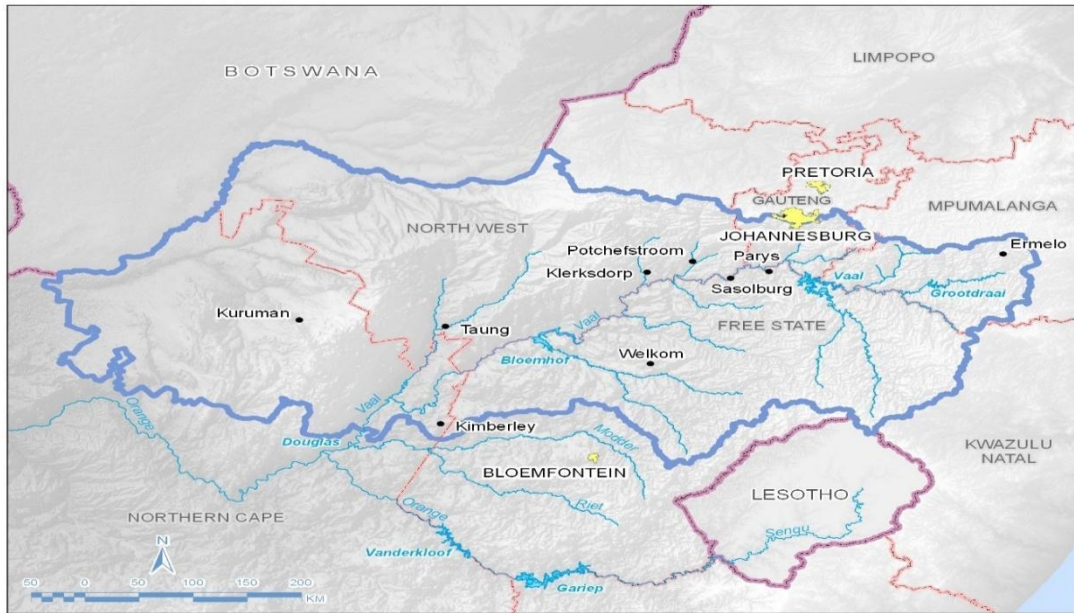


Figure 1.1: Map showing the Vaal Water Management area

Source: Department of Water and Sanitation (DWS), 2017

This study was conducted in the Upper Vaal Management area which comprises a catchment area of 55 565 km². This area is located towards the centre of the country and covers parts of four provinces (Figure 1.2).

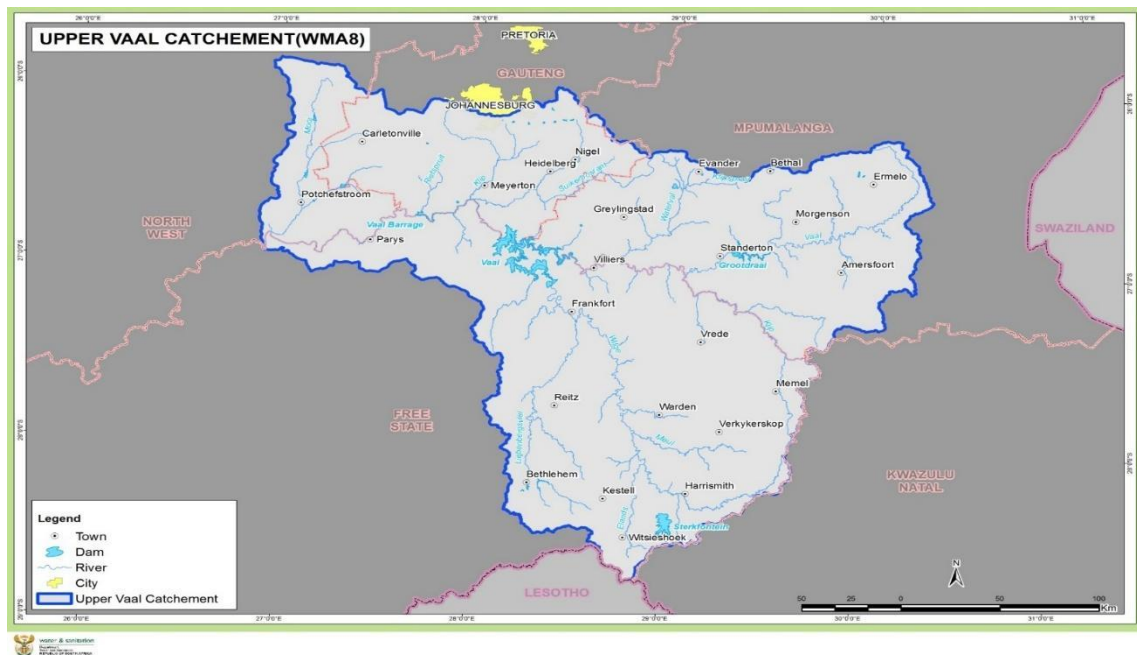


Figure 1.2: Upper Vaal catchment area

Source: DWS, 2017

The Upper Vaal catchment area is divided into sub-catchment regions that include the following water courses: the Mooi River, the Wilge River, the Upper and Lower Klip River, Rietklip, Rietspruit, Waterval, Leeu/Taaiboschspruit, Grootdraai, Vaal Dam, Suikerbosrand, Blesbokspruit, and Upper and Lower Wonderfonteinspruit. Also included in the catchment area are the Vaal, Grootdraai, and Sterkfontein dams.

According to the Department of Environmental Affairs (2012), South Africa generates approximately 98 million tonnes of municipal solid waste (MSW) annually, and the vast majority of this waste is disposed of on landfill sites. The municipalities contributing to MSW generation in the Upper Vaal management area include Dihlabeng, Nketoana, Midvaal, Mogale City, Merafong City, Rand West City, City of Johannesburg, Tlokwe, Ventersdorp, City of Matlosana, Rustenburg, Ngwathe, Metsimaholo, Mafube, Moqhaka, Midrand, Emfuleni, Lekwa Teemaneng, Dipaleseng, Msukaligwa, and Dr Pixley ka Isaka Seme. These areas are in the provinces of Northwest, Free State, Gauteng, and Mpumalanga. Some of the towns that resort under the above-mentioned municipalities where these waste disposal facilities are located are shown in Figure 1.2.

1.4 Layout of the chapters

This thesis comprises of six chapters, including the introductory chapter (Chapter one) that outlines the impact of municipal waste disposal and the study objectives and research questions.

Chapter two focuses on the causes of non-compliance with the regulations by municipal waste disposal facilities. A web search was done using Science Direct, Google, Google Scholar, and EBSCO Host databases. The search was limited to peer reviewed and non-peer reviewed journal articles and excluded other publications such as book chapters, newspaper articles, and conference proceedings. It was also limited by the year of publication by excluding articles that were published before 2009.

Chapter three expounds the development of a cost-effective tool for the management of waste disposal facilities. This integrated waste management (IWM) model offers guidelines to assess the information regarding waste management practices, with a

specific focus on waste management tools and the effective implementation of waste regulations.

Chapter four explores international legislation governing waste management. The South African government introduced waste disposal acts to regulate waste management in the country. Some of these acts are the National Environmental Management Waste Act of 2008 (Act No. 59 of 2008), the National Environmental Management Act of 1998 (Act No. 107 of 1998), the National Health Act (Act No. 61 of 2003), and the Air Quality Act (Act No. 39 of 2004).

Chapter five describes the data generation methodology that was employed to assess the knowledge, practices, and operations of waste disposal managers in charge of waste disposal facilities. Interviews were conducted, and it was found that most municipal operated sites experienced operation and maintenance challenges. Various waste management facilities in South Africa do not comply with waste management licence conditions as determined by the relevant licencing authorities. Therefore, licencing authorities need to ensure that the required conditions to obtain a waste management licence (WML) are met to minimise the current poor level of waste disposal operations to improve the environment and reduce the threat to human health.

Chapter six, which concludes this thesis, offers pertinent recommendations for improving the management of waste disposal practices and facilities. An extensive and longitudinal study should be conducted in all South Africa's provinces to assess the impact of landfills on the quality of groundwater resources across a broad spectrum. The limitation of the study was that it did not evaluate the impact of non-engineered landfills on the water quality of groundwater resources as the content of the water of boreholes, rivers, and dams near these facilities was not tested.

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CHAPTER TWO

THE IMPACT OF NON-COMPLIANCE BY MUNICIPAL-OWNED WASTE DISPOSAL FACILITIES ON WATER RESOURCES IN SOUTH AFRICA: A REVIEW

Abstract

Proper and appropriate solid waste management (SWM) ensures the health and well-being of humans, animals, and the environment. South Africa is a water-scarce country, and dire predictions have been made that water demand will soon supersede all available water resources (Thorne, 2025). Furthermore, municipal solid waste that is dumped on unregulated landfills pollute the little water that is available. Based on an extensive literature review, it was ascertained that minimal information was accessible on the challenges experienced by municipalities in managing solid municipal waste. The aim of the study was therefore to review relevant literature in the quest to determine the reasons why municipalities do not comply with solid waste management regulations and to ascertain to what extent this non-compliance impacts available water resources in South Africa.

This review considered both peer-reviewed and non-peer-reviewed articles on the non-compliance by municipal waste disposal facilities, with particular emphasis on the current South African waste management regulatory framework. The period of publication was determined and the study thus excluded articles published before 2009. A web search was conducted using the Science Direct, Google, Google Scholar, and EBSCO Host databases. Key findings revealed that inadequate service coverage, operational inefficiencies, limited utilization of recycling activities, poor management of hazardous waste, and inadequate landfill space are factors that contribute to ineffective municipal waste management. For example, in South Africa only 10% of waste is recycled, while 90% is disposed of on landfills. The extensive scope of these landfill operations has caused a dire shortage of land where solid waste can be discarded.

It is noteworthy that technologies exist to convert waste to electrical energy which could aid this country's struggling Electricity Supply Commission (Eskom) and reduce load-

shedding. Also, proper waste management will provide numerous additional employment opportunities that will reduce the high unemployment rate in South Africa. However, as neither of these options have been explored and implemented effectively by municipal waste facility managers, this study needed to be conducted to offer in-depth reasons for the imminent collapse of waste management structures associated with South African municipalities.

Keywords: Water scarcity; non-compliance; solid waste; waste management, landfills

2.1 Introduction

Solid waste management is a crucial imperative to achieve Sustainable Development Goals (SDGs) 3 and 6-12 (Table 2.1) as urged by the United Nations and numerous signatories. These goals mandate proper waste management for the achievement of good health and well-being through the provisioning of clean water, sanitation, recycling innovation, and sustainable cities and communities (Waste Aid, 2017). Globally, approximately seven billion people produce waste daily, and much of this waste is not collected, treated, and safely disposed of, causing a global waste crisis (Waste Aid, 2017).

Table 2.1: Sustainable development goals linked to solid waste management

SDG goal number	Description
SDG 3: Good health and well-being	Less exposure to diseases caused by open dumping and burning
SDG 6: Clean water and sanitation	Better sustainable water management goes hand in hand with WASH (Water, Sanitation, and Hygiene)
SDG 7: Affordable and clean energy	Bio-energy opportunities utilising organic waste
SDG 8: Decent work and economic growth opportunities	Waste management is the world's largest industry
SDG 9: Industry, innovation, and infrastructure	Recycling innovation is growing and scalable
SDG 10: Reduced inequalities	The poorest are harmed the most by poor waste management practices
SDG 11: Sustainable cities and communities	Better solid waste management is vital for healthy and resilient communities
SDG 12: Responsible consumption and production	There is a need to shift from waste disposal and dumping to resource management

In South Africa, municipal solid waste management is a salient issue as waste that is indiscriminately dumped pollutes water resources (groundwater and open water bodies such as rivers, dams, and lakes) and affects people's and animals' health while threatening environmental sustainability (Rasmeni and Madyira, 2019). Municipalities in South African provinces also face a solid waste disposal and management crisis due to the lack of landfill capacity (Rasmeni and Madyira, 2019). This is also linked to rapid population growth because, as the population grows, land becomes scarce due to land competition and landfill sites fill up much quicker due to the production of ever-increasing volumes of waste. Practices such as illegal dumping and burning of waste also threaten lives and environmental stability (Rasmeni and Madyira, 2019). In

addition, Rasmeni and Madyira (2019) affirm that the improper management of solid waste results in the emission of greenhouse gases that affect the earth's climate while further polluting the air and water sources near landfill sites. There is therefore a strong correlation between population concentration (generally in cities) and an increased demand for energy sources which, in turn, results in vast volumes of generated waste and improperly managed solid waste systems (Rasmeni and Madyira, 2019). Waste-to-energy facilities can contribute significantly to reaching waste management goals, sustainable development, and environmental protection if they mitigate greenhouse gas emissions and practise resource conservation (Rasmeni and Madyira, 2019), but these will need concerted efforts if inappropriate waste-to-landfill practices are continued.

Previous studies (Abdel-Shafy and Mansour, 2018; Chalhoub, 2018) indicated that approximately 71% of municipal solid waste is disposed of on landfill sites. Much of this waste contains hazardous substances (for instance, batteries, paints, mercury-containing waste, pharmaceuticals, and vehicle maintenance products) and other waste such as cardboard, paper, yard waste, and food that is biodegradable by anaerobic bacteria. Most municipalities in South Africa do not comply with statutory by-laws that regulate waste disposal because they are unregulated, and such waste sites cause water and soil pollution as well as methane emission (Dajic *et al.*, 2015). The main reason why municipalities do not tend to comply with statutory by-laws is the claim that the total cost of unregulated landfills is lower than that of regulated landfills (Machete and Shale, 2015). However, ineffective governmental policies and the ineffective implementation of existing legislation that should guide waste disposal cause inappropriate and sometimes dangerous waste disposal practices by municipalities (Department of Environmental Affairs, 2012). For example, various waste management facilities in South Africa do not comply with licensing authorities' waste management conditions (Braid, 2016). Therefore, licensing authorities need to ensure that the waste management license conditions are enforced to minimize the poor level of waste management operations that currently characterise many, if not all, municipalities in this country. Figure 2.1 presents a flow diagram illustrating the reasons for the collapse of the waste management system in South Africa.



Figure 2.1: Flow diagram illustrating the reasons for the collapse of the waste management system in South Africa

Source: Braid, 2016

This chapter is structured as follows: section 2.2 explains the search criteria used, section 2.3 reviews legislation governing solid waste disposal in South Africa, and section 2.4 elaborates on the solid waste disposal process. Section 2.5 provides more details on the challenges faced by municipalities when disposing of waste, and section 2.6 assesses the impact of poor solid waste disposal on water resources.

2.2 Search criteria

This review considered peer-reviewed and non-peer-reviewed articles that elucidated the non-compliance by municipal waste disposal facilities. A web search was conducted by accessing Science Direct, Google, Google Scholar, and EBSCO Host databases. The years of publication were also considered and the study excluded publications dated before 2009. A thematic method based on topics relevant to this paper's research aim was used to select the reviewed articles, as recommended by Machete *et al.* (2015).

2.3 Legislation governing solid waste disposal in South Africa

In South Africa, waste is governed by various pieces of legislation (South African Waste Management Information Centre, 2016) (Table 2.1). The primary legislation directly

linked to solid waste disposal is the National Environment Management: Waste Act No. 59 of 2008 (Department of Environmental Affairs, 2018) (hereafter referred to as the Act). This Act stipulates the norms and standards that determine the requirements for waste disposal on a landfill as stated in regulations 8(1) (b) and (c). In addition, this Act distinctly provides guidelines for a standard containment barrier design and classifies it as A, B, C, and D landfills (Figures 2.3-2.6).

Table 2.2: Laws governing waste disposal

Legislation	Description
The Constitution of the Republic of South Africa Act No. 108 of 1996	Section 24: Everyone has the right to an environment that is not harmful to their health or well-being.
National Environmental Management Act No. 107 of 1998	The principles set out in this Act apply throughout the Republic to the actions of all organs of state that may significantly affect the environment. Sustainable development requires the consideration of all relevant factors, including the following: (i) that the disturbance of ecosystems and loss of biological diversity are avoided, or, where they cannot be altogether avoided, are minimized and remedied; (ii) that pollution and degradation of the environment are avoided, or, where they cannot be altogether avoided, are minimized and remedied.
National Environmental Management Waste Act No. 59 of 2008	Section 43: Licensing authority: The Minister is the licensing authority unless otherwise indicated by the Minister by notice in the <i>Gazette</i> . The waste management activity involves the establishment, operation, cessation or decommissioning of a facility at which hazardous waste has been or is to be stored, treated or disposed of where: (b) the waste management activity involves obligations in terms of an international obligation, including the importation or exportation of hazardous waste; (c) the waste management activity is to be undertaken by— (i) a national department; (ii) a provincial department responsible for environmental affairs; or (iii) a statutory body, excluding any municipality, performing an exclusive competence of the national sphere of government; (d) the waste management activity will affect more than one province or traverse international boundaries; or

	(e) two or more waste management activities are to be undertaken at the same facility and the Minister is the licensing authority for any one of those activities.
Minimum Requirements for Waste Disposal by Landfill Waste (DWAF) 2 nd ed., 1998	Addresses landfill classification and the siting, investigation, design, operations, and monitoring of landfill sites. In the landfill classification system, a landfill is classified in terms of waste class, size of operation, and potential for significant leachate generation, all of which pose a risk to the environment. Graded requirements are then set for all aspects of landfilling, including public participation.
Minimum Requirements for Water Monitoring at Waste Management Facilities (DWAF, 2 nd ed., 1998)	These guidelines address the monitoring of water quality at and around waste disposal facilities
National Norms and Standards for Waste Classification and Management Regulations, Regulation 634	To regulate the classification and management of waste in a manner that supports and implements the provisions of the Act; To establish a mechanism and procedure for the listing of waste management activities that do not require a Waste Management License; To prescribe requirements for the disposal of waste to landfill; To prescribe requirements and timeframes for the management of certain wastes; and To prescribe the general duties of waste generators, transporters, and managers.
National Norms and Standards for the Assessment of Waste for Landfill Disposal, Regulation 635	To prescribe the requirements for the assessment of waste prior to disposal to landfill unless otherwise directed by the Minister to ensure a better environmental outcome, or in response to an emergency to protect human health, property, or the environment. Waste generators must ensure that their waste is assessed in accordance with the Norms and Standards for Assessment of Waste for Landfill Disposal, particularly in terms of section 7(1) of the Act, prior to the disposal of waste to landfill.
National Norms and Standards for Disposal of Waste to Landfill, Regulation 636	To determine the requirements for the disposal of waste to landfill unless otherwise directed by the Minister to ensure a better environmental outcome, or in response to an emergency so as to protect human health, property, or the environment. Waste generators must ensure that the disposal of waste to landfill is done in accordance with the Norms and Standards for Disposal of Waste to Landfill as set out in section 7(1) of the Act, and waste managers disposing of waste on landfills must only do so in accordance with the Norms and Standards for Disposal of Waste to Landfill in terms of section 7(1) of the Act.

There are also additional criteria that need to be met for waste disposal on a landfill based on the type of waste that needs to be discarded, i.e., type 0, type 1, type 2, type 3, and type 4 (Table 2.3A) (Department of Environmental Affairs, 2013). For example, type 0 waste cannot be disposed of on a landfill unless treated and re-assessed. Type 1 waste can be disposed of on a class A landfill, type 2 on a class B landfill, type 3 requires a class C landfill, and type 4 requires a class D landfill. These criteria are summarised and presented in APPENDIX A in Tables 2.3A to 2.3G attached at the end of this document (Department of Environmental Affairs, 2013).

The Act also stipulates restrictions based on the type of waste that can be disposed of on a landfill, ranging from immediate restriction to a maximum period of eight years (Figures 2.2 to 2.8).

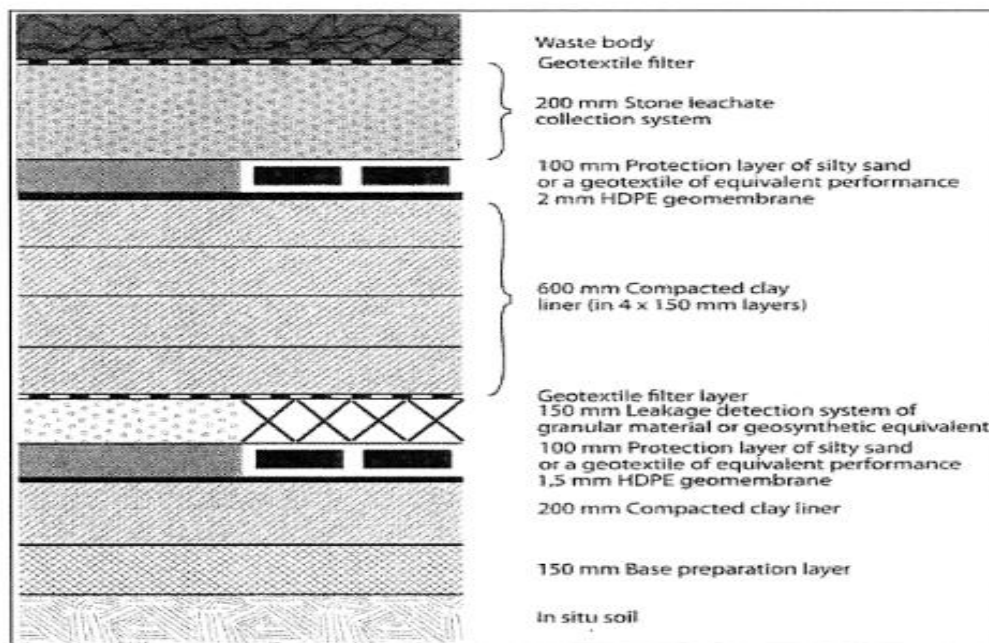


Figure 2.2: Class A landfill design requirements

Source: Department of Environmental Affairs, 2013

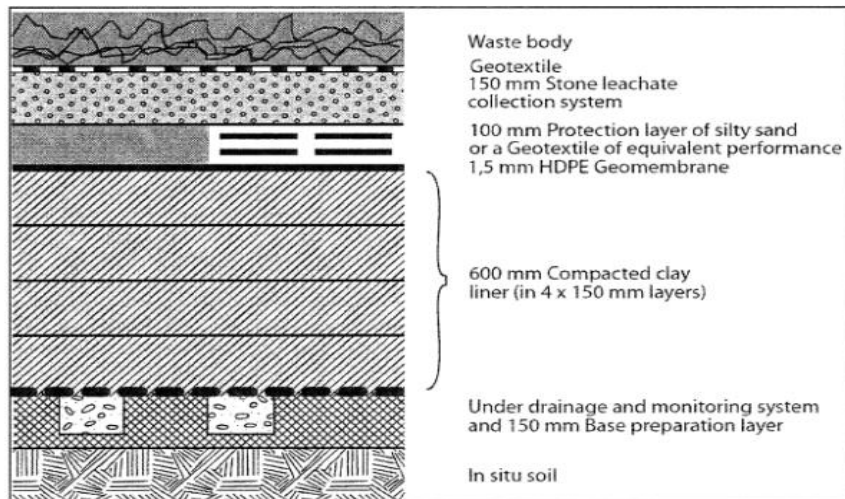


Figure 2.3: Class B landfill design requirements

Source: Department of Environmental Affairs, 2013

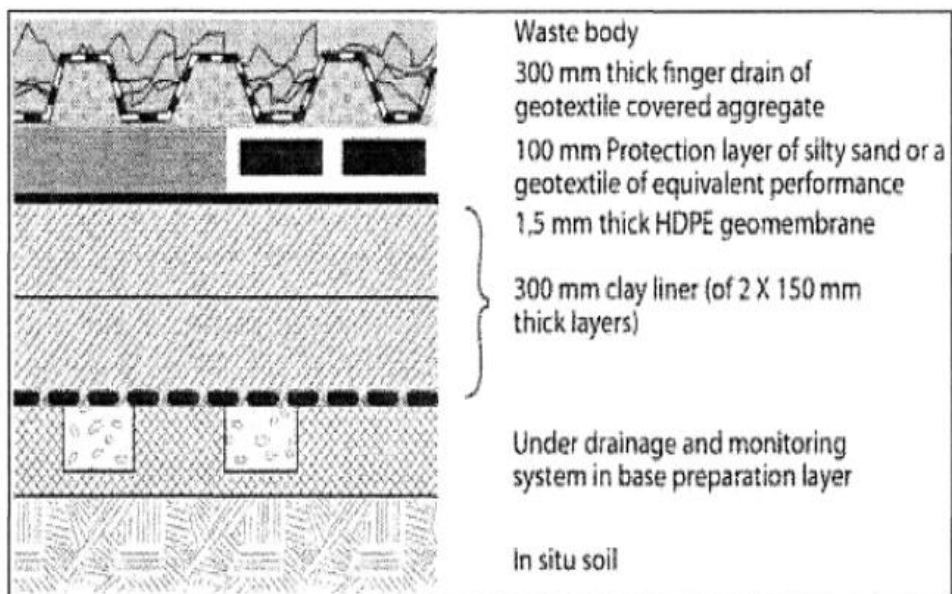


Figure 2.4: Class C landfill design requirements

Source: Department of Environmental Affairs, 2013

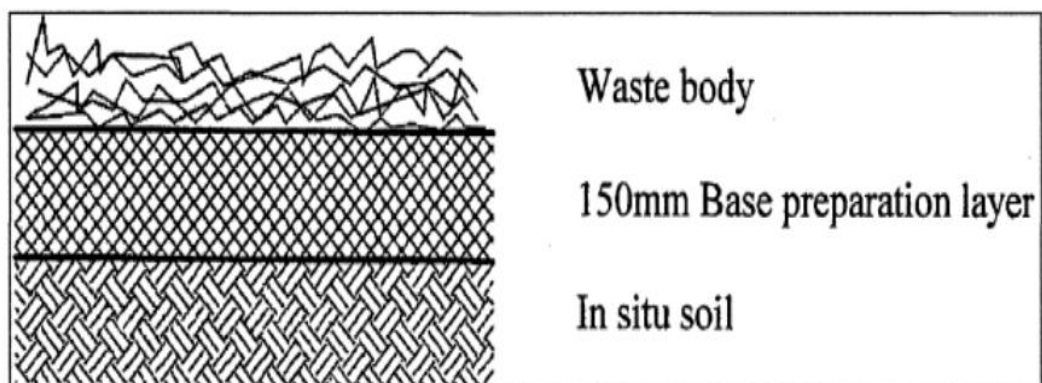


Figure 2.5: Class D landfill design requirements

Source: Department of Environmental Affairs, 2013

2.4 The municipal solid waste management process

Williams (2014) observed that the process of waste management is governed by the seven Rs of waste management: refuse, reduce, reuse, repair, re-gift, recover, and recycle.



Figure 2.6: The seven considerations in the waste management hierarchy

Source: Williams, 2014

Rasmeni and Madyira (2019) state that waste management entails collecting, transporting, processing, disposing of, and monitoring waste materials. The main elements of the waste hierarchy are briefly described by Rasmeni and Madyira (2019) as follows:

- **Waste Prevention:** waste prevention strategies include using less packaging and reusing products and materials.
- **Recycling and Composting:** this involves collecting, re-processing, and recovering particular waste material to make new material and
- **Disposal (landfilling and combustion):** These activities are used to manage waste that cannot be prevented or recycled.

A properly designed landfill should utilise technology to recover methane gas to generate energy. Methane gas which is one of the greenhouse gases that cause global warming. One pound of methane traps 25 times more heat in the atmosphere than a pound of carbon dioxide. Therefore, methane gas sourced from landfills can be burnt to produce electricity, and this will reduce the effects of climate change (Global Climate

Change, 2017). Smith (2020) describes the process of converting waste into energy to produce electricity in detail, and this is summarised in Figure 2.7. This process involves burning waste so that methane can be extracted. For example, in the United States of America (USA) landfills are designed with a digester that breaks down organic materials to produce biogas which generates approximately 17 billion kilowatt-hours of electricity and delivers 98 billion cubic feet of natural gas to households (Environmental and Energy Study Institute, 2021). In South Africa, various pilot projects have also been launched to convert waste into energy for electricity generation.

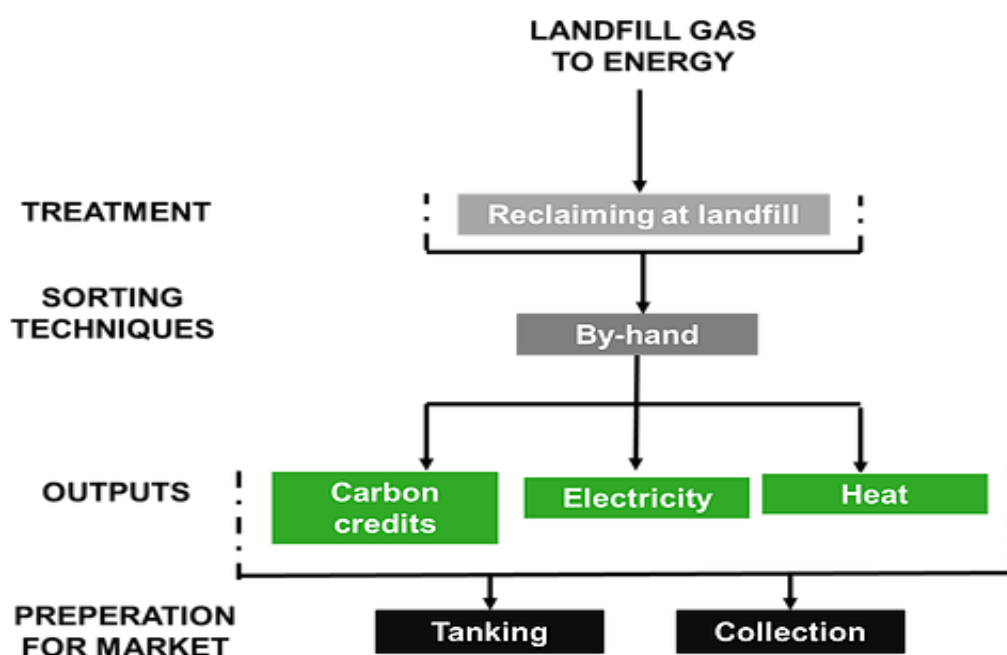


Figure 2.7: Conversion process of solid waste to landfill gas to energy

Source: Alternative Energy Solutions, 2022

Project 1: “Pick it up” is a private company that is contracted by the Johannesburg Metro to pick up/collect waste across this city (Rasmeni and Madyira, 2019). The company owns and operates a waste treatment facility (**Figure 2.8**) and has 11 strategically located waste management depots in the city. These depots include 48 garden waste transfer sites that are open to the public to dispose of garden waste that is transferred to a composting site in the West Rand. There is also the Robinson Deep Landfill where landfill gas is extracted through a network of wells; the gas is then flared as carbon dioxide to generate electricity. Greenhouse gases emitted during the energy generation process are recycled to reduce the emission of greenhouse gases into the atmosphere.

Post-consumer separation of waste at source requires the use of a three-bag system. Waste is then separated at source into bags for paper and other dry recyclables (plastic, tin, and glass). Although participation levels are low, the separation rate is 78% in the higher income group and 22% in the lower income group. Residual waste is collected and disposed of on landfill sites (CSIR, 2018).



Figure 2.8: Energy generating plant at Gauteng waste disposal facility to manage gas

Source: Noe, 2022

Project 2: In 2002, the World Bank did a study in collaboration with the University of KwaZulu-Natal to turn waste generated in the Durban area (eThekweni) into energy (Department of Environmental Affairs, 2003). The project was divided into two phases. In Phase 1, one MWe was installed at the Marianhill landfill site, and in Phase 2, a 6.5 MWe was installed at the Bissar Road landfill site. The benefits of the first phase were that it saved the eThekweni Municipality approximately R10.4 million and generated 24.91 MWh of electricity. The second phase saved the eThekweni Municipality an amount of R95 million and generated 240 MWh of electricity (Department of Environmental Affairs, 2003).

Project 3: The Ekurhuleni Metropolitan Municipality's recent installation of a one-megawatt (MW) landfill gas (LFG) generator at the Simmer and Jack landfill site in Germiston, Gauteng, represents a significant advancement in sustainable waste management and energy generation. This initiative aligns with global trends towards

utilizing landfill gas as a renewable energy source, which has gained traction particularly in South Africa where several operational LFG plants have been established (Nur, 2024). The conversion of landfill gas into electricity not only aids in reducing greenhouse gas emissions, but also contributes to local energy needs, thereby enhancing energy security (Nubi, 2023).

Moreover, the implementation of this LFG generator is consistent with the objectives outlined in the United Nations Sustainable Development Goals (SDGs), particularly those aimed at ensuring access to affordable and clean energy (SDG 7) and promoting sustainable cities and communities (SDG 11) (Tahiru, 2024). By converting waste into energy, the Ekurhuleni Metropolitan Municipality not only addresses waste management challenges, but also contributes to broader environmental and social goals, including reducing reliance on fossil fuels and enhancing local resilience against climate change (Nubi, 2024; Sharma, 2024).

2.5 Solid Waste Management challenges faced by Municipalities

Solid waste disposal is a major problem in urban and rural areas in developed and developing countries (Abdel-Shafy *et al.*, 2018). Previous studies have shown that the process of collection, storage, transportation, and final disposal of waste is a major problem in many urban areas. The main reason for this challenge is the poor economy of developing countries due to the unavailability of resources and competing priorities over resources (Abdel-Shafy *et al.*, 2018). Zurbrügg and Schertenleib (1998) identify five major problems that impede effective MSWM in developing countries:

- Inadequate service coverage;
- Operational inefficiencies;
- Limited utilization of recycling activities;
- Inadequate management of non-industrial hazardous waste; and
- Inappropriate waste disposal on landfills.

2.5.1 Inadequate service coverage and operational inefficiencies

Most developing countries lack resources to cope with the increasing volumes of waste that are generated by ever-growing populations. The norm is that resources for waste disposal are allocated to high-income areas with high tax yields and where residents

have more political influence. A technical problem is that the vehicles that are used for waste collection and disposal need to be sophisticated. However, they are expensive and difficult to maintain, and therefore most vehicles become non-operational after a short time due to non-maintenance and lethargy (Zurbrügg and Schertenleib, 1998). Conversely, operational efficient municipalities in developed countries spend 20-50% of their total municipal expenditure on solid waste disposal. However, in developing countries, approximately 70% of the solid waste that is collected serves only half of the population, and most waste volumes are discarded on uncontrolled open landfills (Zurbrügg and Schertenleib, 1998).

2.5.2 Limited utilization of recycling activities

The problem of limited recycling practices is particularly prevalent in developing countries. For instance, Statistics South Africa (2018) states that only 10% of waste is recycled in this country, while 90% of the waste is deposited on landfills. Poor management and escalating waste volumes have now resulted in a shortage of land for the disposal of solid waste. Recycling can play a crucial role in reducing waste that reaches landfills, but this strategy has not been as efficient as envisaged. For example, South Africa introduced a plastic bag levy in 2003 to reduce the high usage of plastics, particularly shopping bags. Because of the levy, people must pay extra for the plastic shopping bags they receive at supermarkets and other stores for packaging their purchases (Edokpayi *et al.*, 2016). However, although a significant drop of 20% in the use of plastic bags was recorded, Edokpayi *et al.* (2016) argue that this was a short-term reduction that did not result in positive change in plastic and other waste in this country.

2.5.3 Inadequate management of non-industrial hazardous waste

The inadequate management of non-industrial hazardous waste is a matter of serious concern in developing countries, and in South Africa in particular. Of the pathogenic waste that is generated by hospitals and clinics, 85% is regular, 10% is infectious, and 5% is non-infectious. Such waste must be separated into infectious, non-infectious, and hazardous waste containers for proper disposal. However, although hospitals and clinics generally separate their waste, most incinerators are out of order due to

maintenance issues (Zurbrügg and Schertenleib, 1998). The current circumstances result in the build-up of hazardous waste, which presents considerable health threats to healthcare personnel and nearby communities. Additionally, the inadequate disposal of such waste can lead to the contamination of soil and water resources, thus exacerbating environmental deterioration. The insufficient training of personnel involved in waste management further complicates the situation, leading to improper segregation methods and a heightened risk of exposure to harmful pathogens. Tackling these issues necessitates immediate action by policymakers, investment in the necessary infrastructure, and the establishment of comprehensive waste management training programs to safeguard public health and welfare.

2.5.4 Inadequate landfill disposal

In developing countries, most waste is disposed of in landfills, but most of these landfills are poorly managed, which creates various problems that affect human health and the environment (Zurbrügg and Schertenleib, 1998). Serious concerns have been expressed regarding soil, air, water, and aesthetic pollution which can cause human health disorders due to increased greenhouse gas emissions (Abdel-Shafy *et al.*, 2018). In addition, not only general household waste (HW) but also household hazardous waste (HHW) is disposed of on landfills, and there is great concern about the presence of several chemicals in some household products that are discarded as HW. The impact of such waste on the environment is of grave concern, and for this reason the disposal of HHW should comply with current legislation (Abdel-Shafy *et al.*, 2018).

2.6 Wasted disposal trends and opportunities for employment

Any solutions that are offered to resolve the identified problems in waste management disposal should be financially sustainable, technically feasible, socially and legally acceptable, and environmentally friendly (Abdel-Shafy *et al.*, 2018). In South Africa, waste disposal should occur as prescribed in the norms and guidelines that are part of the South African waste disposal framework. The lowest of the three-tier governmental structure is responsible for managing waste disposal. This tier comprises local governments, or municipalities, that are responsible for the budget for waste management in their respective areas of responsibility. They should thus correctly

Table 2.3: Employment growth associated with waste collection, treatment, and disposal

Year	Employment	Growth %
1996 – 1997	9 107	
2002 – 2003	14 386	7.90
2004 – 2005	26 617	36.00
2005 – 2006	26 492	-0.50
2006 – 2007	27 347	3.20

Source: Madubula and Makinta, 2014

Full cost accounting can be used as a decision-supporting tool in conjunction with the collection process. This should occur in conjunction with information on the alternatives that can be implemented while managing waste disposal. Cost assessment is vital to quantify cost-related issues of the waste disposal/recycling processes and to reach workable decisions. Cosgrove and Rijsberman (2018) state that the Financial Conduct Authority (FCA) is an accounting organisation/institution that can help local governments to calculate the actual costs for the improved management of waste systems and services.

2.7 The impact of solid waste management on water resources

South Africa is naturally water-scarce and is the 30th driest country in the world. It has been predicted that, by 2030, water demand will supersede available water resources in this country (Adam, 2021). To exacerbate the situation, available water bodies (rivers, dams, and boreholes) are being polluted. For example, the Vaal River has been polluted beyond acceptable levels, and this has affected natural ecosystems and endangered people's and animals' health (Adam, 2020). Makhadi *et al.* (2020) argue that, over the last decades, waste disposal by landfilling has been one of the main reasons for the contamination of water resources. Municipal solid waste creates vast quantities of pollution due to landfill leachate to both surface and groundwater resources. The leachate from landfills contains unacceptable amounts of dissolved organic carbon, salts, ammonium, and organic compounds (Makhadi *et al.*, 2020).

The geology of an area is one of the crucial factors to be considered when determining the suitability of an area for landfill construction or development. In the Mangaung Metropolitan Municipality, two landfills are currently being used for waste disposal, but neither meets the minimum requirements because they are inadequately designed as landfill sites (Makhadi *et al.*, 2020). For example, any landfill facility must have an underlying barrier line and leachate collection system, as well as proper controls for the health and safety of reclaimers (Makhadi *et al.*, 2020). A study that was conducted in Mangaung indicated that water from landfills was dominated by calcium, magnesium, sulphur, and total dissolved solids, all of which were above the South African National Standard and the World Health Organization's permissible limits for drinking water (Makhadi *et al.*, 2020). A comparative study that was conducted in Ethiopia found that leachate from landfills contained high total dissolved solids and heavy metals that exceeded acceptable levels (Mekonnen *et al.*, 2019). These and other similar studies have shown that most landfills in sub-Saharan Africa do not meet the minimum requirements for standard landfill. Moreover, these landfill sites are situated in terrains that also have a high number of ground and surface water resources, resulting in high rates of pollution of these water resources.

2.8 Summary and future research

The South African government has promulgated legislation to enforce proper waste management and disposal practices. The main legislative document governing solid waste disposal is the National Environmental Management Waste Act of 2008 (Act No. 59 of 2008) (Department of Environmental Affairs, 2019).

Most South African municipalities do not comply with environmental legislation and policies, thereby violating citizens' right to environmental protection. Poor and inappropriate waste management practices have a negative effect on air and water resources, while the Constitution of the Republic of South Africa's Bill of Rights (Republic of South Africa, 1996) clearly mandates the protection of all such resources. The key findings showed the benefits of converting waste into energy as this can add much needed electricity to the Eskom grid, thereby reducing the bane of load shedding in South Africa. In addition, proper waste management can provide employment opportunities and reduce the high unemployment rate in the country. This study suggests that future researchers should investigate the following:

- Developed countries' legislative documents and models that enable them to manage waste more efficiently. These practices should be compared with those utilised in South Africa and guidelines should be provided for the amendment of legislative documents to ensure appropriate and sustainable waste management practices in this country. Such research studies may contribute to identifying the weaknesses in current South African models and legislative documents, and gaps may then be addressed to enable South Africa's local governments to manage waste more efficiently.
- Studies like the current one need to be conducted in provinces and waste systems not included in this investigation to further assess the factors that cause the non-compliance of South African municipalities with solid waste disposal guidelines and available legislation. These studies could use open-ended questionnaires, structured questionnaires, and focus group discussions, or a combination of all three, to generate in-depth data that will further illuminate the issues associated with poor waste management.
- Detailed guidelines that provide a proper framework for solid waste disposal in South Africa should be developed. These guidelines should be incorporated in legislation that mandates the design and operations of municipal solid waste landfills, while severe penalties for transgressions should be implemented to quell any non-compliance with laws governing landfill site operations.

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CHAPTER THREE

GUIDELINES FOR THE DESIGN AND OPERATION OF SOLID WASTE LANDFILLS

Abstract

Landfilling operations remain the main vehicle for disposing of solid municipal waste, especially in sub-Saharan Africa. However, landfills negatively affect the environment as leachate and run-off water pollute groundwater resources. Various international organisations have developed guidelines to alleviate landfill operations' adverse consequences. However, these guidelines mostly apply to developed countries because of their economic capacities, whereas developing countries have limited budgets. The study's main aim was to recommend guidelines that can be utilised for designing and operating landfills that are suitable for the limited economic capacity of developing countries. The guidelines presented contain all the required steps for designing landfills, including landfill site selection, determining geological and hydrological conditions, constructing the drainage system, considering site topography, and determining mechanical stability. Moreover, the proper operation of landfills requires measuring waste volumes and meticulous record keeping, devising a procedure for unloading waste, ensuring waste compaction, providing and using cover material, leachate treatment, and landfill gas management. Managing landfills in this country appropriately is crucial because South Africa has limited water resources, and leachate generated from landfills pollutes groundwater resources that are irreplaceable. Various scholars agree that landfills in South Africa are inadequately operated, which means that waste management in this country is disastrous as 90% of all waste is deposited in landfills. It is recommended that these guidelines be utilised in line with legislative documents to manage solid waste more appropriately and adequately in South Africa.

Key words: Landfill; solid waste; transportation; dumping; land gas filling; leachate

3.1 Introduction

Landfilling is the most prevalent global disposal strategy for solid municipal waste. This method is predominantly applied in low- and middle-income countries that rely on landfilling despite evidence that there are less expensive waste disposal methods (World Bank, 2018). There is also sufficient evidence to suggest that waste that is dumped on landfills influences the environment negatively. Landfills cause pollution of groundwater and surface water, emits greenhouse gases, and can harm human health by contributing to illnesses such as lung cancer, stroke, and cardiovascular disease (Stegmann and Schönenberger, 2018). Various international organisations developed proposals that may be implemented to alleviate the negative consequences of landfill operations that have occurred over the past decades. These standards are available worldwide (Staniškis and Amodeo, 2020).

The major barrier, however, is that these strategies were developed for industrialised nations after considering their economic capacities (Kumar *et al.*, 2004). Therefore, because different countries have different budgets for solid waste management, they may not be appropriate for low- or middle-income countries. Another essential factor influencing landfill emissions is the volume of water that enters (infiltrates) into the waste body (and, by extension, the environmental pollution caused by landfilling). This water is required for the following processes: (1) the microbial biodegradation process; (2) landfill gas generation; (3) pollutant dissolving; and (4) leachate production (Rathore and Das, 2021). As a result, the emissions from landfills are highly dependent on current meteorological conditions. Low- and middle-income countries are generally geographically located in tropical and subtropical zones, which means their average temperatures are higher and more intense throughout the year than those of European countries that are more developed and are geographically located in temperate zones. This means that their average temperatures are lower and more stable throughout the year (Gomez-Sanchez and Vanegas-Ramirez, 2021).

3.2 Purpose of chapter and research questions

The purpose of this chapter is to:

- Recommend guidelines that can be utilised for designing and operating landfills in countries with limited economic capacity; and
- Devise these guidelines in line with South African conditions so that they can guide landfill operators and waste management authorities in the developing world.

The first section (3.3) includes advice for planning and operating landfills, while the second section (3.4) discusses and reviews the preceding information.

3.3. Initial steps in landfill design

Liu *et al.* (2021) assert that the primary goal of landfilling is to provide storage of waste to ensure that it does not affect human health and the surrounding environment. Therefore, waste that is disposed of in the environment should be emission-free (Othman and Azmi, 2022). Vouk *et al.* (2020) mention that another option for environmentally sound landfilling is intensive pre-treatment of all waste types before disposal to prevent hazardous emissions. The latter concept is called ‘final storage landfill’ and usually requires expensive pre-treatment, which will not be affordable for developing countries (Adewole *et al.*, 2020). The International Solid Waste Association recently released detailed guidelines for landfill operations (Cossu, 2020). The steps that are followed when designing landfills are discussed in the following sections.

3.3.1 Landfill site selection

To minimize the impact of landfills on human health and the environment, it is recommended that a site is located at a minimum distance of 500 meters from occupied structures, streams, and water bodies and as far away as possible from any water sources and agricultural activities. With urban populations rapidly increasing in many developing countries, city planners should consider future land use when selecting a site for landfill disposal (Nguyen *et al.*, 2021). Furthermore, it is essential to consider the proximity of airports when selecting a location for landfill disposal. The distance between

the landfill and the airport should be increased to prevent bird strikes. For certain airports, aircraft paths may require distances greater than a few kilometres (Nagalingam and Babu, 2020; Waheed *et al.*, 2020). Conversely, Dery and Kaya (2020) and Awogbemi *et al.* (2021) recommend that distances be kept to a minimum because the cost of waste disposal transportation is almost directly proportional to distance.

Another consideration is the possibility of constructing a buffer zone. A buffer zone should exist between the landfill and residential and even industrial areas. This buffer zone should prevent vectors from migrating to these areas, absorb dust generated by landfill equipment and waste collection vehicles, and reduce noise and odour nuisances caused by the landfill or dumping operations (Almeida *et al.*, 2020; Komolafe *et al.*, 2020; Yadav and Khare, 2021). Such a buffer zone could consist of unused farmland or densely forested vegetation. At Buffelsdraai, a landfill in eThekweni, South Africa, a buffer zone was planted with trees and grass to create a dense forest area.

3.3.2 Geological and hydrological conditions

Landfills should be situated in geological and hydrological settings where the subsurface layers have low hydraulic conductivity of less than $1 \times 10^{-8} \text{ m s}^{-1}$ (Ahmed and Hossain, 2021; Dhiman and Tyagi, 2021; Si *et al.*, 2021). Optimal landfill siting involves selecting locations with subsurface layers that have low hydraulic conductivity ($<1 \times 10^{-8} \text{ m/s}$), which can potentially obviate the need for an artificial liner and result in lower construction costs. Groundwater monitoring systems must also consider the direction of groundwater flow, which depends on the geological and hydrogeological conditions at the site. However, these conditions cannot be reliably obtained from geological maps alone and must be assessed on site during site selection (Kim *et al.*, 2021; Yilmaz and Kirca, 2021; Zeybek *et al.*, 2021).

In considering the suitability of a site for the development of a landfill, it is necessary to have extensive information on the present and future use of groundwater and other water bodies. If nearby water bodies are currently being used as a source of drinking water or have the potential to be used for drinking water in the future, the site may be unsuitable due to the risk of groundwater contamination that comes with landfill operations, and this should preclude a site from being selected as it contains a fatal flaw

(Alhameid *et al.*, 2021; Hailu *et al.*, 2021; Kaczorowska and Rogala, 2021; Kaya and Kaya, 2021).

3.3.3 Transportation of waste

Locating waste disposal sites far away from communities can lead to increased transportation costs and safety concerns for the locals, such as a high risk of automobile accidents, noise pollution, and air pollution (Jain *et al.*, 2020). Access roads to landfills are almost as important as minimizing transportation distances as their construction and maintenance can incur considerable costs for the municipality, which can increase the overall cost of waste disposal (Dąbrowski and Kulczycka, 2020).

3.3.4 Site topography

The costs associated with landfilling are significantly affected by a site's geography. In an ideal situation, the site's topography and a suitable landfill design can be utilised to manage leachate flows without the need for pumping, thus relying only on the gravity flow of the leachate. This is feasible if the landfill design is appropriate and there is a difference in elevation between the landfill's drainage layers, the leachate collection basins, the leachate treatment facility, and the final leachate disposal site (Figure 3.1) (Jia *et al.*, 2019; Wei and Li, 2020; Liu *et al.*, 2021).



Figure 3.1: Construction of the leachate collection basin in the Free State province landfill site

Source: Noe, 2018

3.4 Landfill design

Baseline systems and drainage are important factors that should be considered in landfill design. Landfill design consists of several phases or processes that are discussed in the following sections, namely:

- Baselining systems
- Drainage systems and
- Mechanical stability.

3.4.1 Baselining systems

Due to the actual organic content of waste and increased precipitation rates in developing nations, the emission of leachate from waste buried in landfills is a significant concern (Gernaey *et al.*, 2019; Kibria *et al.*, 2019; Yu *et al.*, 2021). As a result, proper landfill design is required (Melo and Soares, 2021). To design appropriate landfills for developing countries, it is essential to follow principles that ensure waste segregation at point of origin and throughout the landfill operation. One approach to achieve this objective is to construct a basal lining system (Huang *et al.*, 2019; Karim *et al.*, 2020; Zhang and Chen, 2021). Legislation governing landfill operations in developed countries

often mandates the installation of a composite liner at the bottom of the landfill. This liner typically consists of a layer of clay sandwiched between sheets of high-density polyethylene (HDPE) (Figure 3.2) and is typically 40 to 80 cm thick (Cossu and Lai, 2019; Zhang and Chen, 2020; Jahandideh *et al.*, 2021).



Figure 3.2: High-density polyethylene material for lining the landfill site

Source: Noe, 2022

In contrast to developed countries, developing nations often face limitations in building a composite liner due to resource constraints. Therefore, it is suggested that they utilize a single baseliner system that is composed of compacted clay layers (Figure 3.3). It is preferable to have access to clay material near the landfill site to minimize transportation costs and traffic volumes. Hence, selecting a suitable site is crucial to minimize overall landfill expenses (Rahman and Hossain, 2021). International regulations governing landfill construction, such as the EU Landfill Directive, can be utilized to determine the required degree of clay compaction and hydraulic conductivity. In general, the hydraulic conductivity of the clay should be less than 1×10^{-9} meters per second (Farooq *et al.*, 2020).

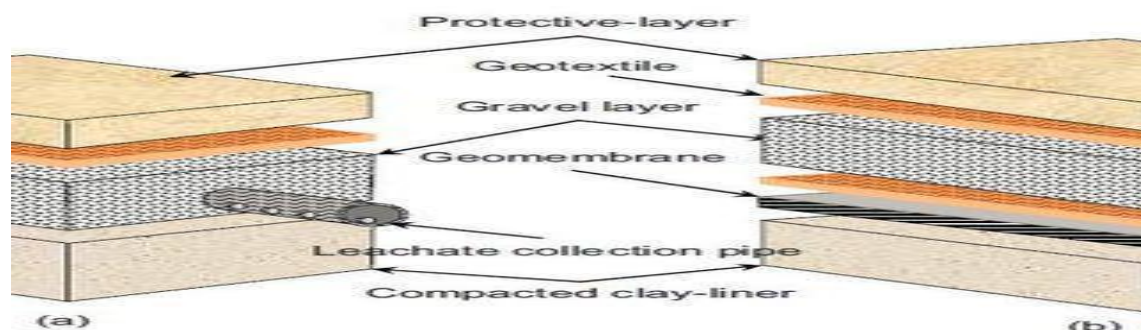


Figure 3.3: Schematic diagram of a baseline system

Key: **a**: single-line system; and **b**: composite-line system (as applied widely in affluent countries).

Source: Zhang *et al.*, 2021

In cases where the sub-surface layer of the landfill site has low permeability (hydraulic conductivity of less than $1 \times 10^{-9} \text{ ms}^{-1}$), artificial base sealing may not be necessary. Instead, it may be sufficient to reduce the low permeability of existing soils by excavating the top 20 to 30 centimetres and compacting this layer using heavy equipment. The costs of installing base lining systems can vary widely depending on the location. In the US, costs range from US\$20 to US\$30 per square meter, while in the European Union, it can be as much as US\$70 per square meter (Bakas and Skouras, 2021).

3.4.2 Drainage system

In every baselining system, a layer of coarse material is placed directly on top of it to serve as the leachate collection system (Figure 3.4). Drainage pipes are installed at low spots throughout the system to facilitate leachate collection. The leachate collection system should have a minimum depth of fifty centimetres, a hydraulic conductivity greater than ten to three meters per second, and a base slope of at least 2% (Yuan and He, 2019).



Figure 3.4: Drainage pipe covered with stones and wrapped with the geotextile
Source: Noe, 2021

Sufficient water drainage capacity at the base of landfills is crucial due to high rates of precipitation and leachate formation. Inadequate drainage of leachate can result in

water-saturated waste zones at the bottom of the landfill (Temilade and Olusola, 2019; Lohani and Goel, 2020). The mechanical stability of landfills can be compromised by water accumulation, increasing the risk of mechanical failure (i.e., waste slides). In tropical countries, landfill slides are common occurrences following heavy rainstorms. For instance, a landfill slide occurred at the Leuwi Gajah landfill in Indonesia, resulting in the collapse of many structures and discharging around 2.7 million cubic meters of waste. This incident resulted in 147 injuries (Okwany and Mbuligwe, 2019; Haque and Hossain, 2021).

To ensure the proper and sustained function of the drainage layer in the long term, a protective layer made of shredded waste, compost, or other fine-particle waste materials should be placed above the drainage layer (Ghazali and Noor, 2021). Placing a protective layer above the drainage layer can prevent waste particles from entering the drainage layer which could cause compression of the underlying waste layers. Once the waste has been discarded, it is compacted and piled up over the protective layer (Wang *et al.*, 2020). To prevent leachate from becoming trapped in the waste material, the protective layer should have hydraulic conductivity that is much greater than 1×10^{-5} m/s and a thickness of between 30 to 50 cm (Ghazali and Noor, 2021). To prevent fine-grained particles from entangling the gravel layer, a geotextile can be placed between the layers to provide protection and ensure drainage (Kjeldsen *et al.*, 2019).

Designing the landfill and any extensions to minimize leachate production is important due to the high costs associated with leachate treatment (Samadder *et al.*, 2019). When constructing a new landfill, it is crucial to plan how the waste will be divided into cells, each with its own leachate collection system. These cells should be separated by embankments and equipped with separate leachate collection pipelines that connect to the main header pipe. The main header pipe should then connect to the leachate collecting basin or treatment facility (Wang *et al.*, 2020). One approach for separating landfill cells is the 'saw-tooth' configuration of the leachate collection system. Using this method, the landfill cells are partitioned into several operating cells, each with a primary leachate collection pipe (Tchobanoglous *et al.*, 2019). It is now standard practice that, during the commencement of landfilling activities, only the leachate collection pipe in the active waste disposal area is connected to the leachate treatment plant. This

procedure helps to minimize environmental impacts and improve the efficiency of the leachate management system (Milenkovic *et al.*, 2020). Other leachate pipes, which release stormwater directly into the nearest watercourse without any treatment, will only be installed in areas not being used for waste disposal in the future (US Environmental Protection Agency, 2018).

3.4.3 Mechanical stability

In the waste management industry, landfill mechanical stability is evaluated and based on several factors, including the types and volume of plastic products present in the waste, the slope angle of the landfill, the level of compaction of the waste material, and the degree to which the waste strata are saturated with water (Lim *et al.*, 2020; Sarker *et al.*, 2021).

Determining the mechanical stability of a landfill is of utmost importance in preventing slope failure and minimizing environmental risks associated with waste disposal (Ljunggren *et al.*, 2021). Recent studies have shown that high levels of plastic content in landfills can significantly impact their stability, as plastics are non-biodegradable and can lead to reduced compaction, increased permeability, and a higher risk of slope failure (Hasan *et al.*, 2019; Han *et al.*, 2020). Additionally, landfill slopes that exceed the recommended repose angle can be unstable, while adequate compaction and saturation of the waste can improve a landfill's mechanical stability (Lim *et al.*, 2020).

The mechanical stability of landfills can be compromised by various other factors, including the limited interface shear strength of certain layers, such as smooth HDPE liners or geotextiles (Ljunggren *et al.*, 2021). Smooth HDPE liners, commonly used in landfill design and operation, are particularly susceptible to limited interface shear strength. This can occur due to poor material selection, inadequate compaction, and poor interface quality. In some countries, such as the US, textured HDPE liners with an asperity height of at least 0.4 to 0.5 mm are used in landfills to mitigate these risks (Mawby *et al.*, 2019). To minimise the risk of landfill slides and erosion, the slope angle should not exceed 25%. In the case of massive landfills (i.e., those of a height of more than 30 m), the maximum slope angle should be reduced or at least have benching installed (Sarker *et al.*, 2020).

3.5 Landfill operations

Landfill operations consist of various stages and processes that include the following:

- Measuring incoming waste volumes and record keeping;
- Unloading of waste;
- Waste compaction;
- Daily cover application;
- Leachate treatment;
- Landfill gas emission management;
- Monitoring landfill emissions; and
- Monitoring leachate and water quality.

3.5.1 Measuring incoming waste mass and record keeping

Accurately measuring the incoming waste mass is crucial for landfill operators and local waste authorities. Landfill operators rely on this information to determine the daily working area, estimate future construction steps, plan for necessary daily cover material, and ensure that waste layers do not exceed the planned height. For local waste authorities, incoming mass data provide valuable information about the amount of waste generated and landfilled at a specific site (Schwartz *et al.*, 2020). Two methods are commonly used to determine the incoming waste mass at landfills, namely a weighbridge facility, which can be quite costly, or counting the number of trucks entering the landfill and estimating their waste loads (Kjeldsen, 2019). Weighing a few waste trucks using similar transportation trucks can be done to reasonably estimate the average waste load per truck (Kumar *et al.*, 2019).

Accurate information on the mass of landfilled waste is essential not only for waste management purposes, but also for financial accounting. For instance, in the case of a landfill serving multiple municipalities, the costs of landfilling must be divided based on the waste amounts delivered by each municipality to determine the deposit fee (Tanskanen and Kangas, 2018). Weighbridge facilities commonly have modern technology that record waste data, including waste mass, origin, truck identification, and arrival time. This data help to track waste management practices and ensure compliance with regulations (Sarker *et al.*, 2020).

In such cases, the costs associated with the landfill must be allocated according to the waste amounts delivered by each municipality (Hossain *et al.*, 2021). This can be accomplished by using the information about the waste mass that has been landfilled. Weighbridge facilities in modern times are equipped with technologies that allow weighbridge staff to document important information, such as the weight of the waste, the source of the waste, the vehicle's identification number, and the time of arrival (Shin and Choi, 2021).

3.5.2 Unloading the waste

To minimize the environmental impact of waste disposal, unloading incoming waste in confined working areas is recommended. This is commonly referred to as the 'working face' (Mandal and Pathak, 2019). The size of the working face at a landfill site should be limited to the minimum required to allow for the efficient movement of trucks and landfill machinery, as stated by the US Environmental Protection Agency (2018).

It is essential to handle the first layer of waste cautiously during the initial waste unloading process at a landfill to prevent damage to the leachate collection system, the base liner landfill equipment, waste trucks, or the waste itself (Othman *et al.*, 2020). Properly designed and constructed access roads must leave space for manoeuvring, and unloading points are crucial in landfill operations to ensure efficient and safe waste disposal. In addition, removing bulky and hard waste and determining the minimum thickness of the first waste layer are essential considerations. For example, the access road should have hard-surfaced ramps to prevent leachate collection overload, and the turning area at the end of the road should be wide enough to accommodate waste trucks and other landfill vehicles (Ljunggren *et al.*, 2021). The first waste truck should unload the waste directly at the end of the access road of the working cell and dispose of the waste horizontally. Bulky and hard waste should be removed from the waste that will be landfilled as the first layer above the protective layer to avoid puncturing the liner or leachate collection system. Ideally, the first layer of waste should be deposited without compaction, and it should have a thickness of about 120 cm (Kjeldsen *et al.*, 2019).

3.5.3 Waste compaction

Compaction of waste and dust suppression are the crucial processes in landfill management to optimize space utilization and reduce environmental impacts (Figure 3.5). Several research studies have suggested that effective waste compaction can help to reduce leachate generation rates (Umar *et al.*, 2019; Gou *et al.*, 2020). Compacted waste increases landfill capacity and enhances its mechanical stability, reduces odour emissions, promotes higher gas generation rates due to anaerobic conditions, and minimizes the risk of landfill fires (Ghazaw *et al.*, 2020).



Figure 3.5: Dust suppression applied after the compaction of waste at the Gauteng landfill site.

Source: Noe, 2018

The most effective way to compact waste on landfills is by spreading it in 30 to 40 cm thick layers, followed by repeated passes of waste compaction equipment (Chen *et al.*, 2018). Zhou *et al.* (2018) state that waste compaction can be achieved by using bulldozers or unique waste compactors. However, the latter may be more efficient but are expensive and landfill operators in developing countries may not be able to afford these specialized compactors (Figure 3.6).



Figure 3.6 Tipper truck, compactor and a bulldozer at the Gauteng landfill site.
Source: Noe, 2018

According to the literature, the degree of compaction achieved in landfilling operations is influenced by several factors, including the compactor size, the number of passes made by the compactor, and the properties of the waste being landfilled (Ghazali *et al.*, 2021). To increase waste density during compaction, repeated passing over the waste by the compactors is required. However, it is important to optimize the number of compactor passes to balance the need for increased waste density and the increased fuel consumption of the compactor, as the latter affects operational costs (Purnomo *et al.*, 2020).

3.5.4 Daily cover application

Daily application of cover is essential for the safe operation of landfills as it helps minimize the negative impacts of landfill hazards such as odours, waste blowing, and the presence of vectors (Kumar *et al.*, 2021). Kumar *et al.* (2022) argue that, in addition to the advantages mentioned earlier, proper waste management practices can also reduce the risk of groundwater contamination, prevent fires on landfills, and improve the overall aesthetic appeal of landfill appearance.

Various authors have observed that landfill operators may encounter difficulties finding appropriate cover material, and this results in exposed waste on the landfill on a daily or weekly basis. They suggest that new compost could serve as an alternative daily

cover material to avoid the expense of transporting soil or other inert material over long distances. This approach, as suggested by several authors, could be considered the "best available practice" for operating landfills, particularly in cases where there is a shortage of soil cover material or financial resources (Kjeldsen *et al.*, 2018).

3.5.5 Leachate treatment

In regions with a tropical climate, the extent of the leachate (or liquid discharge from solid waste) that is generated by landfills is generally high due to high precipitation levels. It is common to observe leachate generation rates exceeding 1 000 litres per square meter per year in tropical countries (Yusof *et al.*, 2021). According to research, leachate quality in tropical countries is similar to that which is produced in developed regions. However, leachate from the former areas is characterized by high levels of organic pollutants, ammonium, and soluble salts. During the dry season, pollutant concentrations in leachate increase due to reduced dilution by rainwater, while it decreases during the rainy season (Nwachukwu *et al.*, 2019).

A common approach for treating leachate in many countries is a sequential series of leachate ponds, where the leachate is treated in a multi-stage process (Wuana and Okieimen, 2018). According to current practice, leachate generated by landfills is treated through a series of processes to reduce its environmental impact. Initially, the leachate is treated anaerobically, followed by aerobic treatment in a pond. Finally, it undergoes further treatment in a maturation pond before being discharged into a sewer or a nearby water channel (Nambi *et al.*, 2021). While not excessively costly, the treatment method used for leachate is not highly effective. Despite being a common practice, few landfills undertake monitoring of the waste entering or leaving their premises to ensure quality (Ghosh *et al.*, 2021). To ensure effective treatment of leachate, it is essential for leachate treatment plants to assess their pollutant removal efficiency using suitable indicator substances such as Chemical Oxygen Demand (COD) or ammonia (Jiang *et al.*, 2019).

To save costs associated with pumping leachate, it is recommended that the landfill base elevation and leachate treatment ponds be situated in a way that facilitates gravity-driven leachate flow (Yadav *et al.*, 2018). To determine the necessary capacity of a

leachate treatment pond, a formula can be used that considers several factors, including the maximum daily precipitation rate, the ratio of leachate to rainfall, the surface area of the landfill, and the required residence time of the leachate in the pond (Huang *et al.*, 2021).

3.5.6 Landfill gas management

When organic material in solid waste decomposes in an anaerobic environment, landfill gas (LFG) is produced, consisting mainly of methane and carbon dioxide with trace levels of hydrogen sulphide (H_2S), volatile organic compounds (VOCs), ammonia, hydrogen gas, and carbon monoxide (Kumar *et al.*, 2021). Proper landfill gas management is crucial due to the potential risks of explosions and greenhouse gas emissions that primarily consist of methane, which is a potent greenhouse gas. The gas collection and treatment process must also account for trace components of waste gas that can pose a risk to human health and safety, potentially leading to fatalities (Cossu *et al.*, 2021). At low doses of 2 ppm, hydrogen sulphide is considered a nuisance, but at higher concentrations exceeding 200 ppm, it can no longer be smelled, and at concentrations surpassing 1 000 ppm, it can cause death within minutes (Kipp, 2018). According to Zou *et al.* (2021), the collection and control of landfill gas are essential for preventing the release of critical chemicals, including methane and trace components. Therefore, effective landfill gas management is crucial for mitigating the environmental and health impacts associated with landfills.

The breakdown of organic matter in municipal solid waste landfills produces primarily methane (CH_4) and carbon dioxide (CO_2) (Jafari *et al.*, 2018). Organic matter in municipal solid waste landfills is a significant source of CH_4 and CO_2 emissions that are generated primarily through microbial decomposition (Cossu *et al.*, 2019). The collection of landfill gas and its appropriate use as fuel in a gas engine for energy generation can be beneficial for all parties involved. Alternatively, a cost-effective option could involve piping the gas to a nearby industrial plant to utilize its energy (Zahedi *et al.*, 2020). The implementation of landfill gas utilization techniques requires the presence of a gas consumer nearby. These techniques typically involve advanced technologies and require significant financial investment. Moreover, utilizing these techniques often

necessitates collaboration with industrialized countries as part of a 'clean earth' development framework (CDM) (Siddique *et al.*, 2018).

In certain countries with feed-in tariffs, electricity projects are implemented without utilizing the Clean Development Mechanism. Another option for managing landfill gas is to flare it, which involves converting CH_4 to CO_2 , but this does not result in energy recovery. This approach is often avoided due to increased operational costs with little to no significant financial benefit (Bogner, 2019).

One method that is effective in reducing landfill gas emissions is to install a methane oxidation layer. This layer allows methanogenic bacteria to convert CH_4 to CO_2 , which can help to minimize greenhouse gas emissions from landfills (Pokhrel *et al.*, 2018). In addition, a methane oxidation layer in landfills may decrease the filtration of rainwater into the landfill, ultimately reducing leachate generation (Thangarajan *et al.*, 2018). National governments should consider incentivizing landfill operators to minimize landfill gas emissions as they are a significant source of greenhouse gas emissions. In fact, they account for up to 5% of total greenhouse gas emissions in developing countries. While there are multiple options to mitigate landfill gas emissions, a third option involving the use of passive landfill gas collection is the most cost-effective system compared to the first two options (Khan *et al.*, 2021).

3.5.7 Monitoring landfill emissions

To evaluate the potential impact of waste emissions on the surrounding environment, it is essential to determine the quantity and composition of the two most significant emissions from landfills, namely leachate and landfill gas (Zhang *et al.*, 2021). Monitoring landfill emissions is crucial in assessing the impact of landfill operations on the ecosystem, especially in tropical areas where limited information exists about the functioning of landfills at total capacity. Previous studies have mostly focused on smaller-scale investigations, thus there is a need for research on the behaviour of full-scale landfills in emerging countries (Ukwattage *et al.*, 2020). Basic guidelines for monitoring leachate, groundwater, surface water, and landfill gas should be included in the operational permit of landfills to ensure proper monitoring of the surrounding environment (Bogner *et al.*, 2018). Regular monitoring of the groundwater and surface

water near landfills is crucial to prevent contamination, while emissions monitoring is also a necessity (Kjeldsen *et al.*, 2018).

3.5.8 Monitoring leachate and water quality

Current regulations stipulate that the quality of leachate must be tested at least twice a year i.e., once every six months (Dinuccio *et al.*, 2020). The evaluation of upstream and downstream surface waters of sewage disposal is crucial if leachate treatment effluent is discharged into these waters. Parameters such as electrical conductivity, pH, chemical oxygen demand, and ammonia content should be closely monitored. Additionally, the efficacy of the leachate treatment facility in pollutant elimination should be evaluated by monitoring the effluent, and treatment techniques should be adjusted as necessary (Bolaños *et al.*, 2019). To evaluate the performance of a landfill's baseliner, groundwater samples should be collected upstream and downstream of the landfill. Effluent analyses should also be conducted using the same standards as those that are used to test raw leachate (Ehrig, 2018). To prevent contamination, it is crucial to regularly monitor ground- and surface water as well as gas emissions near landfills (Malamis *et al.*, 2021).

3.5.9 Monitoring landfill gas emissions

Residents often complain about the odour of landfill gas which has a distinct and unpleasant smell (Akan, 2018). Kjeldsen *et al.* (2019) argue that an explosion may occur when the concentration of methane in landfill gas is above 5% by volume but remains below 15% in atmospheric air (Kjeldsen *et al.*, 2019). Purnama (2019) states that, if the monitoring results indicate that there is the risk of an explosion, such as methane levels near or over 5%, appropriate procedures (such as ventilation and evacuation) should be implemented after consultation with the authorized authority to ensure human and even animal safety and environmental protection. To accurately measure the quantity of volatile organic compounds (VOCs) present in landfill gas, samples must be collected from multiple locations around the waste, as landfill gas contains various types of VOCs that are considered dangerous air pollutants and pose an explosion risk (Pohland and McCarthy, 2019). It is necessary to evaluate the volatile organic chemical compositions in landfill gas to determine potential occupational and environmental health risks. Direct

sampling at gas wells can be conducted, or alternative procedures that meet regulatory requirements can be used (Zhang *et al.*, 2018).

3.5.10 Cover material layer and its application

Once a landfill or a single landfill cell has been filled to its final capacity, an intermediate cover layer that is resistant to settlement of the landfill surface is typically applied over the waste (Benson *et al.*, 2018). According to current landfill design and operation practices, an intermediate cover layer composed of at least 50 cm of soil or compost is used to serve several functions. These functions include preventing erosion by wind and water, reducing water infiltration and gas emissions through at least partial oxidation of methane, promoting vegetation growth, and addressing aesthetic concerns (Wang *et al.*, 2021). To reduce water infiltration rates on landfills, several measures can be taken, including using a cover material with a high water-retention capacity (e.g., compost material), profiling the surface by establishing a slope of 5-10%, and promoting intensive vegetation (Ravindrarajah and Sivakugan, 2019).

According to current landfill design practices, the intermediate cover should be replaced after five to 20 years, depending on the degree of settlement. This should be followed by the installation of a top sealing system, such as a clay liner of at least 50 cm thickness and a soil layer of over 50 cm, which can further minimize the infiltration of water into the waste (Makan *et al.*, 2018). According to current recommendations, the final capping of a landfill should include a dense vegetation cover and a surface slope of more than 5% to promote effective runoff and minimize erosion (Hettiaratchi and Suthaker, 2019).

The availability of cover material is an important determinant of the overall costs associated with landfilling. The daily or weekly application of inert materials on landfills serves various purposes such as minimizing windblown waste, deterring scavenging birds and animals, mitigating fire hazards, and managing other undesirable outcomes (Sowmya and Elanchezhian, 2021; Wong and Wu, 2021). In addition, it is necessary to install a final cover on landfills once they are no longer in use. The cover should ideally be in close proximity to the landfill to minimize the costs of waste transportation and must be installed on top of the landfill (Pandey *et al.*, 2021).

3.5.11 Post-closure care

To prevent unintended consequences for the environment and human health, it is essential to implement proper management and control measures on closed landfills (Sarker *et al.*, 2020). Various studies conducted at MSW sites in mild climates have indicate that post-closure care of landfills must be continued for several decades and even centuries as long as emissions from the landfill pose a threat to human health and the environment. For instance, leachate emissions can cause damage to the ecosystem for an extended period of time (Hogland *et al.*, 2018). The duration of aftercare of landfills is expected to be shorter in tropical regions compared to temperate regions, due to the liquid-to-solid ratio which determines the necessary time for aftercare (Alam *et al.*, 2018). The liquid-to-solid ratio is a measure that indicates the volume of water evaporated by one kilogram of dry solid waste in litres. For instance, if a landfill has an average height of 20 meters, a waste density of 800 kg/m³, and an annual leachate formation rate of 1 000 mm/year, the liquid-to-solid ratio will be five litres per kilogram of waste (Chiemchaisri *et al.*, 2018). Hassan *et al.* (2021) observe that it is necessary to maintain a L/S (liquid to solid) ratio of 5:1 in landfills to reduce emissions to an acceptable level and prevent the need for aftercare for up to 50 years. For comparison, a landfill in a climate zone with 200 mm of rain per year will require 250 years to achieve the same L/S ratio. This implies that post-closure upkeep and the lifespan of landfills are less critical in tropical areas compared to high-income countries that are geographically outside these tropical and sub-tropical regions.

After the landfill has been closed, ongoing care and monitoring are necessary to prevent potential harm to the surrounding environment (Sutherland, 2018). After closure of the landfill, continued monitoring is necessary, with particular focus on water and gas monitoring. The monitoring should assess the condition of different sections of the landfill, such as the final cover, the drainage system, vegetation, and slope stability to ensure proper management and minimize potential environmental risks (Sarker *et al.*, 2020).

3.6 Discussion and summary

The Sustainable Development Goals (SDGs) should, by all intents and purposes, be achieved globally, and all states are expected to do everything within their power to

achieve these goals. In Chapter two it was highlighted that solid waste management is an essential item on the agenda of the Sustainable Development Goals (SDG 3 and SDGs 6-12). Nevertheless, most impoverished countries fail to fulfil these targets because they dispose of massive volumes of waste that have not been segregated on old landfills with outdated environmental infrastructure, resulting in long-term methane emissions from this practice (Krook *et al.*, 2012). Moreover, climate change is a critical issue, particularly for South Africa which has limited access to sustainable water bodies. Leachate from landfills is a factor that contributes to groundwater contamination (Batista *et al.*, 2021). The National Environmental Management: Waste Act (NEMWA) Act No. 59 of 2008 is the central legislation in South Africa that oversees solid waste management (Department of Environmental Affairs, 2008). NEMWA establishes the norms and criteria that govern waste disposal on South African landfills. The standard containment designs (A, B, C, and D) and the sorts of waste that can be discarded on various landfills are among the requirements and stipulations.

However, South Africa does not adhere to these ideals, which is a serious impediment in achieving sustainable waste management practices. For example, the key findings as presented in Chapter four have demonstrated that landfills in the Upper Vaal WMA are not well operated. Moreover, some of the landfills under study are not registered with the South African Waste Information Centre, while some do not keep records about waste disposal, most do not have access control, and local people can access these landfills any time they want. Other challenges are that waste is not separated before or compacted after being dumped on the landfills.

In general, the findings affirm that landfills in the study area are inadequately operated. Oladade *et al.* (2019) noted that a landfill in Bloemfontein posed a significant risk to water and food security. The latter authors observed that the landfill did not have a leachate collection system, and the groundwater tests consequently indicated high quantities of total coliform and *E. coli* that exceeded the authorised maximum limits. Yukalang *et al.* (2017) highlight several concerning factors that are also highlighted by the findings of the current study, such as an unprecedented population increase, personnel ineptitude, legal-political hurdles, and financial constraints, all of which contribute to the inefficient and often inadequate functioning of landfills.

With reference to a wide range of literature, this chapter presented guidelines and key pointers on how to design and manage solid waste on landfill sites. Key criteria that need to be adhered to are waste volume and frequency of dumping record keeping, sound waste unloading practices, compaction, cover application, leachate treatment, and landfill gas emission management. The NEMA establish certain norms and standards for environmental waste management in South Africa, and this legal framework guides the norms and standards that need to be adhered to in any landfill operation. An additional advantage of adhering to these standards is that they describe the processes that can be followed in managing solid waste in detail. However, it is acknowledged that they are based on developed country standards, and it is therefore possible that they will not be appropriate in all circumstances to the South African context. For example, this country's climate differs from that of European countries, and it therefore requires landfills that are designed differently. The existing guidelines should therefore be adapted to apply to South Africa's circumstances and should be used in conjunction with newly designed norms and regulations for managing waste in South Africa.

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CHAPTER FOUR

A FRAMEWORK FOR SUSTAINABLE AND INTEGRATED MUNICIPAL SOLID WASTE MANAGEMENT: DEVELOPED COUNTRIES vs SOUTH AFRICA

Abstract

Environmental degradation caused by waste mismanagement is a global problem. For example, open dumping and burning in low-income countries are the primary waste treatment and disposal methods. This chapter compares the waste management policies and technologies used in South Africa with those of developed countries. In addition, the relationship between municipal and integrated solid waste management is explored and the two types are compared. The commitment of the municipality, residents (i.e., the community), businesses, shop-owners, industrial manufacturers, and other waste producers are crucial to achieve a sustainable waste management system starting and ending at disposal. South African municipalities are legally responsible for the removal of waste, but community involvement in waste management has become increasingly relevant, if not critical, if cities and towns in South Africa are to be kept clean and hygienic. This search used three databases to find studies that met the eligibility criteria so that the findings would answer the research questions and achieve some of the objectives.

Keywords: Environmental degradation; waste management policies; waste management system

4.1 Introduction

In sub-Saharan Africa, approximately 62 million tonnes of waste are generated annually, and the average waste generation per capita per day is estimated at 1.4 kg (Idowu *et al.*, 2019). On this continent, landfilling remains the primary method of disposing of waste. It has been claimed that the latter is the cheapest method and therefore preferable in struggling economies (Idowu *et al.*, 2019). Moreover, due to prevailing poverty, over 90% of Africa's waste is disposed of on uncontrolled dumpsites and landfills, and this practice is often followed by open burning. Godfrey and Oelofse (2017) iterate that South Africa is 20 to 30 years behind developed countries in waste management as it has not shifted away from landfilling towards prevention, reuse, recycling, and recovery. Because most generated waste is sent to a landfill for disposal, South Africa must learn from the success stories of other countries. More particularly, it should learn from the policies and technologies they have implemented to achieve sustainable and non-threatening waste management (Godfrey and Oelofse, 2017). This chapter compares South African waste management policies and technologies with those of developed countries. In addition, the relationship between sustainable municipal waste management and an integrated solid waste management system is contextualised (Batista *et al.*, 2021).

4.2 Overview of South African waste management policies and regulatory guidelines

A wide spectrum of legislation forms the basis of waste management in this country. This includes aspects such as the waste management legal framework and municipal solid waste and integrated soil management regulations.

4.2.1 The waste management legal framework

The most current South African waste management legal framework dates to 1989. Acts and regulations have since been amended and the National Environmental Management Waste Act No. 59 of 2008 (Republic of South Africa, 2008) is the most current framework that mandates the management of waste. The objectives of the Act can be briefly summarised as follows (Godfrey and Oelofse, 2017):

- (1) Protecting health, well-being, and the environment through providing measurable steps for:
 - Minimising the use of natural resources;
 - Reducing the generation of waste in the country;
 - Ensuring the treatment of through safe waste disposal processes;
 - Promoting effective waste management practices; and
- (2) Creating awareness of the impact of waste among the inhabitants of South Africa by:
 - Procuring measurement steps for compliance; and
 - Implementing Section 24 of the Constitution for securing the environment to safeguard the health of inhabitants.

A major weakness of this Act is that it allows the management of waste disposal through controlled and uncontrolled landfills, yet neglects waste reduction, reuse, and recovery (Godfrey and Oelofse, 2017). Godfrey and Oelofse (2017) mention that the legislation for waste management in South Africa has been formalised in four stages: (1) the age of landfilling that started in 1989, (2) the emergence of recycling that started in 2001 with particular emphasis on promoting the single use of plastics, (3) a flood of regulations that started in 2008 when the National Environmental Act was promulgated, and (4) the drive for extended producer responsibility in 2012, which led to the publication of the Integrated Waste Tyre Management Plan.

The South African informal sector is responsible for the collection of 80-90% of the waste, which saves between R309-R749 million in landfill space at no cost to the government (Godfrey and Oelofse, 2017). However, informal waste collection is not legislated; hence, the government promotes cooperatives but most of these have failed due to a lack of infrastructure. Moreover, there are insufficient premises to sort waste, while operational challenges also mar these initiatives (Godfrey and Oelofse, 2017).

4.2.2 Municipal solid waste and integrated soil waste management

Batista *et al.* (2021) iterate that regulations that guide solid waste management face challenges related to trade-offs and hierarchical stakeholder management. The

literature emphasises that separating, storing, collecting, transporting, processing, and recovering solid waste requires multidisciplinary skills (Debrah *et al.*, 2021), such as a participatory approach involving public authorities, community members, and municipalities (Levac *et al.*, 2019). However, no waste management development is sustainable unless reuse, recycling, and recovery principles are practised, including recovering energy from waste to make managing waste reuse more sustainable (Batista *et al.*, 2021). Developed countries enjoy higher levels of economic development than developing countries, whereas developing countries tend to focus on short-term goals for survival that require approaches that limit cost, often to their detriment (Batista *et al.*, 2021). For example, European countries have reduced landfill waste disposal and now prioritise energy recovery, whereas developing countries face socio-environmental challenges that make waste reuse and recovery meagre, and these countries simply do not possess the financial resources to adopt sustainable development practices (Selau, 2018).

4.3 Objectives and research questions

The study's main objective is to propose a sustainable solid waste management framework that could be adopted by local governments in South Africa as they are responsible for waste management. The research questions that guided the investigation that is reported in this chapter were:

- What barriers do South African municipalities face in adopting sustainable waste management practices?
- What are the critical success factors that South Africa should adopt and implement for sustainable waste management?

To answer the above research questions, the researcher first engaged in a systematic literature review to identify the barriers to achieving waste management success and to elucidate the critical factors that may enable the implementation of sustainable waste management practices in South Africa, but more particularly in the study area. This study thus focused on illuminating critical success factors that should be employed to alleviate the environmental impacts of poor waste management strategies on society and the environment. In addition, waste management legislation in Europe (developed countries) is compared with the South African (a developing country) waste

management framework to identify any gaps and offer recommendations for improvement to the latter framework. A holistic framework that has been proposed by Batista *et al.* (2021) focuses on stakeholder participation that is aligned with the United Nations Sustainable Development Goals agenda for 2030.

4.4 Research methodology

A comprehensive literature review was conducted by exploring studies that met the eligibility criteria and that would answer the research questions and objectives linked to sustainable solid waste management. This search was conducted by accessing three databases, namely Google Scholar, Scopus, and Web of Science. The keywords were combined with Booleans “AND” and “OR” in the selected databases. Key search terms included “solid waste”, “public policies”, “landfill and solid waste”, “integrated AND solid waste”, “incineration and solid waste”, and “waste to energy”. The initial search retrieved 147 articles that were subsequently screened for duplicates, and 35 remained. Only studies reported in English were considered, but titles and abstracts from the remaining articles were examined to check whether they addressed waste management and disposal. Following the screening, 30 abstracts remained. Articles that did not meet the criteria were excluded based on: (a) dated articles that fell outside the last ten years up to 2021; (b) relevance of the publications; (c) accessibility (i.e., the content of the article needed to be available in the search databases); and (d) adherence to the scope of the research to answer the research questions and meet the objectives of the study.

4.5 Comparison between European and South African waste management practices

Hangulu and Akintola (2017) iterate that European waste management practices are guided by policies and directives that mandate a shift away from mere landfilling. Moreover, each European Union member state must adopt and maintain these policies and directives effectively. For instance, European Union member states utilise incinerators to control waste and permission to operate these facilities is granted by the European Union. On the other hand, waste management legislation in South Africa persists in allowing ineffective waste disposal practices that negatively impact society and the environment. Simatele *et al.* (2017) support this notion, arguing that the

effectiveness of the waste management hierarchy and community involvement in South Africa in acceptable waste management practices are questionable. To address these weaknesses, the best way will be to provide a cost-effective municipal solid waste management plan. Udofia *et al.* (2015) state that using economists and economic tools will help in achieving improved waste management goals in any country, including South Africa. Awodele *et al.* (2016) indicate that the weakness of South African waste management legislation is that it provides immense power to municipal authorities, arguing that this situation negatively impacts national legislation. Furthermore, in South Africa recycling is predominantly motivated by economic factors, whereas in Europe environmental considerations play a more significant role (Awodele *et al.*, 2016). Thus, the focus on recycling in European countries such as Sweden has twice the economic benefits of dumping it or burning it on landfill sites as is customary in South Africa.

The National Water Act No. 36 of 1998 (Department of Water and Sanitation) and the National Health Act No. 61 of 2003 (Department of Health, 2003) provide practical strategies for using various facilities to safeguard water and ensure the health of South African citizens. However, Oteng-Ababio *et al.* (2017) argue that monitoring and coordinating these regulations have become severe challenges in South Africa, whereas European waste management is regulated by appropriate monitoring processes in all member states. The process of waste management as implemented by the European Union has established an effective and appropriate structure for solid municipal waste. In South Africa, the National Environmental Management Waste Act of 2008 provides measures to minimise waste and ensure appropriate waste disposal even on landfills; but planning and managing waste disposal processes are not appropriate, whereas poor monitoring also exacerbates the situation.

According to Naidoo (2016), waste management compliance and enforcement are addressed by the South African waste management framework as regulated by the National Environmental Compliance and Enforcement Strategies (NECES) of 2006. These guidelines provide a medium-term roadmap that municipalities should follow to ensure positive change and improve compliance and enforcement. The priorities established by the NECES aim to ensure integrated compliance and enforce information management systems within the waste management sphere (Zaman, 2015). In this

context, solid waste management is considered a major issue in urban environments as the rate of waste generation in these settings has escalated significantly since the foregoing decade. A recent report on waste management in South Africa affirms that the current waste management chain should encourage waste recycling and reuse (Sharpley, 2018). The question is, however, if these processes have been implemented in the same way in South Africa as they have been implemented in developed countries to achieve global waste management goals.

Environmental management inspectors are required to monitor section 24 of the Constitution as verbalised in NEMA to ensure that environmental legislation is not contravened. Special regulations to guide the functioning of the Environmental Management Inspectorate (EMI) do not currently exist in South Africa, and such regulations should be introduced to clearly specify the roles, responsibilities, and legislative mandate of these government officials to allow them to better perform their role in the waste management processes (Basdeo, 2016). Both EMI officials and members of the South African Police Service have the authority to investigate persons or companies suspected of violating environmental laws and have the mandate to search and seize when environmental infractions have occurred (Basdeo, 2016).

4.6 The five pillars of sustainable waste management

Batista *et al.* (2021) aver that the solid waste management strategies employed in most developing countries are not sustainable, and South Africa is no exception. There is therefore a high possibility that many of this country's natural resources have been compromised due to a lack of a sustainable waste disposal infrastructure and social inclusion in the waste management hierarchy. A high population density in many urban and peri-urban areas, challenges in sanitation, and geographical challenges have led to the illegal dumping of solid waste on unregulated landfills (Batista *et al.*, 2021). Nahman and Godfrey (2010) argue that municipalities in South Africa face numerous challenges, including inadequate budgets to provide essential waste management services such as collection, transportation, reuse, and disposal practices. In addition, urban planning policies are centred on survival and thus neglect the conservation of sustainable resources and the environment (Batista *et al.*, 2021). For example, developing countries lack updated methods, technical and economic resources, and

support tools for long-term contractual adjustments. Moreover, a lack of suitable waste disposal resources contributes significantly to the illegal dumping and burning of municipal solid waste (Batista *et al.*, 2021). For developing countries to be sustainable, they need to adopt waste recovery technologies that are driven by the principles of the five waste management pillars. The following highlight the impact each pillar has on sustainable solid waste management (Batista *et al.*, 2021).

4.6.1 Pillar 1: Public policy

It has been affirmed by various scholars that governments in developing countries lack the capacity to procure technologies to treat solid municipal waste appropriately and sustainably. For example, in South Africa institutional governance is a salient issue, as current legislation gives too much responsibility to municipalities. The fact that decisions regarding waste management and disposal result in approximately 90% of waste being dumped on landfills (Godfrey and Oelofse, 2017) is because local municipalities are entrusted with this mandate. To rectify this shortcoming, governments of developing countries should act with vision to optimise natural resources without neglecting economic and financial sustainability (Batista *et al.*, 2021).

4.6.2 Pillar 2: Improved waste disposal techniques

Developing countries tend to lack sustainable waste management models that guide well-designed and effective policies that regulate and monitor waste management strategies. The South African government should heed this principle and design and implement more effective management models to guide sustainable waste management practices and, equally importantly, to monitor the implementation of these policies (Kubanza and Simatele, 2019).

4.6.3 Pillar 3: Adherence to a sound legal framework

Municipal managers in South Africa tend to function in isolation as they do not educate the communities in their respective jurisdictions about legal and financial issues related to waste management. Moreover, very few, if any, law enforcement structures implement legal penalties to curb non-compliance with waste disposal by-laws. This

situation is exacerbated by the energy sector's (Eskom and the Department of Energy and Mineral Resources) inability and lack of political will to prioritise waste-to-energy conversion, which is an oversight that will incur immeasurable costs for this country in the not-so-distant future (Nyika, Onyari, Dinka and Bhardwaj, 2021).

4.6.4 Pillar 4: Public-private partnerships (PPPs)

In developing countries, the administration of PPP contracts should be well managed because long-term contracts between municipalities and private waste disposal businesses are likely to promote responsible operations and lead to compliance with updated and appropriate waste management policies (Batista *et al.*, 2021).

4.6.5 Pillar 5: Energy recovery

In South Africa, waste is discarded on landfills with poor infrastructure. This common practice across the country does not encourage waste-to-energy initiatives and results in environmental degradation. Therefore, municipalities in this country, and by extension in developing countries with a similar problem, should allocate enough funds to upgrade and modernise their waste management infrastructure. A pivotal requirement is that waste that is recovered should be converted to energy, especially in South Africa where the exceptionally high rate of load shedding has become a serious issue. However, to achieve this goal, highly skilled personnel who can manage and maintain such a sophisticated infrastructure is required (Nyika, Nyanga and Mafore, 2023).

4.7 Barriers that impede appropriate solid waste management

Batista *et al.* (2021) refer to various barriers that impede municipalities from practising sustainable solid waste management. These challenges are categorised into three groups: (1) poor public policies that lead to financially unfeasible projects and lack of diagnostic tools; (2) limited public-private partnerships that result in restricted funding, poor resources, and contractual flaws; and (3) poor energy recovery due to limited incineration and lack of space for expanding landfills. Table 4.1 summarise these barriers.

Table 4.1: Taxonomy of barriers that impede proper waste management

Categories	ID	Barriers	Description
Policy implications	B1	Financially unfeasible projects	Lack of coordination between public, private and social factors; Public policies do not encourage economic sustainability and social well-being.
	B2	Poor public policies	Inefficient and ineffective institutional actions that do not serve the best interests of the residents that municipalities should support; Poor collection, transportation, and disposal of MSW; Government programs without specific procedures and with poor outcomes.
	B3	Municipal plans lack diagnostics	The prevalence of non-systematised information; Work teams lack specialised technical training; Integrated management practices are not prioritised; Non-vigorous procedures to forge relationships between citizens and public-private institutions.
PPPs	B4	Temporal limitation of contracts	Governance instruments are not measurable and cannot be enforced, especially in terms of infrastructure projects; Mechanisms encourage poor waste management instead of a vigorous, effective system.
	B5	Restricted funding and resources	Lack of financial, economic and legal support for the energy recovery of solid waste; Complex or no interaction between public and private companies.
	B6	Linear and reductionist risk management	Financial statements with superficial assessments without exploring risks, impacts and probabilities; Economic activities do not ensure a dignified existence for all.
Energy recovery	B7	Deadlock in waste management	The improper predominance of landfills without prioritising energy recovery from MSW.
	B8	Waste to energy	Devaluation of waste from incineration without highlighting the lack of landfill space; Mistaken valuation of landfills.
	B9	Depreciated solid waste reuse	Mismatch in waste management systems without aligning energy recovery with waste management; Lack of awareness of the potential to recover energy from MSW—instead, it is discarded in a manner that causes water, air, and soil pollution.

4.8 Proposed Framework for Sustainable Waste Management in South Africa

This section presents and discusses a previously developed sustainable solid waste management framework for South Africa (Figure 4.1). This framework pivots around the cooperation among three key stakeholders, namely government, the community, and industry (or businesses) and addresses the key barriers to sustainable waste management practices (B1 – B9) (see Table 4.1) and how these should be resolved. A multidisciplinary approach to waste management skills development should therefore involve the three major stakeholders who work collaboratively from the foundation of the five pillars (public policy, disposal techniques, legal aspects, PPPs, and energy recovery) to address the barriers that impede appropriate waste management.

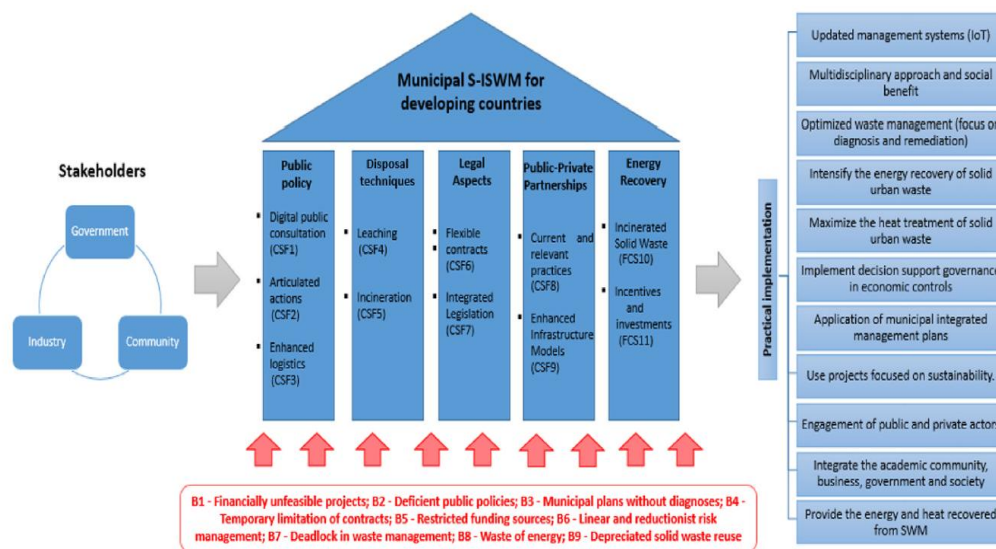


Figure 4.1: Framework for sustainable solid waste management for South Africa
Source: Batista *et al.*, 2021

When public policies regarding municipal solid waste management are formulated, a priority should be that these policies will benefit all the major stakeholders (Batista *et al.*, 2021). These policies should primarily encourage the reuse and recovery of waste. In South Africa, recycling has been encouraged for many decades, as this practice is driven by social needs and the demand for resources. In fact, waste sorting facilities for tin cans have existed in major urban areas such as Pretoria and Johannesburg for many years, while the reuse of plastics, plastic bags, and bottles/glass has also been initiated (Godfrey and Oelofse, 2017). However, not much else is done officially to ensure the recycling and reuse of waste. Currently, approximately 60 000 to 90 000 informal waste collectors scrutinise all of South Africa's landfills for dumped glass, paper, metal, glass,

and plastic recyclables, but most of these facilities are not legislated (Godfrey and Oelofse, 2017). These informal waste collectors save municipalities millions of rands per annum and therefore, instead of relying on cooperatives that lack infrastructure and capacity to recycle and reuse all waste, waste collectors could play a significant role in waste recycling if they were included in the current waste management structure (Godfrey and Oelofse, 2017). The latter authors thus argue that current government legislation should be amended to include the role and function of waste collectors in the waste management hierarchy.

Maintaining waste disposal facilities not only requires policy and monitoring, but a sense of civic responsibility as well, as appropriate waste management strategies ensure a clean environment for all (Yazdani *et al.*, 2017). Creating effective and all-inclusive by-laws for the operational management of waste is pivotal in ensuring that legislation encourages improved waste management. The PPP is a critical factor that links public participation and private companies. Legal aspects should work hand in hand with the PPP, and financial and economic support should be included in all municipal management plans. For instance, improved usage of appropriate machinery/equipment for proper waste disposal and the appointment of skilled municipal workers in waste management facilities should be prioritised. Moreover, the South African government should prioritise waste management by providing incentives for municipalities that properly incinerate waste instead of depositing and burning it indiscriminately on landfills. Utilising waste for energy generation will be a significant benefit for this country that is plagued by insurmountable energy problems. Extra megawatts of electricity can therefore be generated and loaded onto the current Eskom grid (Batista *et al.*, 2021).

4.9 Conclusion

South Africa has been able to create a recycling economy over the last three decades, but this is partly due to the efforts of the active informal waste sector that collects waste in streets and from landfills. Because significant volumes of recyclable waste are still discarded on landfills, it is widely acknowledged that this sector should be formalised and given recognition in the policies that guide MSWM. When viewed through the lens of the regulatory framework, the history of South Africa's waste and recycling industry can be divided into four distinct phases: the age of landfills, the beginning of recycling,

the establishment of regulations, and the implementation of extended producer responsibility. However, when the reality of the situation is acknowledged, it appears that this country has not moved far beyond the first age, as landfilling is still the predominant waste management method that is applied and formalised in this country. The South African waste management policy framework encourages waste avoidance, reuse, recycling, and recovery to limit the amount of waste ending up on landfills. However, the response to this policy has not been particularly successful, as only 10% of municipal and hazardous waste is diverted from landfills. Moreover, the implementation of this policy is left to the devices of local municipalities with little government intervention, and it is a sad fact that many municipalities in South Africa are plagued by inefficiency, corruption, and maladministration to the point of collapse.

The success and efficacy of the local government system can be measured by how efficiently and appropriately waste is managed. Waste is no longer regarded as a burden in developed countries but as a resource that can be integrated into energy production systems. Therefore, as the volumes of waste that are now generated in South Africa are unprecedented in its history, significant opportunities exist for leveraging waste as a secondary source of energy for social, economic, and environmental benefits. In South Africa, some waste processing plants have introduced initiatives to utilise new waste-treatment technologies and are considering using some methods European countries are using to address waste management issues. For instance, the use of new types of energy through processes such as pyrolysis, gasification, and combustion has been encouraged. However, very few of these efforts are visible in society at large, and they seem to pale in comparison with the Eskom disaster.

A major adjustment in the mindset of all stakeholders in the waste management hierarchy is required not in the future, but as soon as possible. This can be accomplished if the government and the private sector work collaboratively to introduce cutting-edge, creative, and integrated recycling practices to this country, and this needs to be done without political interference and nepotism. A joint effort by the South African government, businesses, industry, and ordinary citizens who are the key role-players in recycling at source will only be effective if common ground is found to ensure the

sustainability of recycling and waste-to-energy efforts. In practical terms, this means that the huge volumes of waste that are sent to landfills will only be significantly reduced if everyone actively participates in waste recycling and re-use initiatives. However, this will require creativity, collaboration, innovation, commitment, and a shift in mind-set for the circular economy model to build a future that is sustainable for all citizens of this country.

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CHAPTER FIVE

INVESTIGATION INTO THE NON-COMPLIANCE BY MUNICIPAL-OWNED LANDFILLS IN THE UPPER VAAL CATCHMENT AREA

Abstract

Water scarcity is a major challenge in South Africa. This situation is exacerbated by non-engineered landfills that contribute to groundwater pollution that makes such sources unsuitable for human consumption. The main aim of this study was to assess the impact of municipal landfills on groundwater resources in the Upper Vaal catchment area. Four data collection tools were used: an observational checklist, a geographic positioning system (GPS), a structured and unstructured questionnaires, and a Canon EOS 200D camera. The researcher personally visited all the operational waste disposal facilities. The structured and unstructured questionnaires were administered to one representative of each of the 31 waste disposal facilities that were visited in the study area. The sampled participants completed the questionnaire in their offices, and they accompanied the researcher on a field visit to the respective facilities. A key finding was that the average distance between some houses and the landfill sites was only one to two kilometres. In addition, 94% of the boreholes that were visited near the landfills still contained water. However, 58% of the municipalities had never conducted groundwater monitoring, while the 42% who were doing so only monitored groundwater quarterly or twice a year. It was also found that compliance reports for municipalities to manage landfills officially were rarely submitted. This suggested that the municipalities under study managed the groundwater resources in their areas quite poorly. The quality of the borehole water was not tested, but their close proximity to the landfills raised the issue of health implications for households who utilised water sources close to the landfills. It is recommended that the national government and municipalities allocate a larger portion of their budgets for the improvement of landfill infrastructure to capacitate them to convert waste to energy. This will protect groundwater resources from pollution by municipal landfill leachate.

Keywords: Water pollution; groundwater resources; municipal leachate; non-engineered landfills

5.1 Introduction

Solid waste management is addressed in some of the UN's Sustainable Development Goals (SDGs 4, 8, 11, and 12) (Adekele *et al.*, 2021): Goal 4 advocates for inclusive environmental education for all; Goal 8 promotes productive jobs and sustainable economic growth; Goal 11 is a proponent of safe, sustainable cities and human settlements; and Goal 12 promotes sustainable production and consumption (Adekele *et al.*, 2021). It is estimated that the world generates approximately 2.01 billion tonnes of municipal waste annually (World Bank, 2022). In 2012, South Africa generated approximately 108 million tonnes of solid waste and 90% of the generated waste was discarded on landfills (Adekele *et al.*, 2021). In 2017, the volume of waste generated in South Africa increased to 54.2 million tonnes per annum, of which hazardous waste comprised 66.9 million tonnes per annum (Adekele *et al.*, 2021). This shows that the rate of waste generation is increasing rapidly and that, in future decades, there may not be enough landfills for waste disposal in South Africa. According to earlier studies (Ayeleru *et al.*, 2018; Bundhoo, 2018), waste in major cities is discarded indiscriminately in streets, in public places, and on illegal dumpsites. Moreover, population growth has been significantly linked to increasing waste generation rates (Adeleke *et al.*, 2021; Ayeleru *et al.*, 2018; Bundhoo, 2018; Kubanza and Simatele, 2020). The major challenges that impact inefficient waste collection and disposal are lack of funding, limited staff capacity, poor data on waste collection and analysis, and limited research (Adeleke *et al.*, 2021).

Waste management is a major challenge for local and provincial governments as well as the national government (Viljoen *et al.*, 2021). The major problem is that waste management budgets are under strain, and therefore municipalities have poor waste collection rates due to a lack of equipment and staff as well as poor infrastructure. Insufficient or lacking measures to treat and convert waste into energy and poor recycling methodologies are also severe challenges that most municipalities in South Africa have failed to address (Dlamini *et al.*, 2019). Moreover, municipalities' failure to properly collect waste has led to the burden posed by illegal dumping.

Municipal solid waste (MSW) includes household and commercial waste (Viljoen *et al.*, 2021), and there are various necessities that guide the generation and storage of solid waste. The collection and transportation of solid waste from source to landfill in an

environmentally and socially acceptable manner are key priorities in the waste management process (Kubanza and Simatele, 2020). In the current dispensation and considering the SDGs to which South Africa is a signatory, the major goal of municipalities should be to transition from landfill-based waste management to resource recovery waste management solutions through re-use, recycling, and composting practices (Dlamini *et al.*, 2019). Whether this goal is achievable in the current dispensation is a debate that is ongoing among scholars and waste managers alike.

Previous studies (Adekele *et al.*, 2021; Alao *et al.*, 2021; Ayeleru *et al.*, 2018; Dlamini *et al.*, 2019) have advocated for other strategies of solid waste management, including zero waste and waste-to-energy recovery. A zero-waste society is achieved when resources are conserved through production, reuse, and product recovery without contaminating the environment and posing a risk to human and environmental health (Adekele *et al.*, 2021). The effects of waste on the environment are enormous and are not limited to the emission of greenhouse gases, such as methane, that cause global warming 30 times higher than carbon dioxide. Air pollution, noise pollution, and chronic diseases such as lung cancer and anaemia have become the bane of societies in developing countries (Adekele *et al.*, 2021; Dlamini *et al.*, 2019; Kubanza and Simatele; Njoku *et al.*, 2019).

In South Africa, poor waste management has various detrimental effects, but waste-to-energy technologies can add extra megawatts to the Eskom grid, thus promoting clean and healthy local environments (Alao *et al.*, 2021; Dlamini *et al.*, 2019). The practice of dumping 90% of waste on South African landfills is not sustainable, and South Africa must urgently adopt appropriate solid waste management strategies if relevant Sustainable Development Goals are to be realised (Kubanza and Simatele, 2020).

This study aimed to explore the reasons why municipalities do not comply with solid waste management regulations and to determine to what extent this non-compliance impacts available water resources in the Upper Vaal water management area of South Africa. The following key research questions were posed:

- What are the major factors that cause municipalities in the study area not to obtain a licence for appropriate waste disposal?

- What major factors influence these municipalities not to comply with waste management legislation?
- Are municipal employees well-trained and qualified to operate landfills?
- Why is the disposal of solid waste on landfills still a 'better bet' for the municipalities in study? and
- What are the critical success factors that Upper Vaal should adopt and implement for sustainable waste management?

The section below presents the conceptual framework that guides the waste management process from generation to processing and final disposal. The discourse then presents the methodology that was used while the data and key results are discussed. Pertinent recommendations for proper waste management are offered, while ideas for future research are also highlighted.

5.2 Conceptual framework

Adeleke *et al.* (2021) indicate that the Integrated Municipal Solid Waste Management (IMSWM) framework (Figure 5.1) promotes waste prevention, recycling, recovery, and controlled supervision of waste disposal in an environmentally friendly manner. The framework comprises of two components: the physical component and the governance component. The physical component entails waste generation, collection, disposal, treatment, and revenue value through recycling and energy recovery, whereas the governance component includes stakeholders, the public and private sectors, municipalities, financial sustainability, waste management policies, and institutional waste management (Adeleke *et al.*, 2021).

Ayeleru *et al.* (2018) assert that integrated waste management planning was introduced in South Africa to improve waste management at reduced cost and with minimal environmental impact. Each municipality is therefore required to develop an integrated municipal solid waste plan in line with the National Waste Management Strategy (Ayeleru *et al.*, 2018). The key components of integrated solid waste management plans are waste generation, separation at source, storage at source, collection, transport, transfer, recovery, treatment, processing, and disposal (Adeleke *et al.*, 2021). Kubanza and Simatele (2020) iterate that the National Waste Management Strategy has eight

goals, including the effective and efficient delivery of waste services (Goal 2) and the requirement that people should be aware of the impact of waste on their health (Goal 4). In South Africa, there are various pieces of legislation that govern waste management, including the Municipal Systems Act No. 32 of 2000, the Mineral and Petroleum Resources Development Act No. 28 of 2002, and the Air Quality Act No. 39 of 2004. These laws mandate sound waste management and decision-making strategies and guide the final disposal of all types of waste (Kubanza and Simatele, 2020).

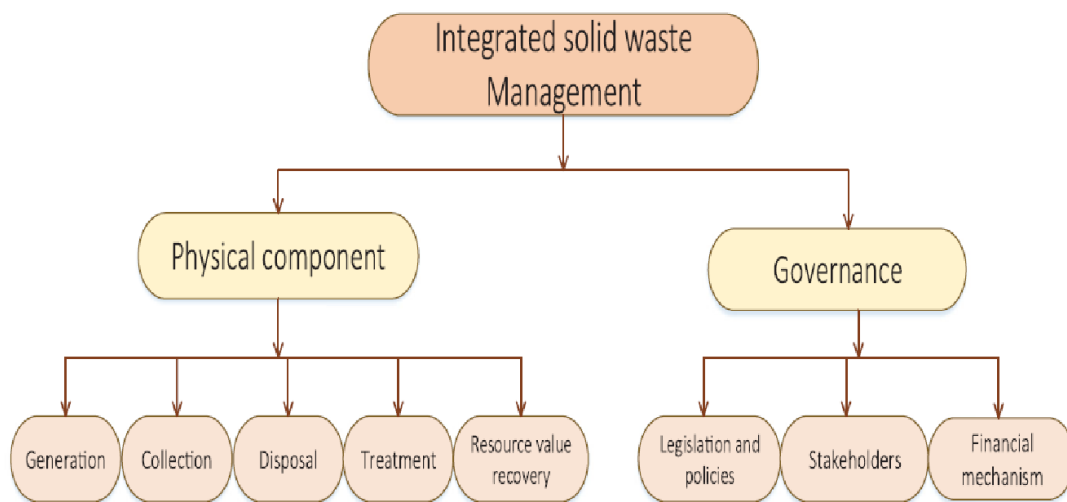


Figure 5.1: Components of the Integrated Waste Management Framework
Source: Adekele *et al.*, 2021

5.3 Research methodology

The following aspects are discussed, namely;

- Study site location;
- Research design;
- Research strategy;
- Research approaches and sampling method;
- Study population, sampling, and sampling size;
- Data collection and
- Data analysis and ethical clearance.

5.3.1 Study site location

The Vaal Water Management area (WMA) is located in the centre part of South Africa and covers large parts of the north-eastern region of the country. The Vaal WMA contains three separate watershed areas: the Upper Vaal (55 565 km²), the Middle Vaal, and the Lower Vaal catchment basins (Figures 5.2 and 5.3). The area extends all the way to Ermelo to the north and the KwaZulu-Natal province to the east. It then runs just west of eSwatini in the east and crosses all the way to Kuruman in the Northern Cape in the west. The Vaal World Heritage area lies in northwest Botswana and is bordered by the Crocodile River and the Olifants River catchment areas to the west. It is bounded to the southeast by Lesotho and to the southwest by the Upper and Lower Orange River catchment areas (Department of Water and Sanitation, 2015). The southern half of this WMA is in the Free State and extends to the confluence of the Mooi River and the Vaal River. The southeast region falls primarily in the province of Mpumalanga, while the northern and western parts are in Gauteng and NorthWest provinces respectively. The southern half is located entirely in the Free State province (Basson and Rossouw, 2003).

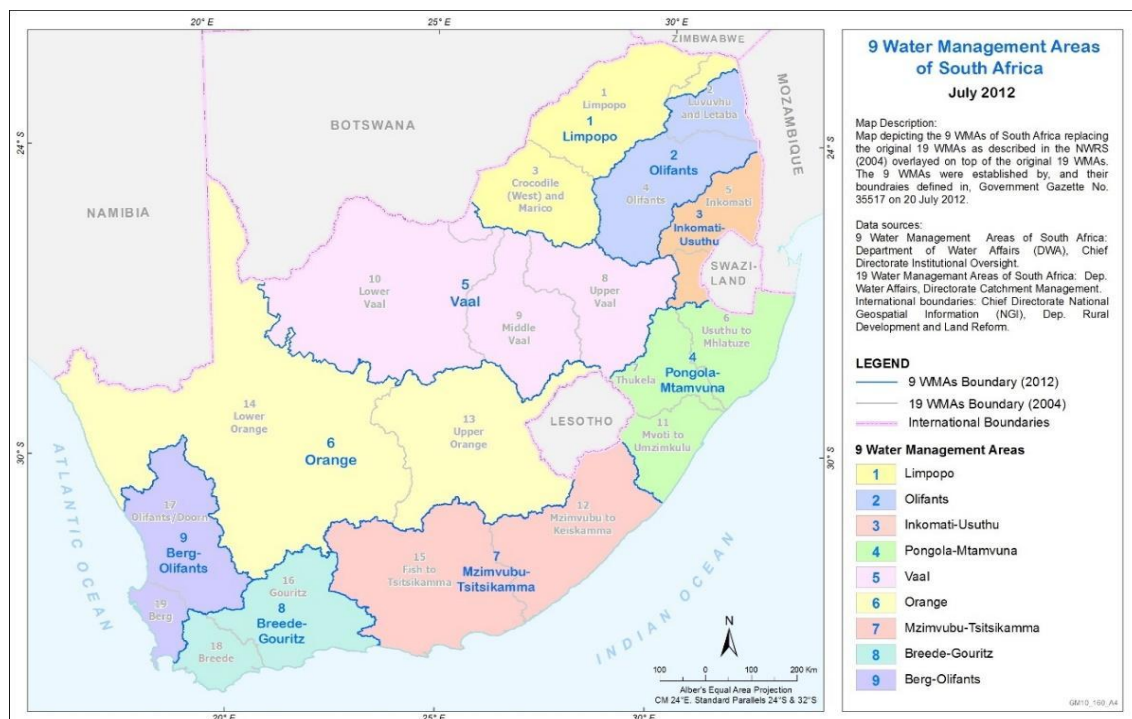


Figure 5.2: Boundaries of the water management areas (WMA) in South Africa
Source: Department of Water Affairs and Forestry, 2013

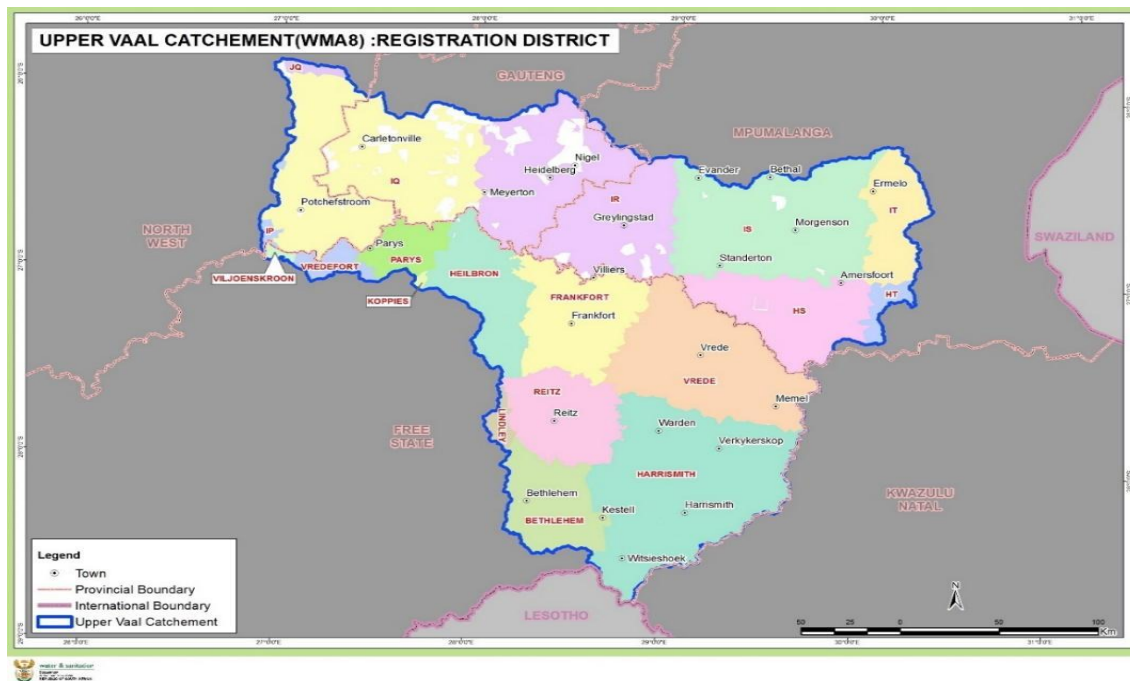


Figure 5.3: Map of the Upper Vaal catchment area
Source: Department of Water and Sanitation, 2017

5.3.2 Research design

A research design refers to the methods and procedures that are used to collect and analyse data (Boru, 2018). Various research designs can be utilised, including exploratory, explanatory, descriptive, and evaluative designs. After careful evaluation, the design that is chosen becomes a comprehensive study plan that integrates all the research components logically and consistently (Saunders, Lewis and Thornhill, 2009). This study adopted an explanatory research design as its goal was not to provide comprehensive answers to pre-existing concerns, but to investigate the research topic. In most cases, this type of research is conducted to analyse a subject that has not yet been narrowly defined (Mbaka and Isiramen, 2021).

5.3.3 Research strategy

Researchers allow their cognitive processes to be guided by the research strategy, allowing them to complete the study objectives methodically (Mackenzie Corporation, 2014). According to Johannesson and Perjons (2014), a research study is "an overall plan for carrying out a research investigation". The experimental, survey and case study strategies are all distinct research techniques. This study adopted the case study

research strategy to assist in analysing the real-life situation associated with municipal landfills to determine why certain aspects were the way they were. The study therefore utilised a minimal population sample, as advised by Garvis (2015) and Yin (2014).

5.3.4 Research approaches and sampling method

Creswell (2014) distinguishes between three research approaches, namely the quantitative, qualitative, and mixed methods approach.

Quantitative research aims to obtain objectivity, control, and precise measurement. Deductive designs are used in this approach to prove, disprove, or build evidence supporting specific theories and hypotheses (Leavy, 2017). A quantitative research design includes collecting and analysing numerical data that can be analysed using statistical techniques to investigate a phenomenon by looking at the relationships among various factors systematically and scientifically (Eyisi, 2016).

Qualitative research, according to Creswell and Creswell (2018), is a method that researchers use to explore and understand the meaning that individuals or groups ascribe to a social or human phenomenon or problem. This research process commonly involves emerging questions and qualitative procedures such as open-ended interviews. The goal of qualitative research is to obtain knowledge on how a certain individual or group of individuals think as well as the meanings they attach to various aspects of the studied phenomenon (Okeke and van Wyk, 2015). Data are typically collected in participants' setting, and data analysis inductively builds from particular to general themes.

Mixed-methods research entails mixing or integrating qualitative and quantitative research methodologies and data (Creswell and Creswell, 2018). Qualitative data are often open-ended and do not include predefined responses, whereas quantitative data typically comprise of closed-ended responses, such as those that emerge from structured questionnaires or psychological instruments. The mixed methods research design addresses the complex concerns and problems that emerge from using both the quantitative and qualitative approaches (Maxwell, 2016). The mixed research technique is a problem-centred approach to research in which methodologies and theories are

employed to solve the research problem based on the relevance of data that address the current topic (Leavy, 2017).

This study employed the mixed methods approach. This means that the researcher used both open- and closed-ended questions in a questionnaire to collect data from selected municipal representatives.

5.3.5 Study population, sampling, and sampling size

In the context of this research project, the term 'population' refers to the total population of people, events, or things of interest that could potentially have participated as respondents in the study (Saunders *et al.*, 2009). All the municipal personnel in the Upper Vaal WMA involved in the disposal of solid waste served as the population of the study.

As the entire population was far too large to include in the study, sample selection had to be applied. There are two primary categories of sampling: probability sampling, which includes simple random, systematic, stratified, and cluster sampling, and non-probability sampling, which may employ the quota, snowball, purposive, and convenience sampling methods either singly or in combination. This study used purposive sampling, which is a non-probability sampling technique. Purposive sampling thus entailed selecting units (in this case questionnaire respondents) for the sample based on the characteristics that the researcher sought in that sample. The population was represented by 31 respondents who answered the questions in the copies of the questionnaire they received. One respondent from each of the facilities was selected for questionnaire administration. These people were sampled by requesting the facility manager to identify a representative who would be best informed about the history, structure, and operations of the targeted waste management facility.

5.3.6 Data collection

The Department of Water and Sanitation, Gauteng Operational Office was contacted to outline the Upper Vaal catchment area's demarcation. Different provincial departments

of Environmental Affairs were requested to provide a list of waste disposal facilities that comprised both operational and closed sites.

Four data collection tools were used in the study: an observational checklist, a geographical positioning system (GPS), a structured and unstructured questionnaire, and a Canon EOS 200D camera. All the operational waste disposal facilities were visited in person by the researcher. An observational checklist was used to record waste streams received at the site, observe the operation and management of the waste disposal facility, and determine if a groundwater monitoring system was in place at each site. The GPS was used to record the coordinates of all the waste disposal facilities. When the observational study had been completed, the coordinates of all the waste disposal facilities in the study area were entered into the Google Earth Pro System for mapping, and the data were used to measure the distance from the facility to the nearest residential dwelling/s (Figure 5.4). Thirty-one (31) structured and unstructured questionnaires (one per waste disposal facility) were administered. The sampled municipal representatives responded to the questionnaire in their own time in their offices, and field visits along with the researcher were then conducted. A total of 57 structured and 21 unstructured questions were included in the questionnaire. The copies of the questionnaire were administered in English as all the respondents were proficient in this language even though their mother tongues were mostly of African origin.

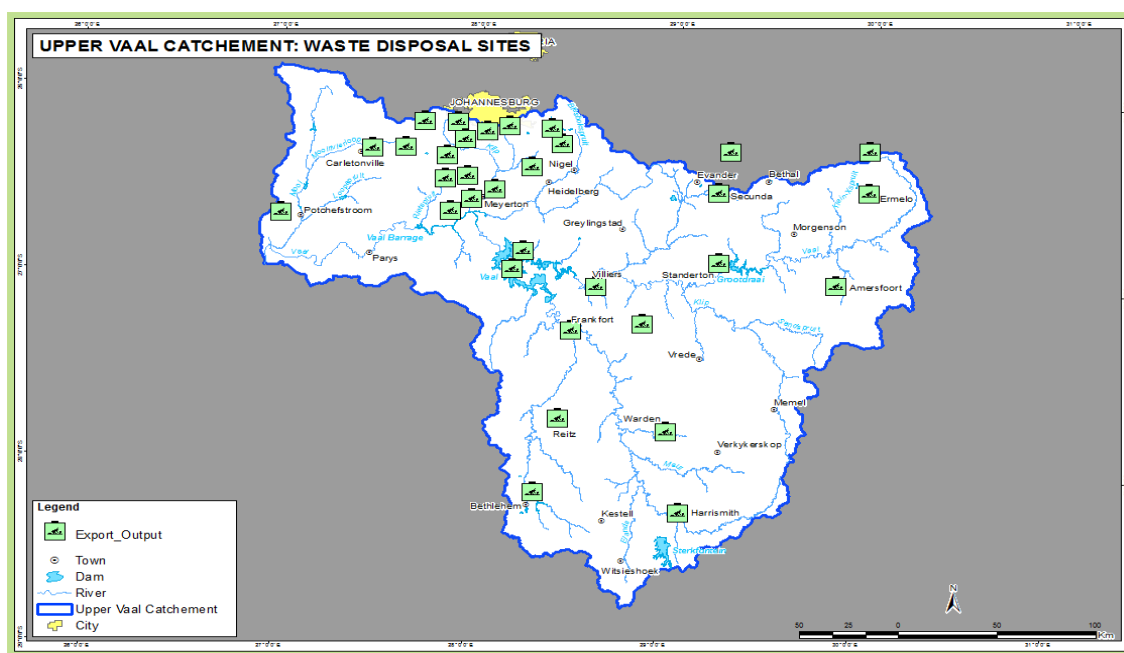


Figure 5.4: Sampled waste disposal facilities in the Upper Vaal catchment area
 Source: Department of Water and Sanitation, 2019

5.3.7 Data analysis and ethical clearance

The SPSS software (version 21, 2012) was utilised to analyse the data. Descriptive statistics (frequencies and percentages) were generated to organise, summarise, and present the data in a convenient and informative way. For the qualitative data, the researcher read, coded, and interpreted the respondents' answers to the questions in the questionnaire. This enabled the researcher to identify the fundamental factors associated with the study area's waste disposal facilities (Creswell, 2009). The study was approved by the Health Sciences Research Ethics Committee of the University of the Free State (Appendix C). The study commenced after approval by the management of each waste disposal facility (Appendix D) and the Ethics Committee of the university. The respondents were informed of the purpose and objectives of the study and they were assured of the voluntary and confidential nature of their participation.

5.4 Results and discussion

This section presents the data and reports the study findings. These findings are organised according to the study objectives. First, the respondents' demographic information is discussed. The discourse in the following section provides information

about South African legislation that controls landfills and groundwater monitoring, and the third section contains information about the layout of landfills and the equipment used for landfill management. The fourth section presents the data based on the examination of landfill management and the various types of solid waste that were deposited at each site. The final section provides information on groundwater monitoring and landfill site planning.

5.4.1 Demographic details of the respondents

The demographic information of the respondents revealed that the largest percentage (87%) was male, while only a small percentage (13%) was female. The majority (30%) was between the ages of 40 and 50 (Figure 5.5). Regarding working experience, 35,5% of the respondents had three to five years' experience, while the working experience of the rest ranged between six months to two years (Figure 5.6).

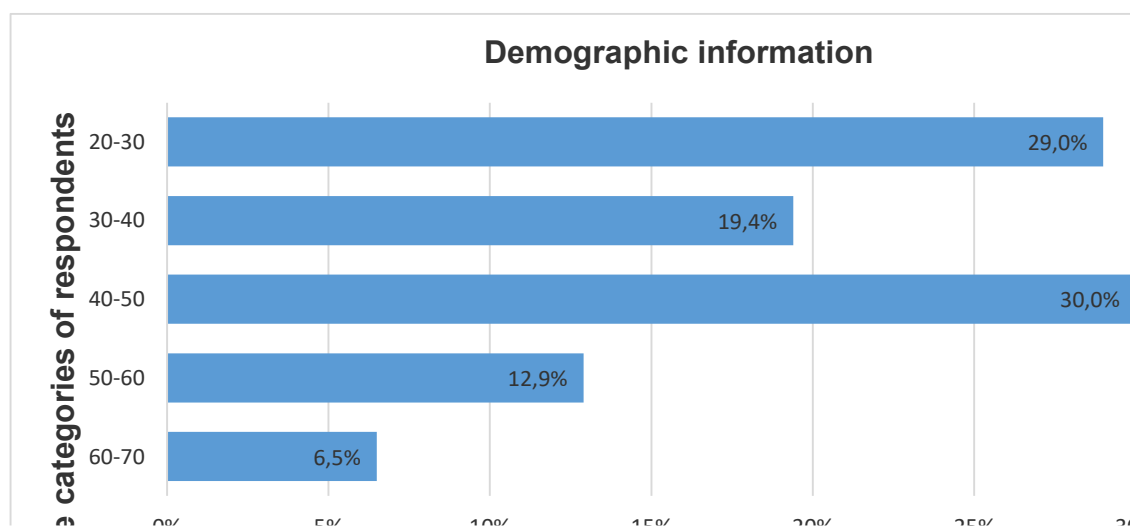


Figure 5.5: Age categories (n = 31)

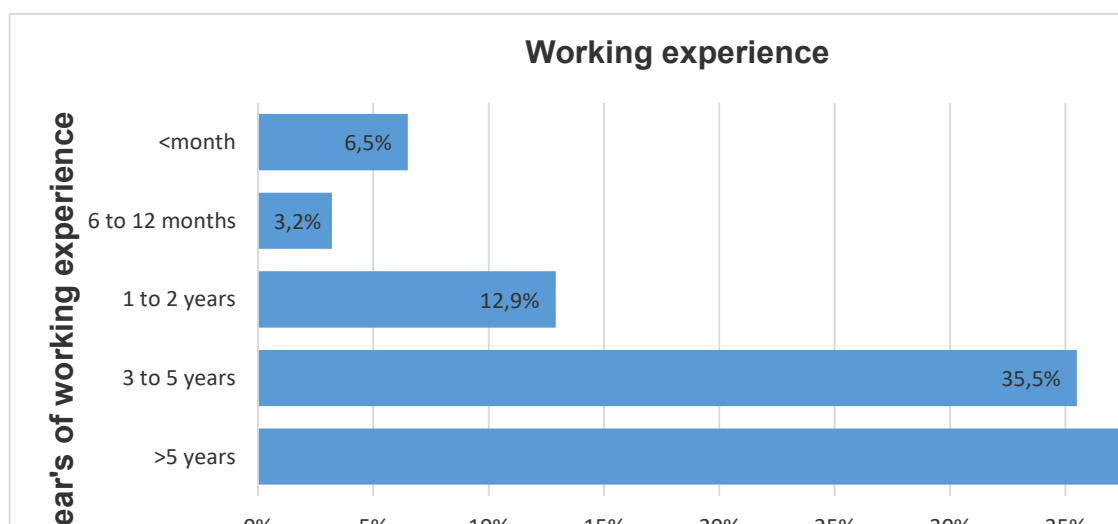


Figure 5.6: Years of working experience (n = 31)

5.4.2 Education and training

Education was key in understanding the competencies of the respondents (Figure 5.7). The majority of the respondents (48,8%) had a tertiary qualification, while 16,1% had either a secondary school (Grade 8 to 11) or a matric (Grade 12) qualification. Only 6,4% had either primary or no education. The respondents were asked whether they had attended any training sessions in waste management, and it was found that a large majority (71%) had indeed attended such training sessions, whereas 29% had not attended any additional training sessions at all. Although the respondents had attended training sessions, the duration was quite limited. For example, 39% had been exposed to training that had lasted for a week, whereas 32% had not been exposed to training at all. On the other hand, 3% of the respondents had received training that had lasted between a month to a year, whereas 7% had attended extensive training for over a year (Figure 5.8). The top four courses that the employees had attended were environmental management (16,1%), environmental law (9,7%), landfill management (9,7%), and waste handling (9,7%) (Table 5.1).

Figure 5.9 indicates that the respondents averred that training was beneficial as it improved the standard of landfills, while 40% believed that an environmental management course/training would improve their knowledge for more effective and efficient waste management and uplift the standard of the sites being managed. Moreover, 30% believed that training related to the operation of landfills would lead to

new ideas and enable the efficient operation of sites, while 20% did not really know which training courses they could attend to improve their knowledge and attain higher site standards. Five percent (5%) of the respondents indicated that attending courses, gaining knowledge of environmental law and recycling, and sound classification of waste type strategies would improve the standard of sites.

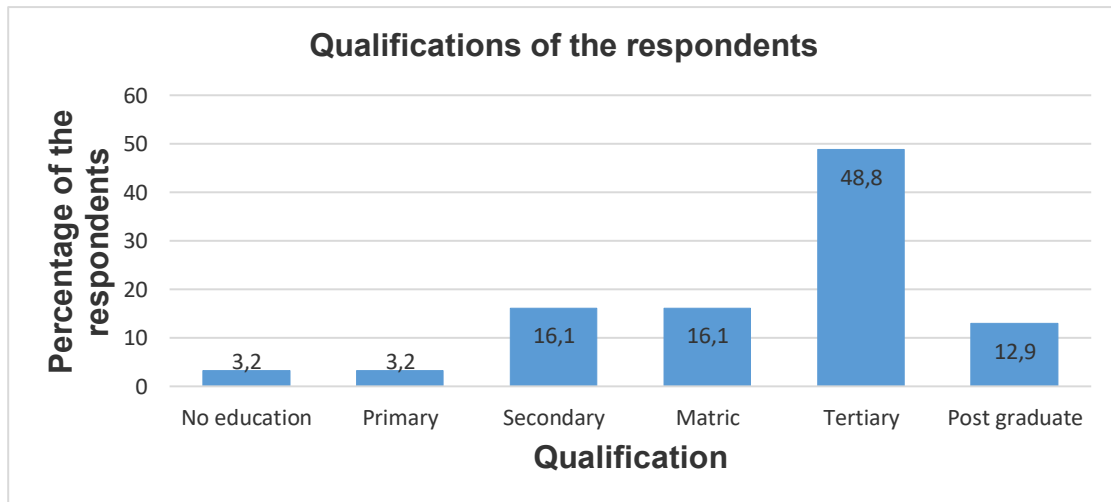


Figure 5.7: Qualifications of the respondents

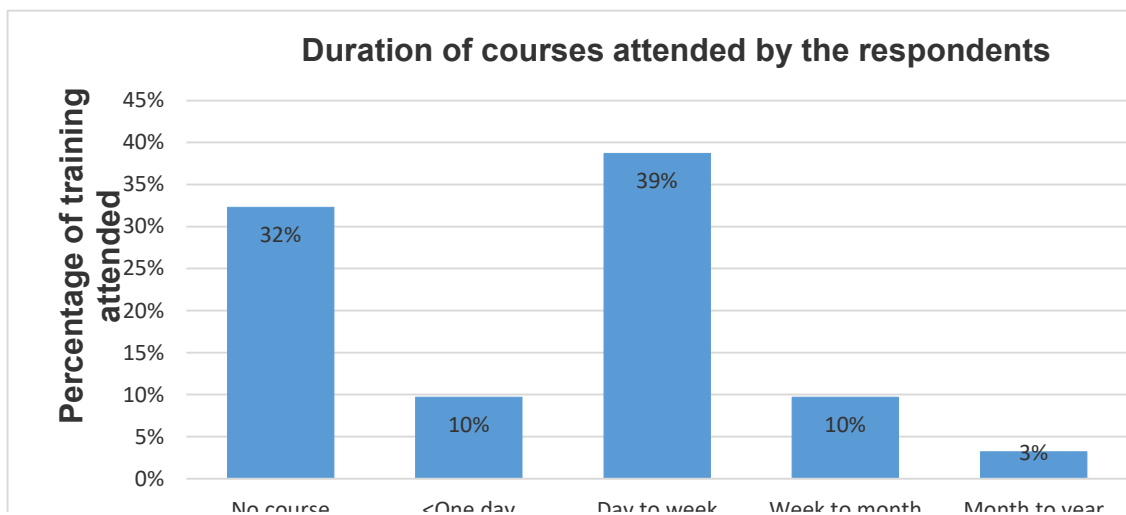


Figure 5.8: Duration of courses attended by the respondents

Table 5.1: Types of courses attended by the participants

Course	Percentage (%)
No course	32,3
Environmental management	16,1
Environmental law	9,7
Landfill management	9,7
Waste handling	9,7
Waste management	6,5
NQL 4	6,5
Waste group	3,2
Recycling	3,2
Handling, storage, and transportation of waste	3,2



Figure 5.9: Types of training requested by the respondents

5.4.3 Information about landfills as waste disposal facilities

Figure 5.10 presents information about the legality of the operations at the waste disposal facilities under study. A vast majority (85%) of the waste facilities had an operating licence. The Environmental Conservation Act No. 73 of 1989 (Roberts, 2013) was the primary legal basis for the majority (80%) of the operating licences that had been issued (Figures 5.12). In contrast, 75% of the municipalities had received approved designs before the landfills were constructed, and approximately 15% of the landfill facilities had not been in possession of an approved design when they were constructed. This suggests that some municipalities might have been issued with permits to construct the landfill site but did not operate it according to the conditions in

the issued permit. In addition, most of the respondents (51%) was unaware whether or not South African drinking water standards are used for the monitoring of water quality (Figure 5.11). However, many of the respondents had at least a tertiary qualification, and some had attended additional courses on landfill management (Table 5.1).

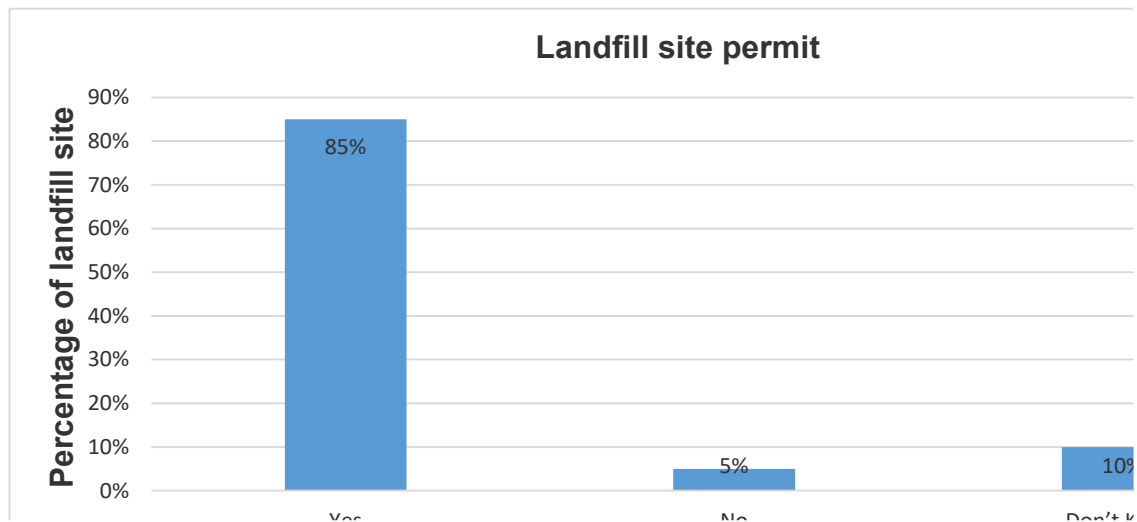


Figure 5.10: Does the landfill have a valid authorisation

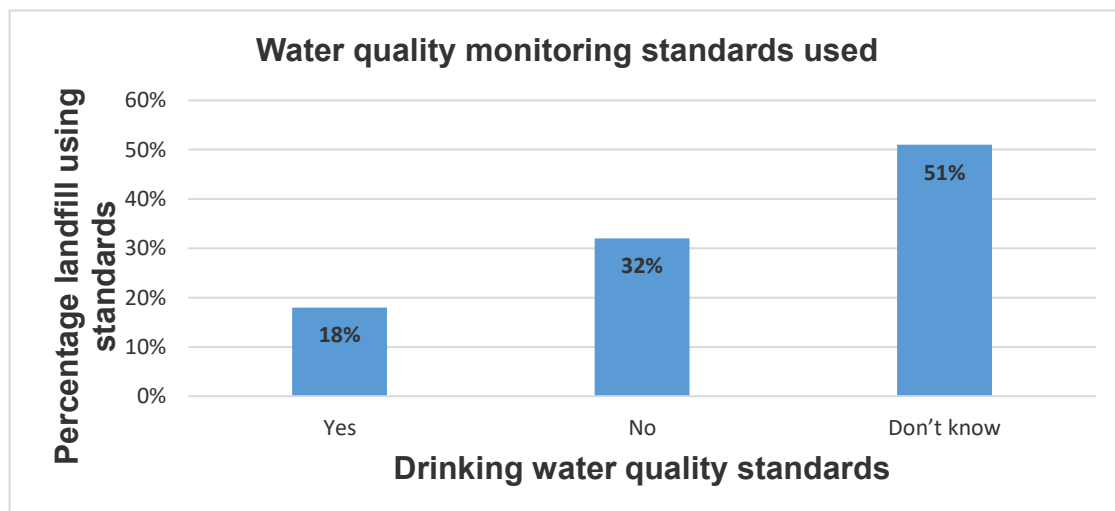


Figure 5.11: Rates of SA drinking water standards used for water quality monitoring

The respondents indicated that some of the municipal landfill sites (30%) had licences as required by the National Environmental Waste Act No. 59 of 2008, while others responded that the waste disposal facility had been authorised a long time ago and that they were utilising a permit (25%) as mandated by the Environmental Conservation Act No. 73 of 1989 (Figure 5.12).

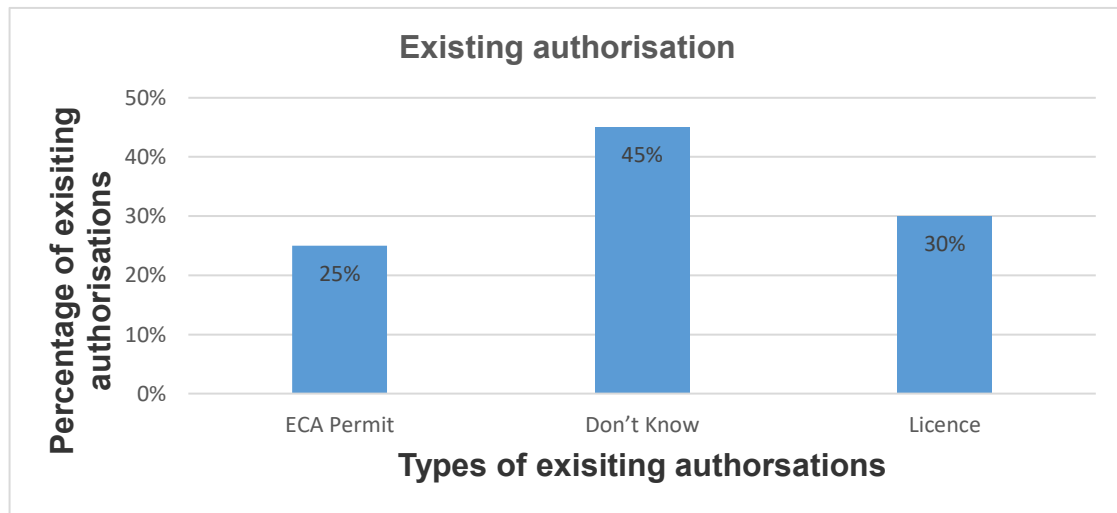


Figure 5.12: Types of existing authorisations

Furthermore, some respondents (5%) pointed out that they did not know if their respective landfill sites had any timespan authorised for operation, while 40% indicated an authorised lifespan of 5 to 10 years (Figure 5.13).

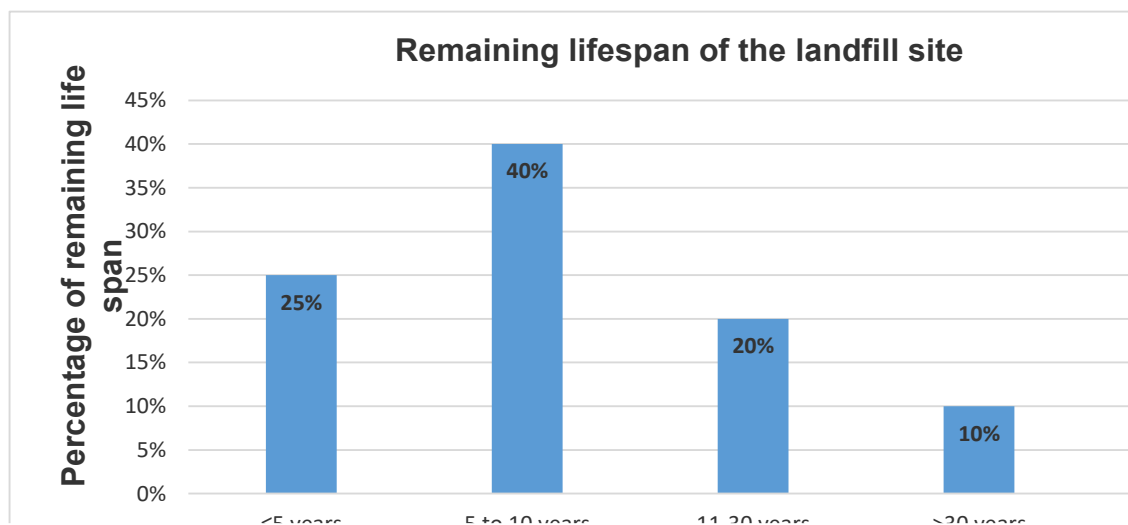


Figure 5.13: The remaining lifespan of the landfill site

On the same issue, 60% of the appointed officials in charge of the sites indicated that these sites had been in operation between 1990 to 2000, while 40% had been operational between 2001-2014 (Figure. 5.14). To prevent unauthorised entry to the sites, 68% stated that infrastructure was not in place to control unauthorised access (35% of the sites had a concrete wall and 10% had a wire fence). It was evident that

access control was a challenge and that infrastructure was dilapidated due to theft. Only 10% of the sites was fenced (Figure. 5.15).

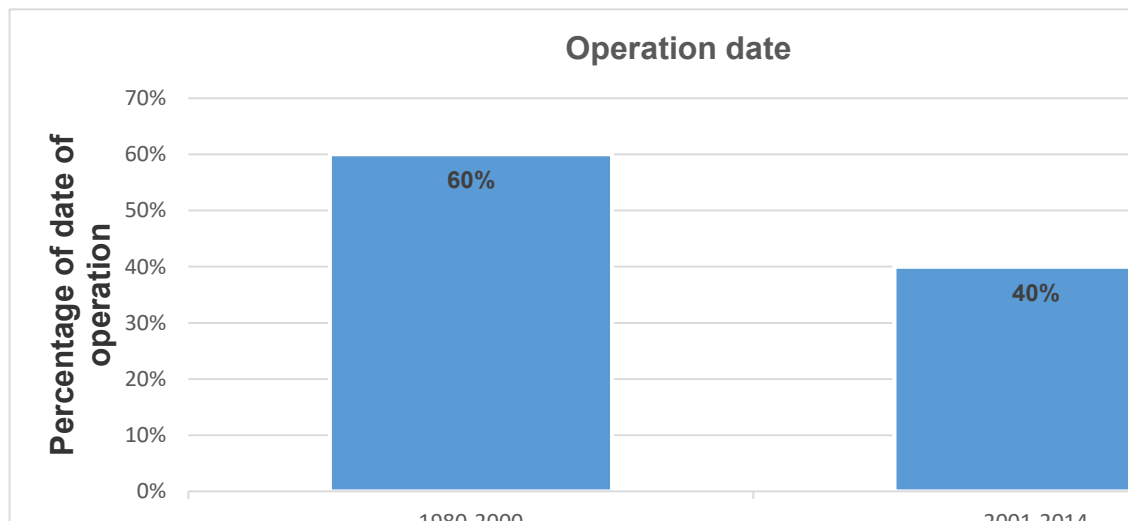


Figure 5.14: Year in which operation started

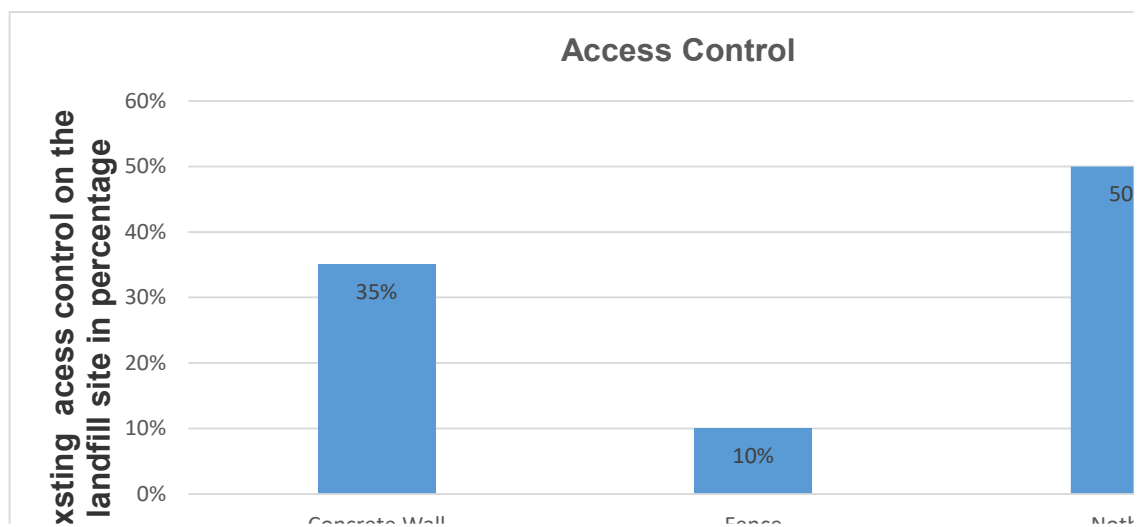


Figure 5.15: Types of access control to landfill sites

Regarding adherence to regulatory requirements and optimal operation, 75% of respondents indicated that their landfill sites have approved designs for effective construction and operation. On the contrary, 15% reported having no approved designs, and 10% were unable to confirm this information (Figure 5.15).

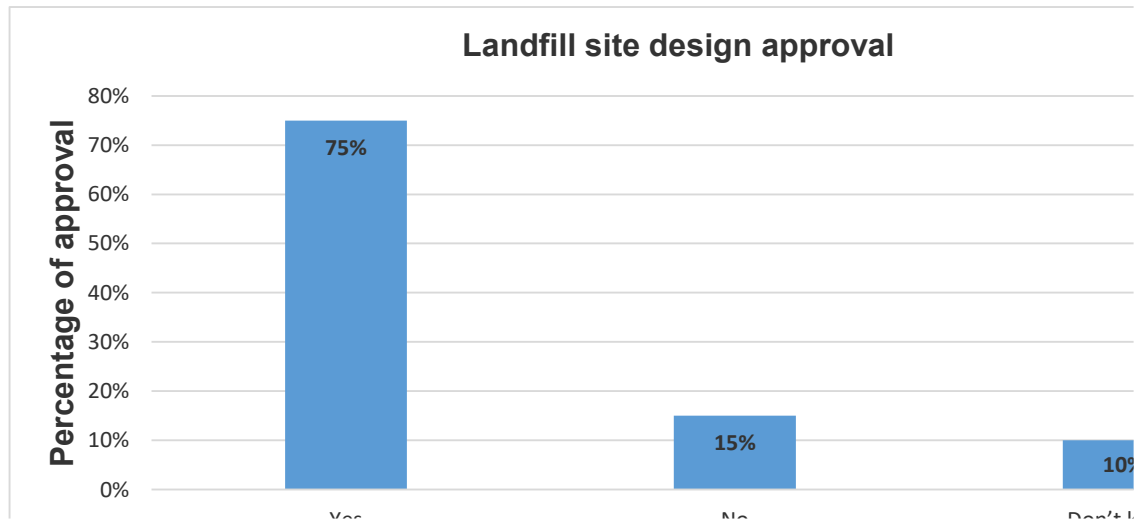


Figure 5.16: Landfill site design approval

5.4.4 The design of the landfills and the equipment used for landfill management

The findings revealed that the volumes of waste disposed of on the selected landfills ranged from 10.3 to 37.8 m³ per day. This means that the highest volume of waste disposed of in the study area per month was roughly 1 134 m³.

This could have a direct impact on the landfill sites' longevity because it was found that many of these landfills (40%) had a lifespan of 5 to 10 years, while a few (25%) had a lifespan of less than five years (Figure. 5.17).

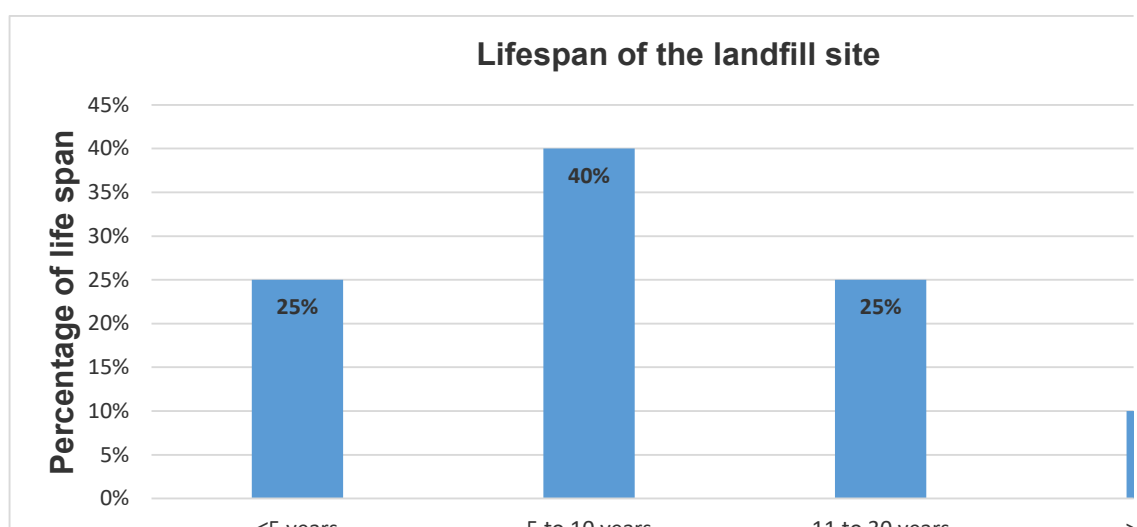


Figure 5.17: The lifespan of the landfill sites

It was obvious that, without effective waste management strategies, most landfill sites would reach capacity very quickly. The threat that this pose is highlighted by Lando, Djamaludahina, Arifin and Aprianto (2022), and it was disconcerting to learn that most of the respondents were unaware of the end use of the respective landfill sites, particularly those that would soon reach the end of their lifespan. This suggests that operations at these sites would be ongoing despite reaching the end of life which may lead to increased groundwater pollution.

Figure 5.18 depicts the equipment used for landfill operations, such as waste compacting. According to the respondents, most of the landfills in the study area lacked suitable equipment. For instance, only 8% had all the required equipment (tractor, tipper truck, front-end loader, and compactor), while 31% had a tipper, front-end loader and compactor (Figure 5.19). This was deemed an unacceptable state of affairs as Campitelli, Kannenjieber and Schebe (2022) point out that effective waste management practices can significantly enhance landfill performance.

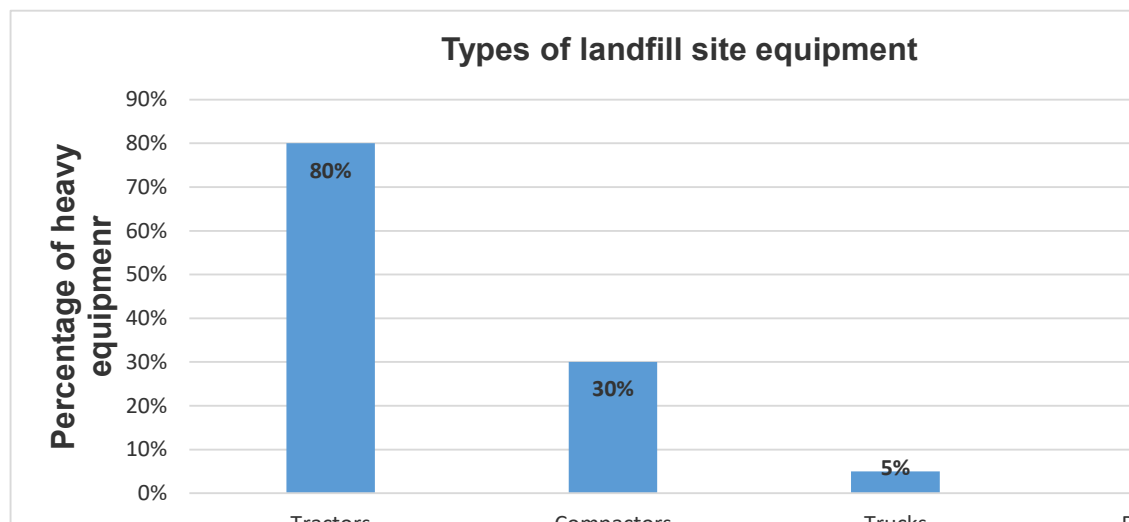


Figure 5.18: Types of landfill site equipment

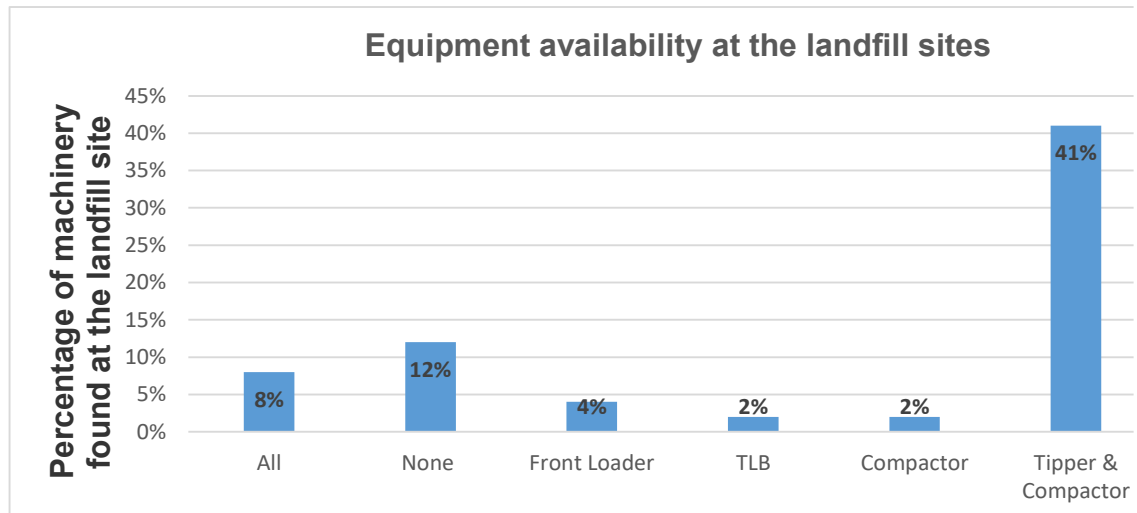


Figure 5.19: Equipment availability at the landfill sites

In addition, 50% of the respondents mentioned that proper equipment was essential while 40% believed that good management practices at landfill sites would ensure positive change. Ten percent of the respondents reasoned that education could play an important role in changing the status of the sites from poor to acceptable or good (Figure 5.20).

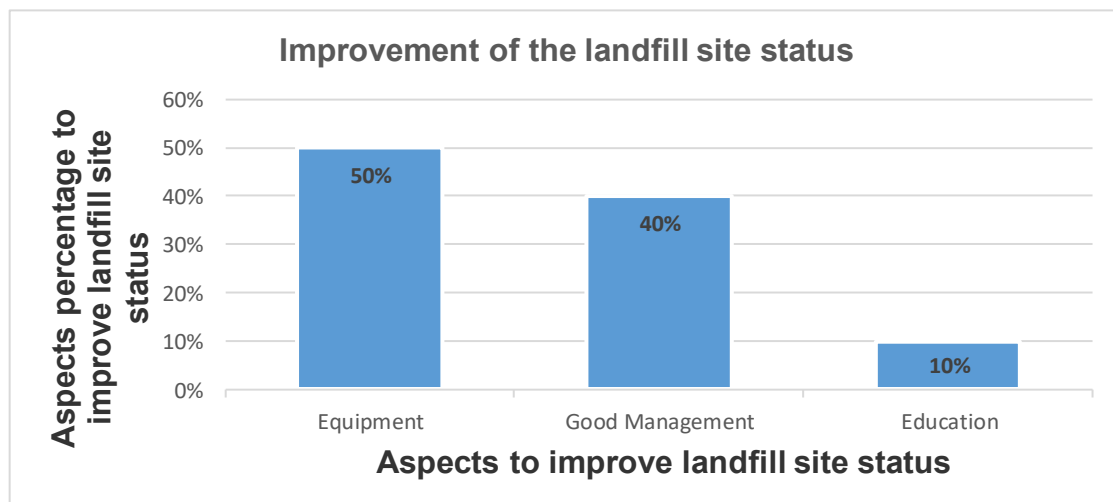


Figure 5.20: Aspects to improve the status of the landfill sites

5.4.5 Operations at the landfill sites and types of waste handled

Most of the landfills (71%) in the study area were registered with the Waste Information Centre (WIC) of South Africa, whereas only a few (26%) were not registered with this body (Figure 5.21). It is worrying that approximately 29% of the waste disposal facilities

under study did not follow proper landfill site classification procedures, which is contrary to the legal requirement for landfill approval (Figure 5.22).

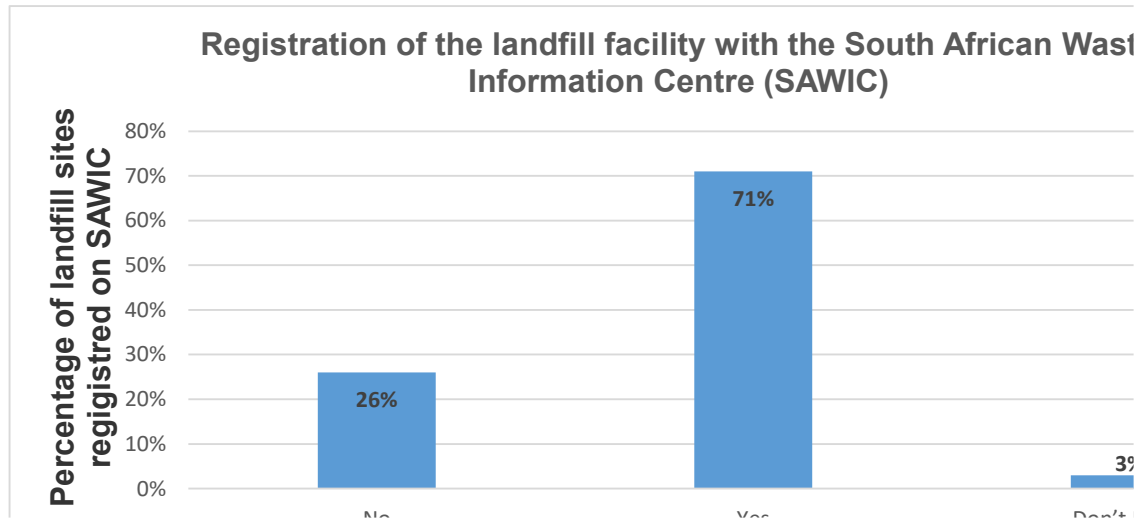


Figure 5.21: Registration of landfill facilities with the South African Waste Information Centre

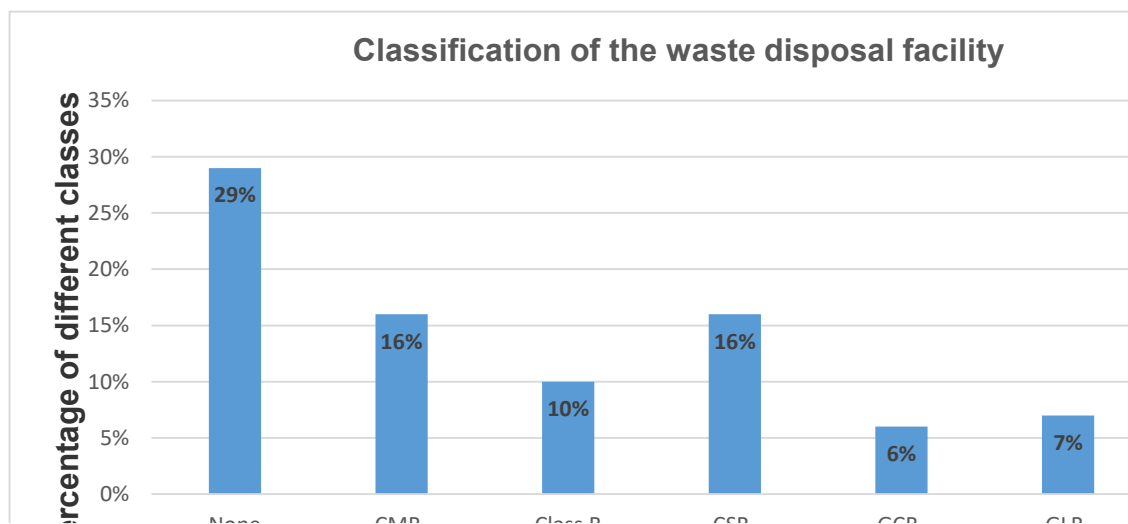


Figure 5.22: Classification of the landfill sites

The waste types that were predominantly disposed of on these landfills were plastics, paper, wood, tin cans, construction materials, tyres, and sewerage sludge (Table 5.2).

Table 5.2: Summary of types of waste, fencing, and access control (n = 31)

Types of waste received	Percentage %
Plastic, paper, glass, food waste, tins, wood, construction materials, garden refuse	32,3
Plastic, paper, glass, tins, wood, construction materials, garden refuse	41,9
Plastic, paper, glass, food, tins, wood, construction materials	6,5
Plastic, paper, glass, food, tins, tyres, wood, construction materials	9,7
Tyres, wood, construction materials, garden refuse	6,5
Tyres, wood, construction materials, garden refuse, sewerage sludge	3,2
Fencing	
Yes	87,1
No	12,9
Access control	
Staff	6,5
Lock and key	9,7
Staff and boom gate	16,1
Staff, boom gate, lock and key	12,9
Staff, lock, key	25,8
Not locked	29,0

The findings revealed that record was kept of the waste being processed at 74% of the landfill sites (Figure 5.23). Only a few (10%) landfills were fenced with different fencing materials (Figure 5.24). In addition, approximately 68% of the landfills had access control with a locked or boom gate (Table 5.2). However, it was noted that some (68%) of the landfill sites were not locked and therefore community members had access to them at any time.

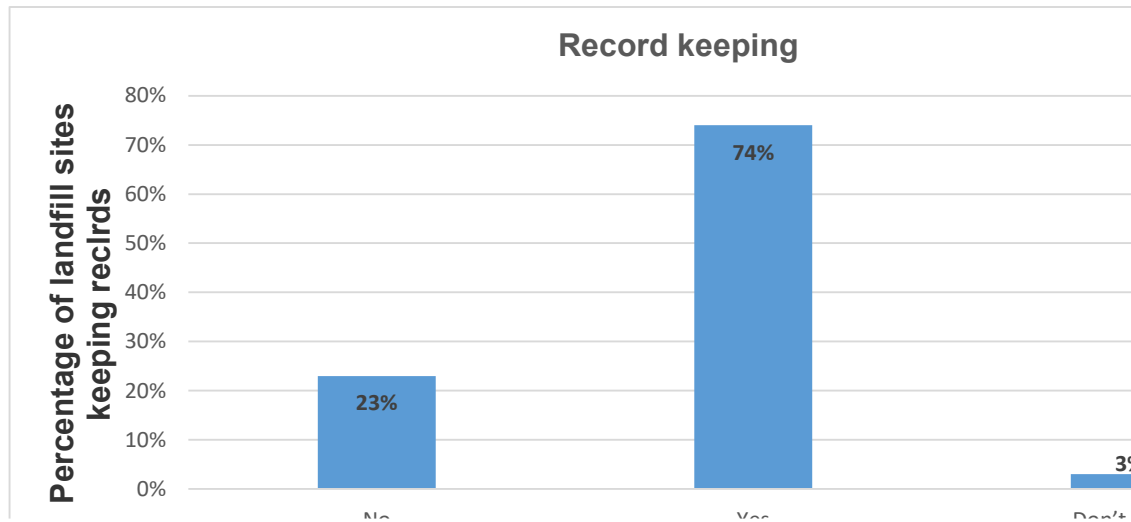


Figure 5.23: Record keeping of waste received

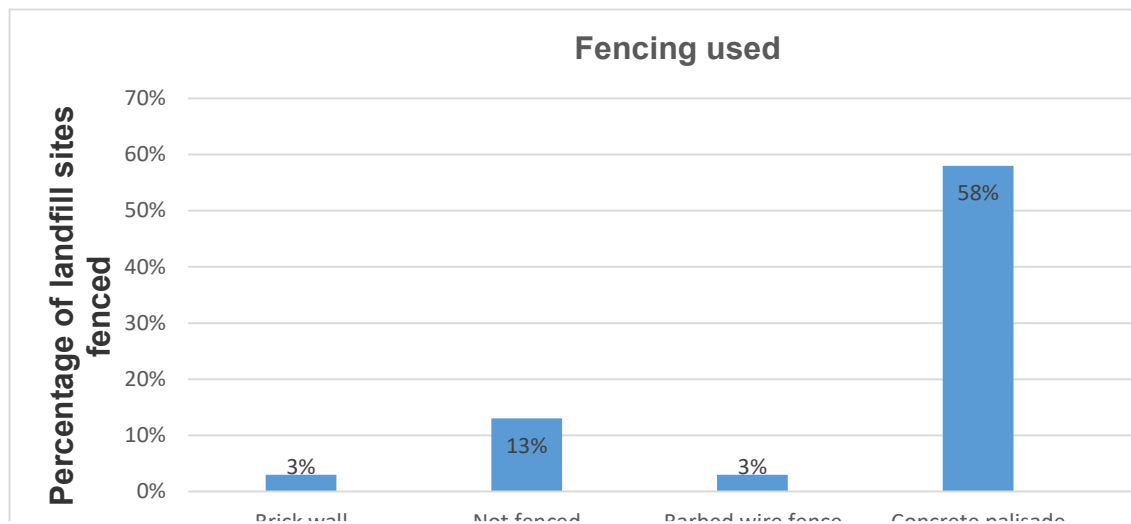


Figure 5.24: Fencing used

No access control was in place at 68% of the landfill sites, meaning that anyone could gain entry to these sites at any time. However, 87% of the sites was fenced. Of these, 58% was fenced with concrete palisades to minimise unauthorised entry to these sites, while some (26%) had some form of wire fencing (Figure 5.25).

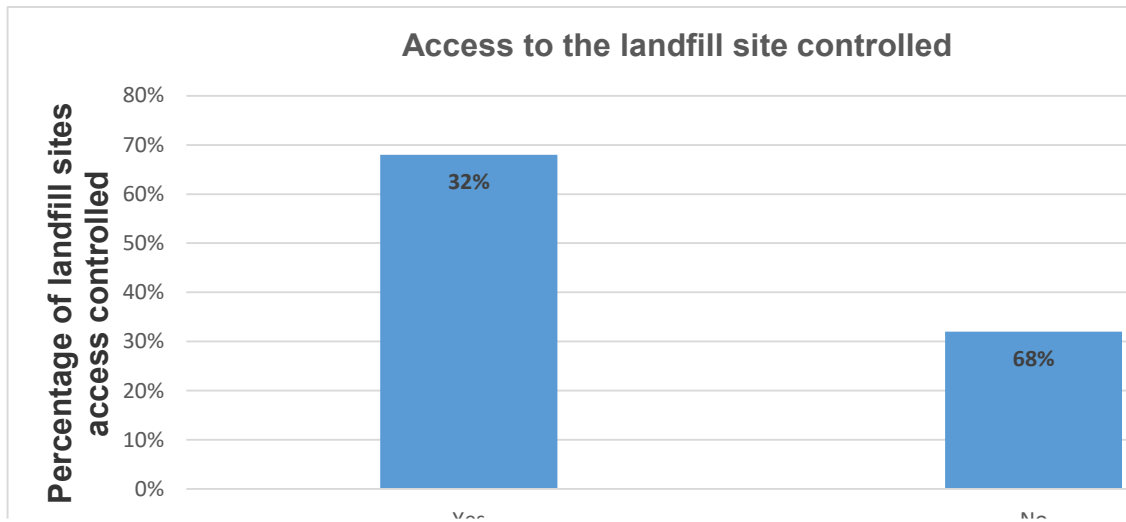


Figure 5.25: Access control to the landfill sites

The results indicated that some best practices and good management were practiced at some landfill sites such as waste compacting (61%) and/or the covering of waste cells (55%) (Figure 5.26 and Figure 5.27).



Figure 5.26: Waste compaction/covering on landfills

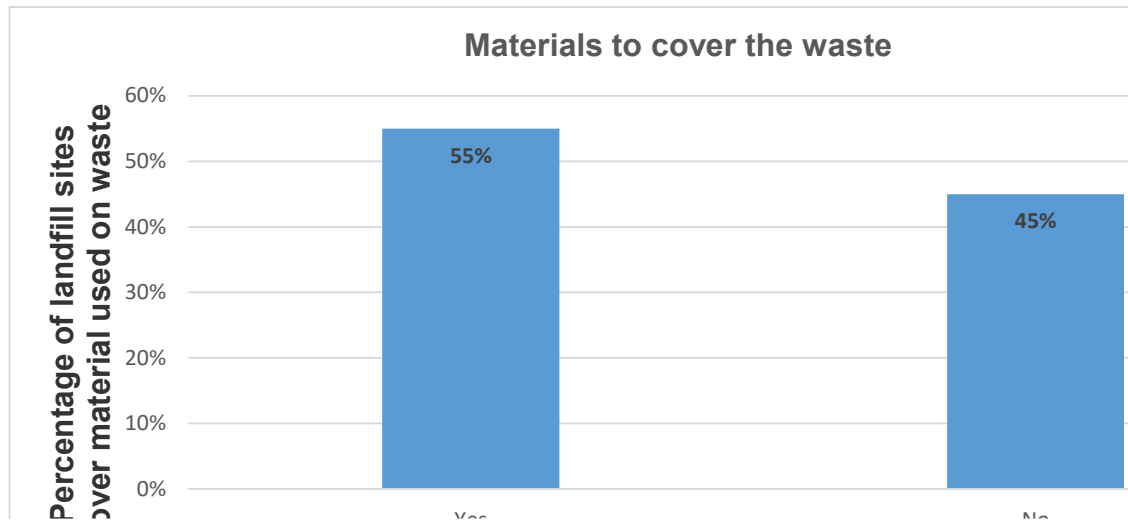


Figure 5.27: Materials used to cover working cells

Furthermore, to manage stormwater, the respondents mentioned the following: the use of the trench method (25%) and a berm (15%). However, 60% pointed out that there was no mechanism to control stormwater (Figure 5.28). This means that stormwater was not managed well at most of the landfills, and the strong possibility existed that this led to contaminated water mixed with clean water in the water resources used by humans and animals. Figure 5.29 presents a photographic example of the specific stormwater control mechanism implemented on the landfill site.

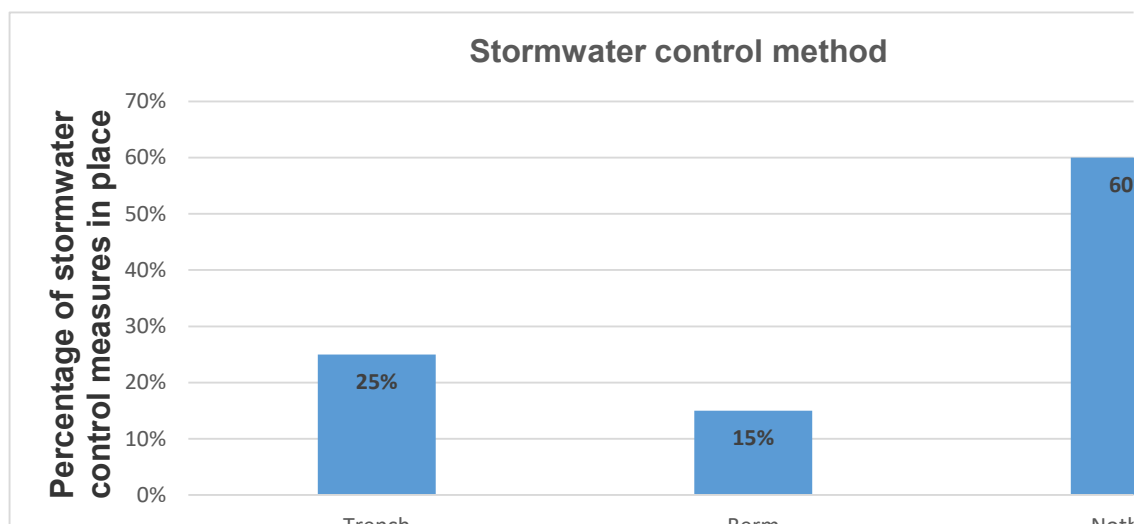


Figure 5.28: Stormwater control method



Figure 5.29: Channel to control stormwater at a landfill site in Gauteng province
Source: Noe, 2018

5.4.6 Human habitation at or near landfill sites

Some challenges were observed in terms of the proximity of human dwellings to the landfill sites. For instance, 97% of waste pickers/recyclers resided in the proximity of the landfill sites, with approximately 32% of these residing within waste facility parameters. Of these, 60% recovered materials to sell for a living (Figure 5.31) and 25% recovered waste to reuse in their households or to make fire to cook due to a lack of electricity. Only 15% of the sites were devoid of waste pickers on site, which was attributed to the distance recyclers had to travel to reach these sites and/or to access control (Figure 5.30 and Figure 5.32).

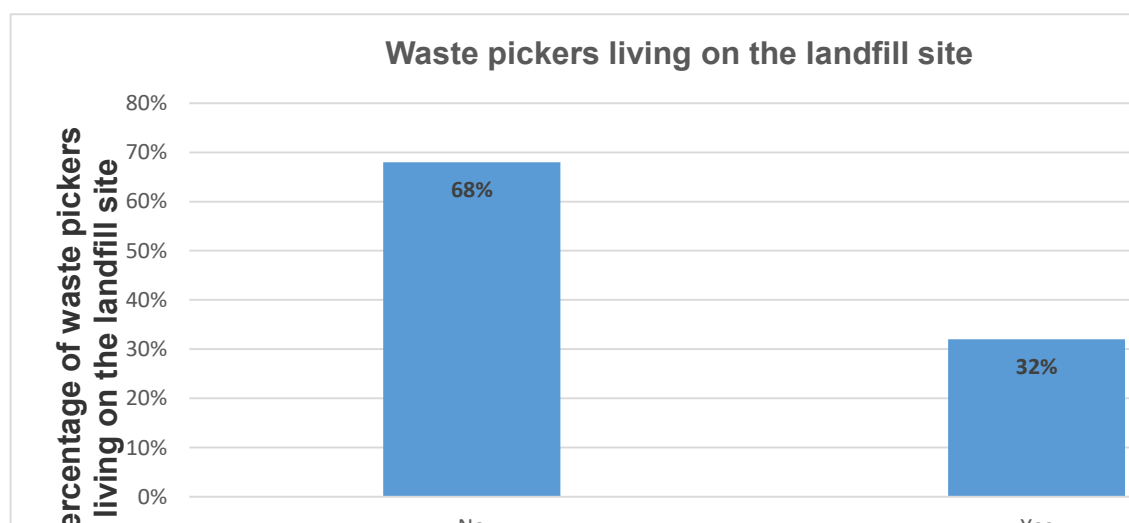


Figure 5.30: Waste pickers living on landfill sites

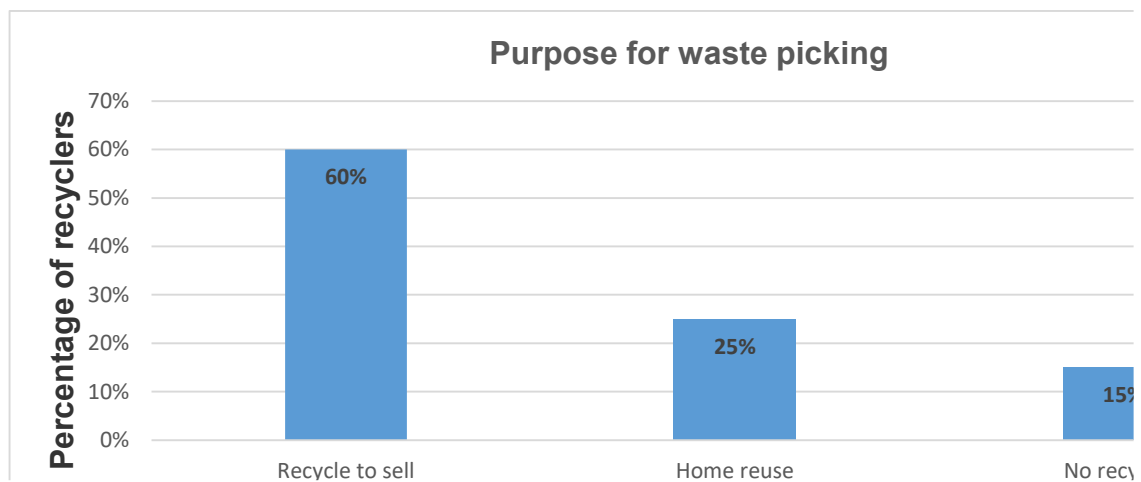


Figure 5.31: Purpose for waste picking



Figure 5.32: Waste pickers gathering recyclables at a landfill site in Gauteng
Source: Noe, 2018

Osama and Lamma (2021) argue that informal recycling has a positive impact on preserving the environment as such recyclers play a role in conserving the natural resources while minimizing pollution. Observation by the researcher revealed that paper materials were blown everywhere at 62% of the landfill sites, resulting in an unsightly and unkempt appearance (Figure 5.33 and Figure 5.34). Due to a massive volume of wastepaper, some waste dumps were set alight, emitting smoke that posed a health threat to humans and animals in the proximity of these sites. In addition, 87% of the respondents indicated that waste recycling was not being practised at the landfills under study (Figure 5.35).

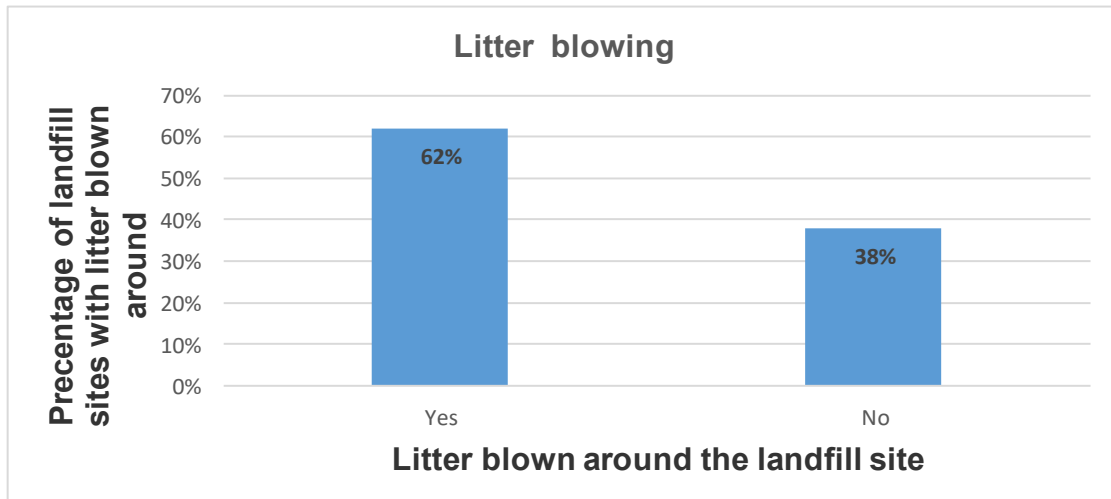


Figure 5.33: Litter blowing



Figure 5.34: Wind-blown litter at a landfill site in Northwest province
Source: Noe, 2018



Figure 5.35: Waste recycling on the landfill site

5.4.7 Groundwater monitoring, distance to dwellings, boreholes, and water reliability

Figure 5.36 indicates the extent of groundwater monitoring at the landfill sites, and it was found that only 42% of the sites actually monitored groundwater and/or leachate. It was evident that most of the municipalities did not conduct groundwater monitoring, meaning that these municipalities would be unaware of any groundwater pollution and would not be prepared to deal with leachate contamination of water resources.

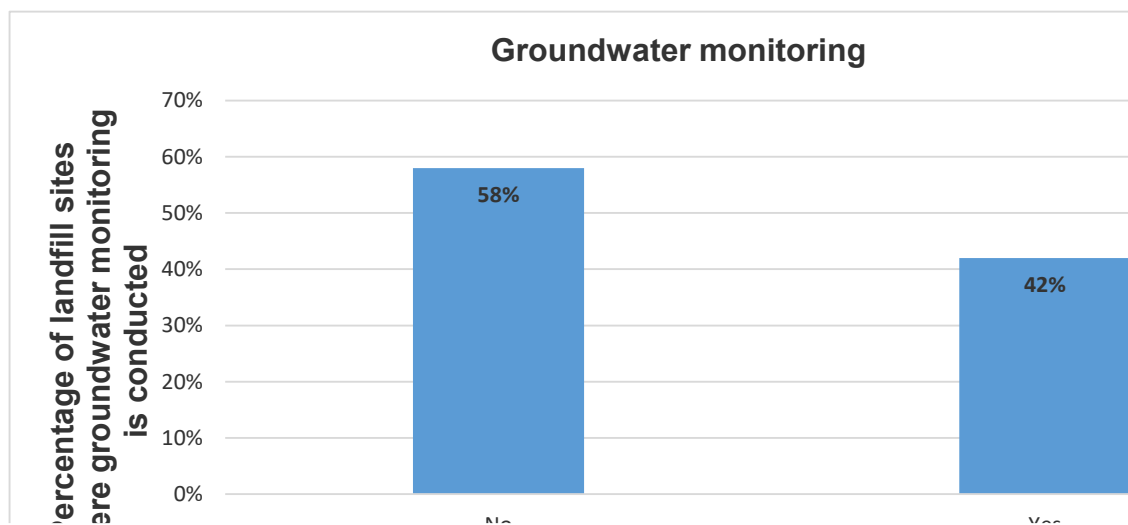


Figure 5.36: Groundwater monitoring

Only 5% of the respondents stated that groundwater monitoring was conducted by the municipalities, while 30% was conducted by private companies (Figure 5.37). There is a clear need for targeted educational session to municipalities to enhance their understanding of, and commitment to, groundwater monitoring requirements.

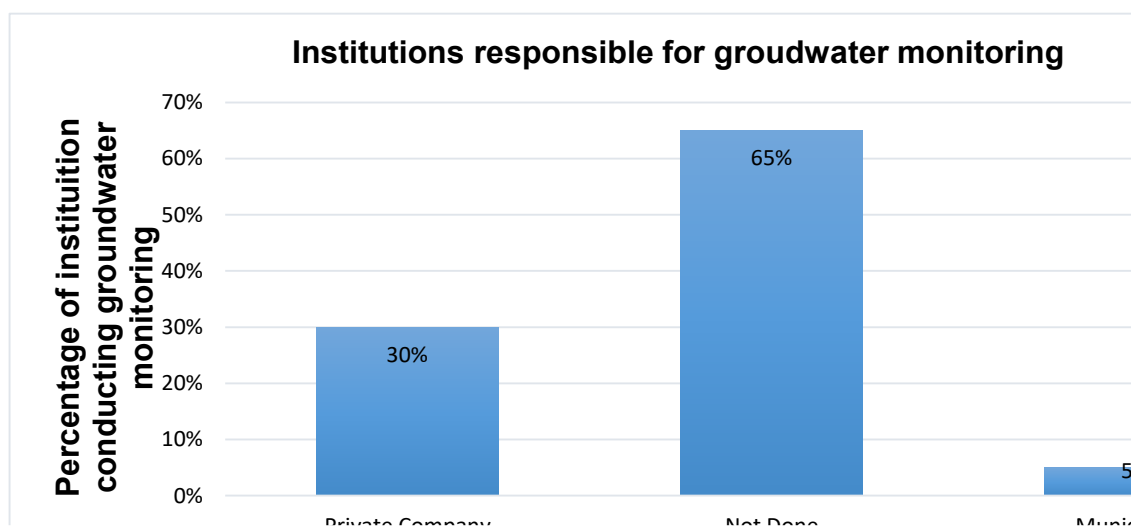


Figure 5.37: Institutions responsible for groundwater monitoring

Most respondents (80%) were aware that leachate could cause pollution to the environment, while 20% were not sure if it could cause harm to the environment and water resources (Figure 5.38).

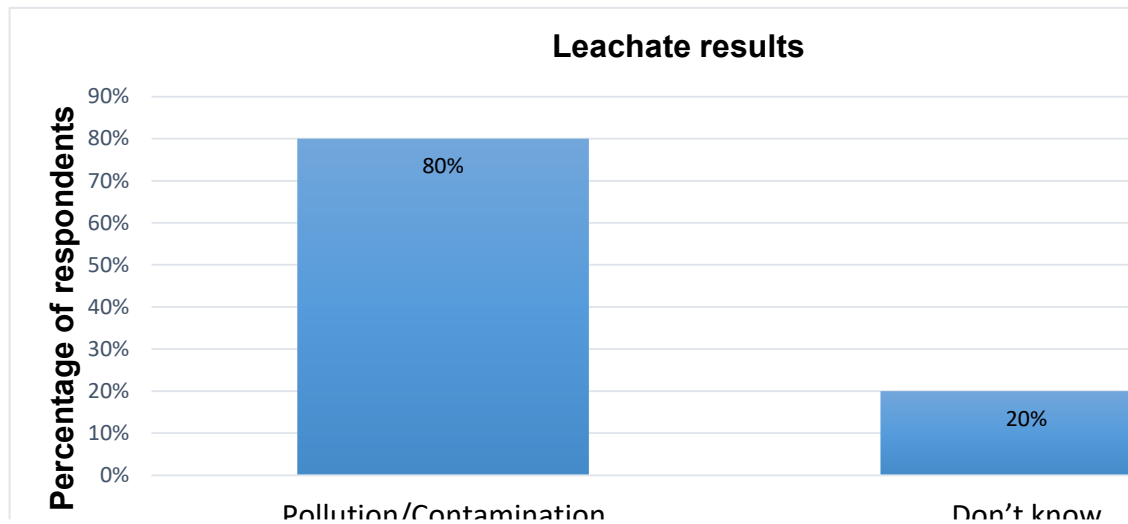


Figure 5.38: Consequences of leachate to the environment and water resources

It was also found that the distance between some landfills and dwellings was one to two km (32%). However, in some cases (26%) the distance between dwellings and the landfill parameters was less than 500 metres, while some dwellings (16%) were located within 100 metres of landfill sites (Figure 5.39).

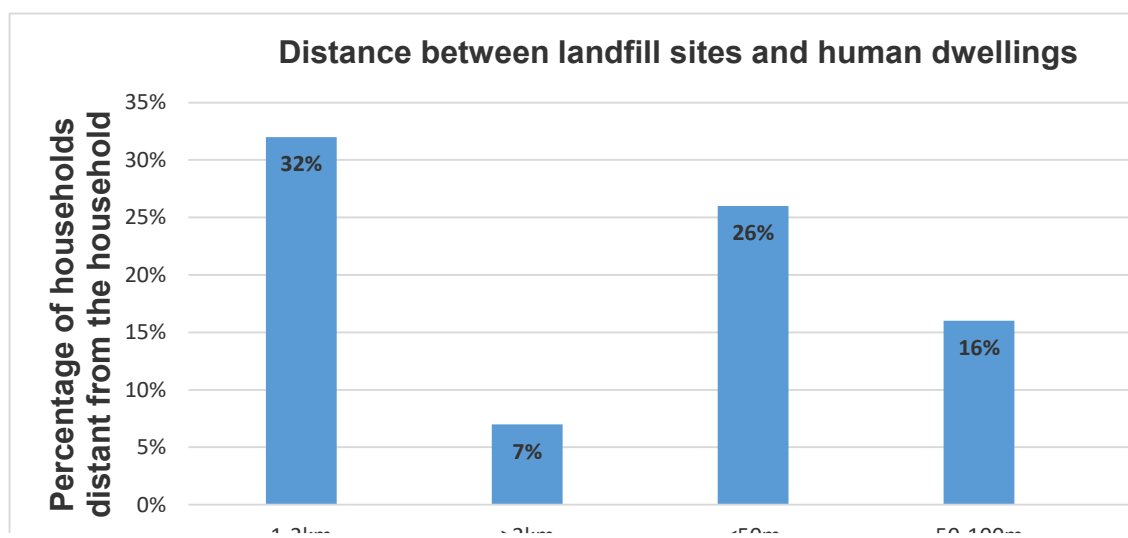


Figure 5.39: Distances between landfill sites and human dwellings

It was also noted that 32% of the landfills had boreholes for groundwater monitoring, while 42% did not have such boreholes (Figure 5.40 and Figure 5.41). Only 42% of the sites actually monitored groundwater. However, 58% of the municipalities did not conduct groundwater monitoring, and even those that conducted groundwater monitoring (29%) did so only quarterly or twice per annum (Figure 5.42).

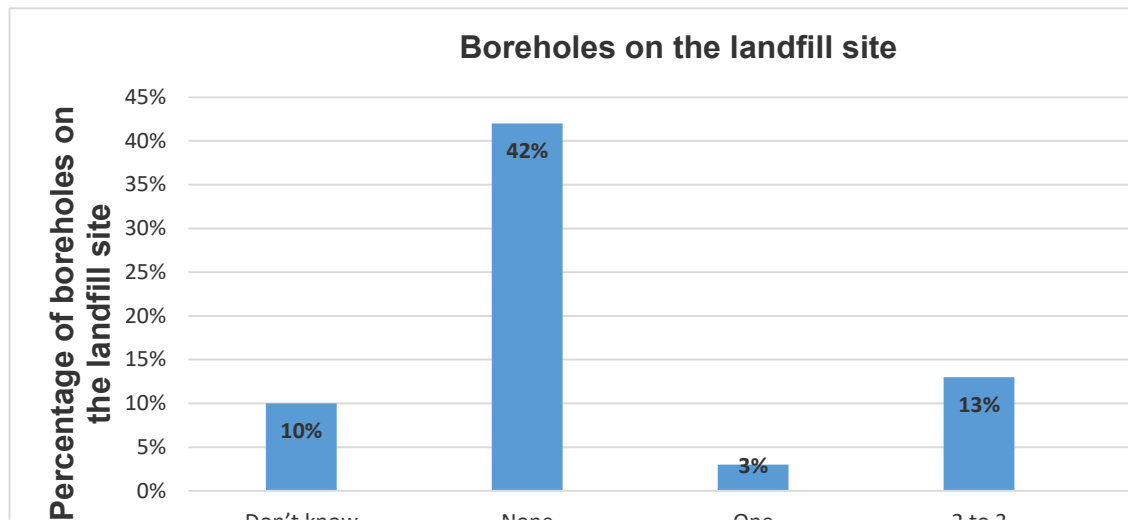


Figure 5.40: Number of boreholes at landfill sites



Figure 5.41: Boreholes up gradient and down gradient of a landfill site in the Free State province

Source: Noe, 2020

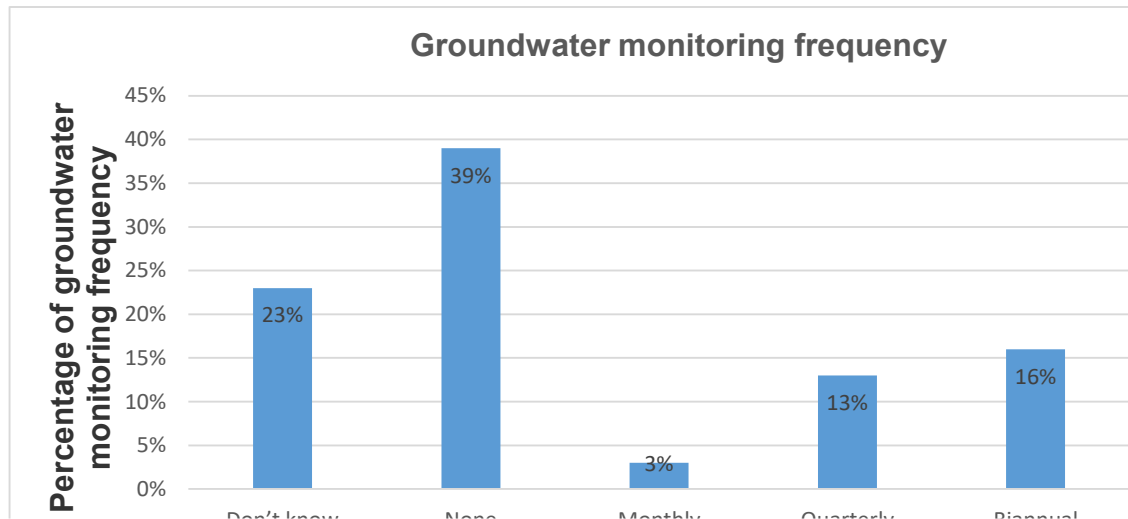


Figure 5.42: Groundwater monitoring frequency

5.4.8 Design of landfill sites

The findings indicated that compliance reports were rarely submitted by the municipalities to the authorities as is stipulated in licencing conditions. In fact, it was revealed that 42% of the municipalities did not compile a geohydrology report, 58% conducted no compliance audits (Figure 5:43). Approximately 61% of the landfills generated leachate, whereas 45% did not have a leachate collection system (Figure 5.44, Figure 5.45, and Figure 5.46).

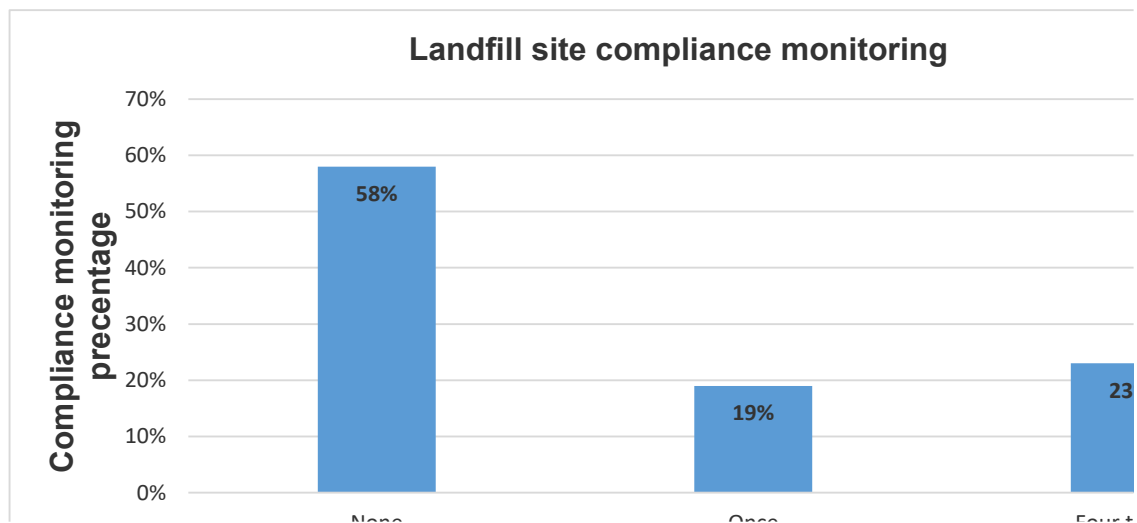


Figure 5.43: Landfill site compliance monitoring

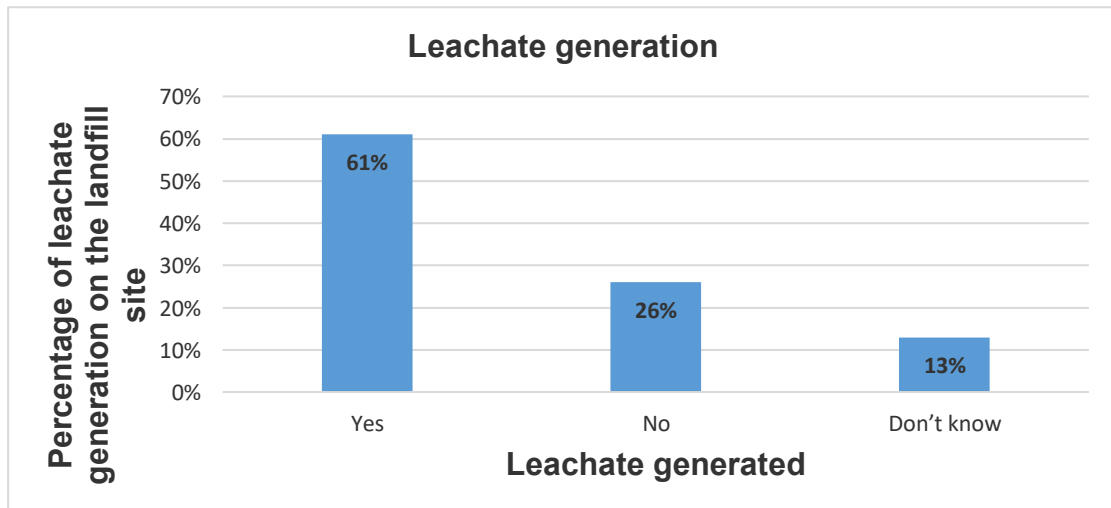


Figure 5.44: Leachate generation

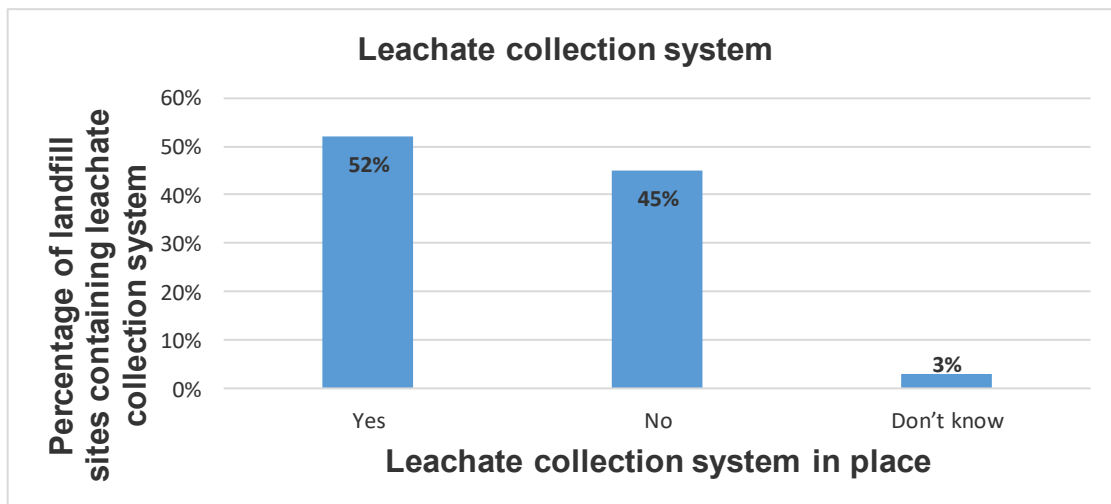


Figure 5.45: Leachate collection system



Figure 5.46: Leachate collection system at a Gauteng province landfill site.
Source: Noe, 2018

Moreover, 68% of the landfill sites did not have a gas monitoring/management system (Figure: 5.47). The findings also revealed that waste was burnt at 58% of the landfills, whereas 42% did not engage in any burning of waste. Where waste was burnt, it was found that community members and waste pickers generally set the waste alight (Figure 5.48).

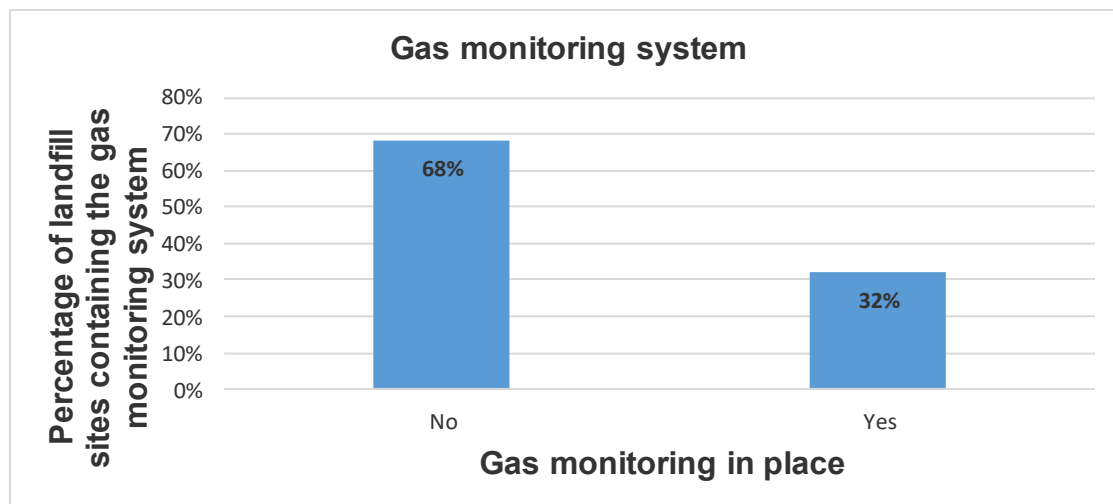


Figure 5.47: Gas monitoring system in place



Figure 5.48: Waste burning at the landfill sites

The respondents also indicated that the environmental impacts most likely caused by the respective landfill sites were groundwater pollution, air pollution, bad odours, and the release of pathogens that could cause diseases.

When the respondents were asked if they thought that municipal managers, such as their seniors, were aware of the threats posed by the respective sites, 40% mentioned that they did not think so as managers did not visit the sites to inspect them or to identify any problems or non-compliance threats. It was commendable that 60% of the respondents were aware of conditions at the respective sites, and it was evident that the conditions and site statuses were discussed during Council meetings (Figure 5.49).

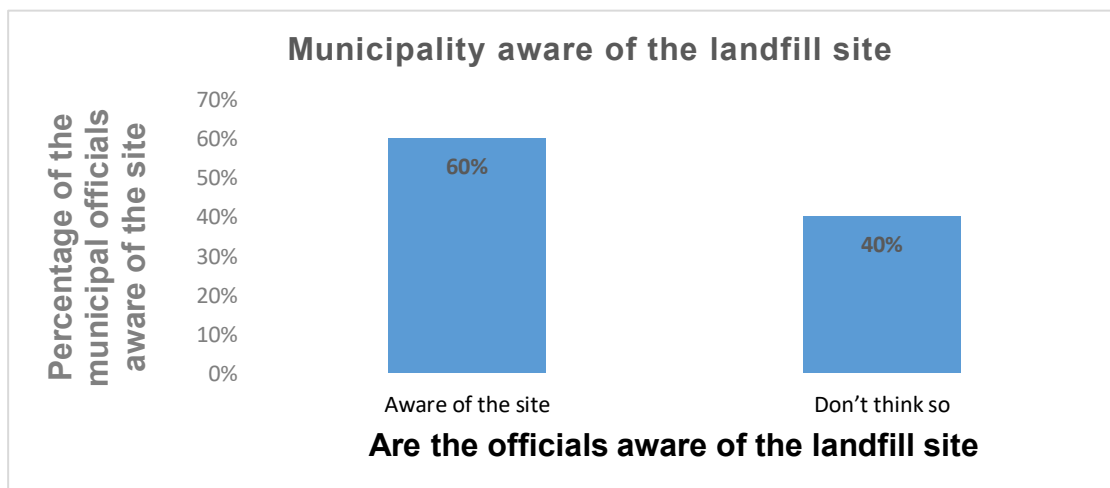


Figure 5.49: Municipality officials aware of the landfill site

According to the data in Figure 5.50, it was argued that a sound budget (65%) and the good management of equipment/machinery (35%) were deemed key requirements for the effective and efficient provisioning of MSWM services and the well-being of communities. It was believed that such provisioning would improve the status of all sites.

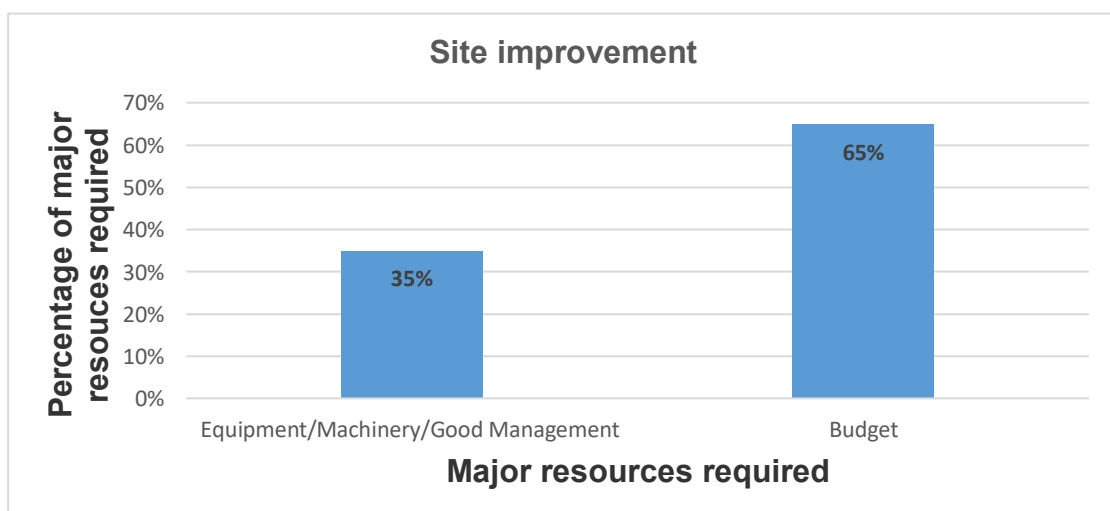


Figure 5.50: Major resources required to improve operations at landfill sites

Two major contributors to environmental and resource threats were identified, namely water pollution (70%) and air pollution (30%) (Figure: 5.51).

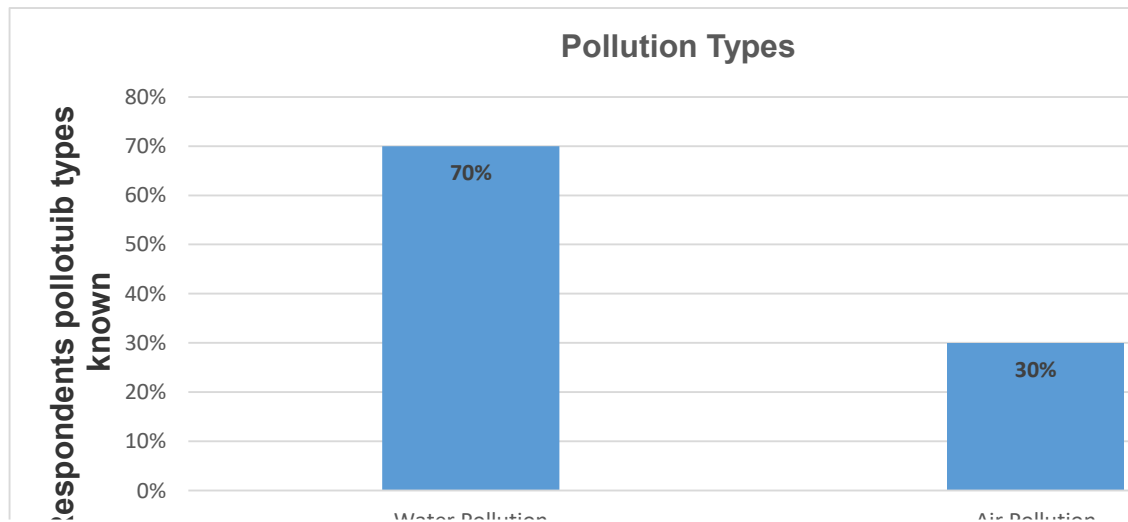


Figure 5.51: Types of pollution posing a threat to humans and the environment

It was encouraging to note that the participants were aware that if landfill site operations and maintenance were not up to standard or did not meet basic required standards, it would have a detrimental impact on the environment and water resources. Hence, the percentages of respondents who were either unaware of the submission of groundwater monitoring reports (29%) or who were aware of the failure to submit such reports (42%) were extremely disconcerting findings (Figure: 5.52).

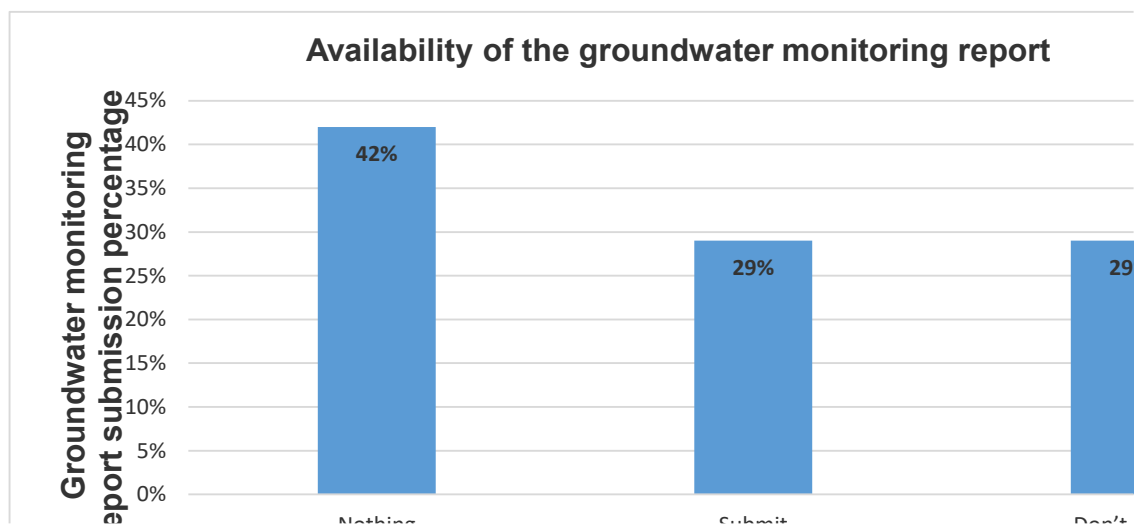


Figure 5.52: Submission of landfill site groundwater monitoring reports

5.5 Discussion

The discussion that follows reflects on the design of and conditions at the waste disposal facilities under study. The discourse focuses on operational procedures at the landfill sites as well as the types of waste being handled. The discussion highlights the threat of pollution that occurs or might occur near landfill sites, and this is followed by recommendations to improve current waste management policies.

5.5.1 The design of and conditions at the landfill waste disposal facilities under study

To meet an organisation's or company's strategic objectives, the employment of skilled personnel is a key factor (Investopedia, 2021). The findings indicated that most of the respondents had a tertiary education, but only a few were in possession of a postgraduate degree. It was noted that 48,8% and 16% had a secondary school or matric certificate respectively. Education is essential for the sound and effective operation of landfill sites, as the predominance of low-skilled workers leads to increased occupational health risks (Milovanovic, 2019).

Previous studies (Adeleke *et al.*, 2021; Maeteletja, Manganyi and Wichmann, 2019; Njoku *et al.*, 2022) suggest that approximately 90% of the waste generated in South Africa is sent to landfills. The current investigation revealed that the majority of landfills under study were registered as required by the Environmental Conservation Act of 2008. However, it was intriguing that only half of the landfill waste design plans had been approved and that the facilities followed the minimum requirements as published by the Department of Water Affairs. In fact, all landfill designs should be approved as all groundwater resources need to be protected. The fact that some landfill designs were not approved clearly poses a threat as groundwater resources may be polluted by leachate due to poor monitoring and managing measures.

The National Environmental Management Act outlines the requirements for waste disposal and the standard containment barrier design that classifies waste as A, B, C, and D (Figures 2.2, 2.3, 2.4, and 2.5 in chapter 2). According to the findings, most of the landfills under study were not designed according to recommended specifications, and therefore it will be impossible for them to handle solid waste properly. Moreover, it

was found that 50% (half) operated only one cell which filled up quickly due to the volumes of the various waste types received (Figure 5.53).

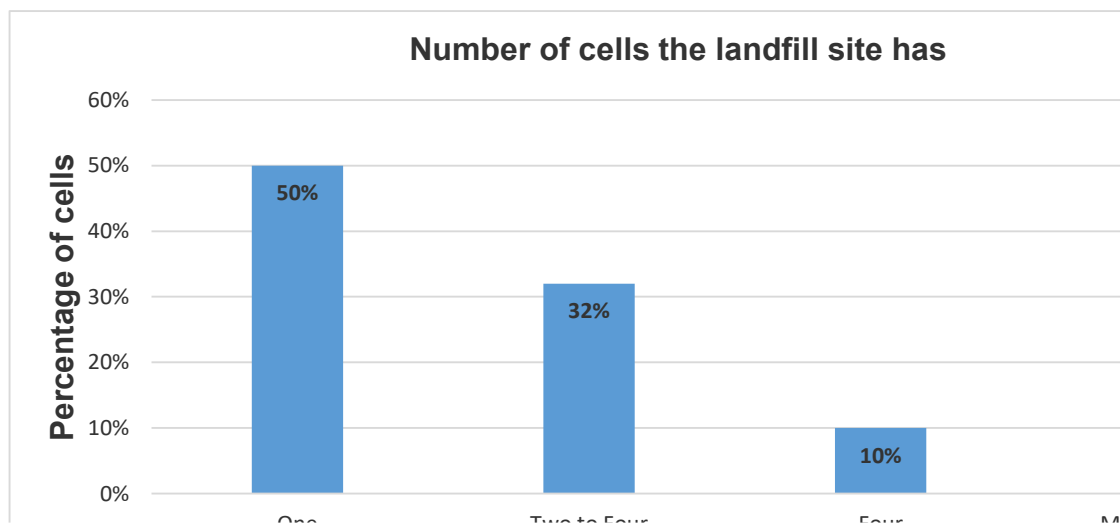


Figure 5.53: Number of cells at the landfill sites

Adeleke *et al.* (2021) conducted a study on waste generation in the provinces of South Africa and found that Gauteng generated the highest volumes of waste. This was attributed to urbanisation as many people migrate from other provinces to Gauteng in search of better living conditions. In addition, the predicted escalation in population growth means that waste generation rates will also accelerate in the future, and thus many of South Africa's landfills will run out of capacity without any space for further waste disposal or expansion. The study found that the remaining lifespan of the landfills under study ranged from less than five years to thirty years. The business-as-usual approach in terms of waste management is therefore not sustainable.

The physical component of the IMSWM framework (Figure 5.1) advocates for waste recovery and reuse. Adeleke *et al.* (2021) propose several strategies that South Africans can employ to reduce the volumes of waste reaching landfills, such as:

- **Separation at source:** This strategy could potentially divert enormous waste volumes from landfills and enhance material recovery. However, this measure has not been successfully employed since its initiation due to the failure of enforcement by municipalities.

- **Waste collection and disposal:** This means waste collection occurs at source and transportation is needed to the point where it will be treated, recycled, or discarded.
- **Waste collection frequencies:** The most crucial parameter is a realistic waste collection frequency, which usually depends on climate. Higher temperatures cause microbes to degrade food waste, and this results in bad odours and disease-causing organisms to multiply. It has been suggested that waste should be collected at least twice a week, but this depends on the cost of collection and the availability of suitable equipment (Adeleke *et al.*, 2021; Maeteletja *et al.*, 2019; Godfrey and Oelofse, 2017; Njoku *et al.*, 2019).

According to the findings of this study, most of the municipal landfills do not have the correct equipment for effective solid waste management. This can be attributed to poor planning and budgeting for effective solid waste management. Most of the respondents (65%) believed that if an ample budget was allocated to each site, it could be run effectively, while 35% believed that the availability of suitable equipment and appropriate machinery would play a vital role in operating landfill sites in a more efficient manner.

5.5.2 Operations at landfill sites and types of waste handled

The findings showed that most landfills in the study area were not managed appropriately or optimally as many of their operations seemed faulty. Almost two-thirds of the landfills were registered with the South African Waste Information Centre, yet monitoring these sites seemed a key problem. Moreover, registration in itself does not ensure sound operational practices; in fact, approximately two-thirds of the landfills did not keep the required records while only some kept records and compiled reports, but these were often not submitted. The South African Waste Information Centre requires that reports be updated and submitted according to established guidelines. The landfill facilities' failure to do so is thus highlighted as a severe infringement that needs to be addressed as a matter of urgency. This finding also suggests that not only landfill site managers, but also the South African Waste Management centre is at fault.

The South African Waste Information Centre was established by the Department of Environmental Affairs in 2005 and is mandated to capture routine data on the tonnages of waste generated, recycled, and disposed of in South Africa on a monthly or annual basis (South African Waste Information Centre [SAWIC], 2021). Based on the municipal employees' report that they did not submit the information collected about waste disposal, it seems logical to suggest that the information in the SAWIC database is not up to date, which paints a dire picture for waste collection strategies in the future. The lead authority should thus urgently adhere to its mandate by implementing strict regulations to ensure that such information is submitted. If not, responsible persons who fail to do their jobs should be held accountable through the strictest of penalties.

According to the results, a small proportion of the landfill sites was not fenced. However, due to landfills' sensitive environmental nature and the dangers they pose, it seems pertinent to expect that access to *all* landfills is controlled and monitored. It was disconcerting to find that many gates to landfills were not locked and that residents (among them children) in the vicinity seemed to access these premises at will. The researcher also observed that access to the landfill sites was not controlled by municipal staff. Many waste pickers were also observed on the landfills where they picked paper, cardboard, scrap metals, plastics, cans, and bottles to sell for a living. Schenck *et al.*, (2019) mention that money can be made by waste pickers when selling these recyclables, but their income is dependent on factors such as the volumes of recyclable waste delivered to the landfill, the accessibility to the recyclable waste, the weather, and the fluctuating prices of recyclable waste types. It has been estimated that, on average, waste pickers can earn around R770 in a good week and R290 in a bad week. The literature affirms that this practice diverts a colossal volume of waste from landfills back into the economy (Purchase *et al.*, 2021), but the problem that is highlighted is the uncontrolled and unmonitored manner in which these recyclers access and utilise these sensitive environmental areas.

Two other key observations were that waste was being burnt on some landfill sites while waste pickers were scuttling on and around these landfill sites in the vicinity of the burning waste. It is therefore argued that the polluted air these people regularly inhale may pose a serious health threat as it has been reported that the smoke generated by

burning waste may cause lung-related diseases (Adeleke *et al.*, 2021; Maeteletja *et al.*, 2019; Godfrey and Oelofse, 2017; Njoku *et al.*, 2019). The health risks associated with informal waste recycling is caused by exposure to hazardous substances such as mercury, lead, the gases in light bulbs, and asbestos that can disrupt the endocrine system. In addition, informal waste pickers are prone to diseases such as asthma, anaemia, and high blood pressure (Njoku *et al.*, 2019). A high percentage of the respondents indicated that wastepaper is usually blown by the wind in a haphazard manner over landfill sites and across fences, and this is one of the reasons why community members burn waste on landfills. However, the smoke and gases that are released exacerbate air pollution and usually affect the health of community members who live close to the landfills (Njoku *et al.*, 2018).

The National Environmental: Waste Act No. 59 of 2008 (South Africa, 2008) establishes criteria for waste disposal by landfill. Such waste is classified into five types (types 0, 1, 2, 3, and 4). These types of waste were discussed in section 2.2. The literature indicates that only about 13% of waste generated in South Africa is recycled, while the remaining waste is discarded on landfills where it is sometimes sorted into different waste types (Table 5.2). Integrated solid waste management practices (Figure 5.1) require the treatment and recovery of waste. During the field visits, the researcher observed that waste was not sorted on site although record keeping was a practice at some sites. It was also observed that the most prevalent waste types were plastics, paper, glass, wood, building materials, and tin cans, which can all be recycled effectively for future use. Discarded garden refuse can be composted and used effectively to invigorate the soil.

This study generated findings that were similar to those of Adeleke *et al.* (2021), Ayeluru *et al.* (2018), and Bundhoo (2018). Ayeluru *et al.* (2018) reasoned that municipal solid waste challenges may be solved when waste items are recycled and reused or converted into raw materials for other production processes. They mentioned that, if properly recycled, this can divert vast volumes of waste from landfills in South Africa. They further state that the industrial economy promotes the linear model system of material consumption, whereby resources are extracted for product manufacturing until they reach the final consumer, who discards products after their shelf life has expired.

Therefore, this kind of material management is not sustainable. However, the zero waste or circular economy is more sustainable and beneficial as its primary goal is to ensure that the value of products is retained, the economy is improved, job creation is advanced, and greenhouse gas emissions are reduced (Ayeluru *et al.*, 2018).

5.5.3 Groundwater pollution near landfills sites

In developing countries, many households depend on groundwater for domestic purposes and for irrigating their small backyard gardens (Amano *et al.*, 2021). However, the contamination of groundwater resources often renders the food that is cultivated unfit for human consumption, while treating groundwater resources is costly (Amano *et al.*, 2021). Municipal solid waste is commonly poorly managed in developing countries, and the largest portion of waste is dumped at non-engineered landfill sites. The findings of the current study showed that most of the landfills were not suitably engineered, and it was concluded that this situation posed a great risk of groundwater contamination. Abiriga *et al.* (2020) assert that the leading pollution problem caused by municipal solid waste is landfill leachate, as this leachate contains both soluble and insoluble organic and inorganic compounds (Figure 5.54). As a significant percentage of the landfills under study was operated without a leachate collection system, a pivotal question is therefore how leachate is controlled in the study area so that it does not contaminate groundwater resources. This is a pertinent question as many boreholes were observed in the vicinity of the landfills under study, yet the quality of the water they contained had reportedly never been determined.

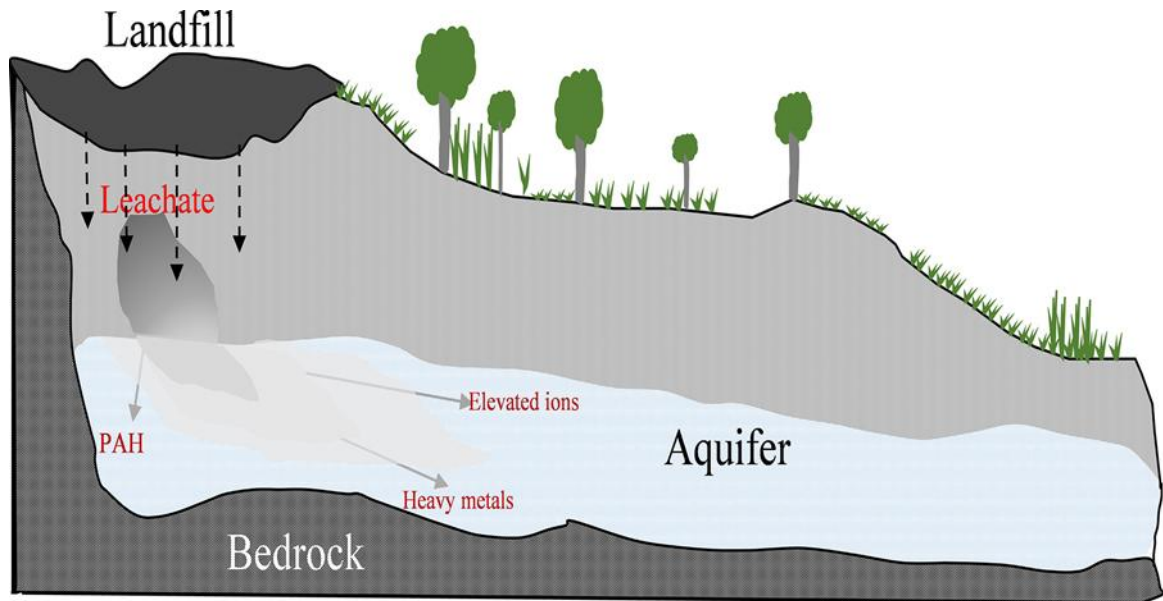


Figure 5.54: Groundwater contamination by landfill leachate

Source: Abiriga *et al.*, 2020

A key finding was therefore that the landfills under study were operated with minimal attention to groundwater contamination. This was demonstrated by the following:

- Of the 31 respondents, 58% indicated that groundwater monitoring was not conducted at their respective landfill sites.
- Most of the municipal solid waste sites conducted no groundwater monitoring of boreholes in their vicinity.
- Geohydrology reports were not compiled and submitted.
- Compliance audit reports were not compiled and submitted.

Abiriga *et al.* (2020) mention that the prime reason for poor groundwater monitoring is that the site selection of a landfill is based on geological suitability criteria, but if an impact study is not conducted and if these criteria are not considered in site selection, groundwater pollution becomes inevitable. Moreover, the situation is exacerbated if borehole positioning is either unknown or does not occur, as was the case at some landfills under study. It also becomes a challenge to monitor the extent of groundwater pollution. Figure 5.55 indicate the positioning of boreholes as found by the current study.

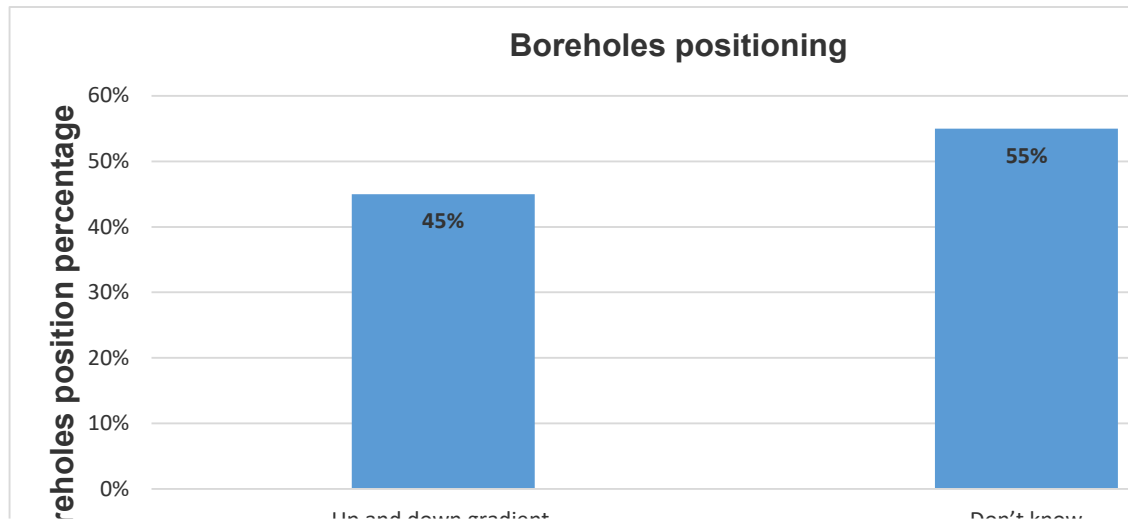


Figure 5.55: Boreholes positioning.

The findings affirmed that many landfills in the study were poorly engineered, or were not engineered at all, which might be the case across South Africa if this trend holds true. As some landfills that were visited were found to be within 100 m of residential dwellings, leachate must have, over time, reached the groundwater resources used by these families. Many families thus drink and use this contaminated water which they source from boreholes, rivers, streams, or ponds. This poses a severe threat to their health; hence, the water quality of all water sources around the landfills should be regularly monitored as a matter of urgency. This call is echoed by Makhadi *et al.* (2020), who found that a non-engineered landfill in Bloemfontein caused heavy metals such as lead and arsenic to enter groundwater resources, while selected boreholes had a high rate of total dissolved solids and coliforms. Amano *et al.* (2021) conducted their study in Ghana and found that non-engineered landfills polluted groundwater resources to the extent that the water's turbidity, hardness, and heavy metal concentrations were above the WHO limits for drinking water quality. This finding affirms that non-engineered landfills do pollute groundwater resources.

The researcher observed many households living close to landfills at distances ranging from 500 m to 2 km. Therefore, groundwater that has been polluted by leachate poses both health and environmental risks in these areas. Njoku *et al.* (2019) noted that landfill operations are generally associated with contamination of surface and groundwater by leachate from the waste, especially if the landfill lacks adequate liners. It was reported

that residents living near the landfills frequently experienced breathing disorders. Other health-related issues were influenza, eye irritation, physiological weakness of the body, back pain, skin disorders, hearing impairments, and asthma (Njoku *et al.*, 2019). Not all these afflictions could be attributed to groundwater pollution, and the authors recommended further research.

5.6 Recommendations for the Improvement of Waste Management Policies

Because landfill leachate can contaminate groundwater resources, it is highly likely that the water resources in the vicinity of the landfills under study should not be used for human consumption. Because South Africa is a water-scarce country, all newly available groundwater resources must be managed with particular attention to minimising pollution from landfills and other sources. The IMSWM framework includes critical physical and governmental components that, if properly managed, can improve South Africa's current solid waste management system.

Municipalities should drastically reduce the volumes of waste they discard on landfills. This practice is not sustainable, and there will not be space to dispose of waste in the coming decades due to predictions of an unprecedented population growth. It is therefore recommended that South Africa adopts a circular economy that is based on sustainable development practices. Waste such as tin cans, plastics, garden refuse, paper, and cardboard boxes should be separated at household level. Adeleke *et al.* (2021) suggest that this could divert vast quantities of waste from landfills as these types can be recycled and reused according to waste recovery principles. Garden refuse and discarded food can be used for composting. For example, the 'Pick it up' project in Johannesburg has garden waste transfer sites that are open to the public to dispose of garden and plant-based refuse. Municipalities should construct several sites near communities where garden waste can be dumped, and the municipalities can generate extra income by composting and packaging this material and selling it at a profit.

One primary goal of the circular economy is to provide job opportunities. Godfrey and Oelofse (2017) assert that informal waste pickers are responsible for recycling 80-90% of waste, which saves municipalities up to R748.8 million in waste disposal costs per annum. However, informal waste pickers who are constantly rummaging through waste

on landfills are prone to contract diseases. Currently, the municipalities prefer to work with private partners as they lack the funds and infrastructure to collect and manage solid waste effectively. The study thus recommends that the government accelerates economic growth and promotes decent work opportunities in the recycling sector by training informal waste pickers in the handling of hazardous waste and providing them with protective clothing. In addition, they should be paid a minimum wage, and they can make extra cash through recycling and selling various waste materials.

South Africa is experiencing increasingly higher load-shedding incidences due to Eskom's inability to meet the energy demand of households and industries. It is therefore recommended that government accelerates the introduction of waste-to-energy technologies that will promote clean and healthy environments through waste recovery for electricity generation (Dlamini *et al.*, 2019). This can be implemented in five ways:

- Bioreactors can be obtained to store renewable energy and produce synthetic bio-methane at household level. This will help to achieve a methane-free atmosphere. These bioreactors produce energy that can contribute to household electricity needs (Natural Resources Institute Finland, 2015).
- Latent energy can be extracted from landfills to produce heat or electricity through thermal and biological processes. This includes gas recovery, incineration, and anaerobic digestion of separated bio-degradable waste fractions (Dlamini *et al.*, 2019).
- Current landfills in the study area are already old and cannot convert gas into energy. It is recommended that the government allocates increased budgets for infrastructural development at landfills so that all landfills in the country can convert waste to energy. In addition, this will reduce climate change and stop affecting groundwater resources (Nyika, Nyanga and Mafore, 2023).
- The IMSWM system includes the roles of legislation, stakeholders, and financial mechanisms. Various legislations governing solid waste management in South Africa include the principles expounded by the National Environmental Management: Waste Act No. 59 of 2008 and the National Water Act of No. 36 of 1998. These two pieces of legislation provide clear guidelines for managing solid waste and groundwater resources. However, the implementation and

enforcement of these laws pose serious problems. It is therefore recommended that the government should employ highly skilled personnel who are qualified to interpret and enforce relevant laws. They should also provide a sufficient budget to empower waste management authorities to execute their duties effectively (Nyika, Nyanga and Mafore, 2023).

- Local municipalities should forge partnerships with local communities before implementing waste management services. Poor communities tend to burn, dump, or bury their waste, and if they are trained how to make extra money through waste recycling and composting, many communities will no longer dump but recycle their waste (Kubanza and Simatele, 2020).

5.7 Limitations of the Study

A limitation of the study was that it did not evaluate the impact of non-engineered landfills on the water quality of groundwater resources as the content of the water of boreholes, rivers, and dams near these facilities was not tested. Although the study by Makhadi *et al.* (2020) assessed the effect of non-engineered landfills on the environment in Bloemfontein, it is prudent that similar studies be conducted at national level. It is therefore suggested that an extensive and longitudinal study be conducted in all South Africa's provinces to assess the impact of landfills on the quality of groundwater resources across a broad spectrum.

Another limitation of the study was that some identified personnel did not want to participate in the study due to the issue of trust as the researcher is a government official. They probably believed that they would be reported for non-compliances. The respondent's selection was based on the relevance to the research objectives rather than random inclusion. Participants were chosen based on their professional roles and direct involvement to the operation of the landfill sites. The inclusion criteria ensured that each respondent possessed knowledge and insight necessary to provide meaningful data. In addition, clear communication was maintained with participants to explain the purpose of the study, the confidentiality of the responses, and the voluntary nature of participation.

The researcher did not include privately owned landfill sites to compare their operations with those of the municipal landfill sites as the former sites receive hazardous waste as well as general waste.

Sites that were excluded were those that were no longer operational as they had reached capacity and were preparing for operational closure. Limbro Park in Gauteng and Deneysville and Sasolburg landfill sites in the Free State were issued capping and rehabilitation authorisations between 2008 and 2016.

5.8 Conclusion

This study, which was conducted in a major water catchment area in South Africa, investigated the operations at landfill sites in the study area with a view to assessing the potential impact of municipal landfills on groundwater and other water sources. The key findings indicated severe shortcomings in the engineering, structure, and operations of most of these landfill sites. In essence, it was found that most of the landfills under study were not properly engineered and were not properly monitored, posing a serious hazard to groundwater and other water resources. Moreover, none of the landfills were properly operated as specified by the National Environmental Management: Waste Act No. 59 of 2008. One oversight that stood out was that the landfills did not record or submit adequate or updated information on the waste they received. As a result, the estimated volumes of waste generated by the 31 landfills under study and their impact on humans and the environment, and by extension on South Africa as a whole, are questionable. Moreover, groundwater monitoring was not adequately conducted or sustained. For instance: (1) Water in boreholes near residential settings was not monitored; (2) most of the municipalities under study did not compile and submit geohydrology reports; and (3) most municipalities did not produce or submit compliance audit reports.

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CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

South Africa generates approximately 107.7 million tonnes of waste per year, of which over 90% is diverted to landfills. South Africa has a comprehensive legislative system for waste management, and therefore it is a conundrum why this system is failing. The National Environment Management: Waste Act No. 59 of 2008 is the main waste management legislative framework in South Africa as it establishes rules and criteria for waste disposal on South African landfills (Department of Environmental Affairs, 2011). On face value, it thus appears that the country has a solid legislative structure to regulate waste disposal, but it is experiencing severe challenges with waste management that require immediate attention (Matinise and Oelofse, 2022). For example, when travelling through major cities such as Johannesburg and Pretoria, one might witness waste at every turn. Population growth, urbanisation, a lack of appropriate waste disposal compliance by citizens, and inadequate governance and monitoring on the part of municipalities are the most prominent causes of ever-increasing annual volumes of waste (Awino and Apitz, 2024). The approach to waste management in South Africa, which is to carry on as if nothing is wrong, cannot continue in its current form, and quick and decisive action is required.

Godfrey and Oelofse (2017) elaborate on the history of waste management and recycling in South Africa. They allege that the main drivers of recycling in South Africa are social needs and, to a limited extent, government initiatives. For example, the South African government issued the White Paper on Intellectual Property and Waste Management and the first National Waste Management Strategy (NWMS), which were the first technical waste management support policy documents. After that, DEAT guidelines were published that were meant to assist municipalities in implementing an effective NWMS. Since 2000, local recycling has grown, which is driven by efforts by industry and investment by producers and manufacturers (Godfrey and Oelofse, 2017). Surprisingly, the South African informal sector, in the form of waste collectors, is recycling approximately 85% of this country's waste, saving between R309 to R749

million in landfill costs at no expense to the government. It is estimated that there are approximately 75 000 informal waste collectors operating in South Africa (Godfrey and Oelofse, 2017). These informal waste collectors are doing an excellent job, whereas municipalities prioritise co-operatives, yet many claim that the co-operative system has been a great failure (Kardelen, Erköse and Eryar, 2023). For this reason, this study assessed the main factors causing non-compliance by municipal-owned waste disposal facilities with available legislation and the impact of this tardiness on South African water resources. Various research questions were posed in the chapters, but these were underpinned by the following key research questions:

- What are the causes of municipal waste disposal facilities' failure to comply with legislative directives?
- What is the total cost incurred by waste disposal facilities in South Africa?
- What factors are associated with the prevalence of non-compliance by municipal-owned waste disposal facilities in South Africa?
- Which model or set of guidelines can be used to develop a cost-effective waste disposal strategy for municipalities in South Africa? and
- What are the critical success factors that South Africa should adopt and implement for sustainable waste management?

6.2 Reasons why municipal waste disposal facilities do not comply with legislation

In Chapter two it was acknowledged that South African municipalities are in crisis and will run out of landfill capacity in a few years. For example, Creamer Media (2021) estimates that major cities such as Johannesburg, Tshwane, and Cape Town are left with less than ten years of ground space for landfilling. The article adds that landfilling is at an average density of 1 t/m³, implying that municipalities will require approximately 10 million m³ to address the landfill need in the near future. Improper waste management leads to emissions of greenhouse gases, and this accelerates climate change and pollutes groundwater resources in a country that is already burdened by water scarcity. The discourse in Chapter two indicated that a high population correlates with huge quantities of waste, while a fast-accelerating population growth will be accompanied by accelerated rates of waste generation.

Generally, South Africa relies on landfilling as its main waste disposal method. However, waste can be turned into a resource if managed appropriately. For example, South Africa is currently struggling with load shedding, and many communities and industries are left with up to eight hours of no electricity daily. To curb this travesty, waste-to-energy facilities can contribute valuable extra megawatts to the Eskom grid.

Most South African municipalities do not comply with waste management legislation as they construct and utilise unregulated landfills, claiming that such unregulated landfills are cheaper and thus more cost-effective (Machete and Shale, 2015). One reason for this non-compliance is the poor enforcement of waste management legislation. A salient question is: Who grants licences and then *monitors* municipalities' operations at unregulated landfills?

Braid (2016) identifies several challenges that lead to poor waste management in South Africa, namely refusal by the national government to accept responsibility for poor waste management practices. This is because the waste management mandate has been spiralled down to local municipalities where this mandate is thwarted by poor accounting and budgeting for waste management, lack of staff (particularly competent staff with a sound work ethic), lack of funding, and poor implementation of the legislative framework due to limited monitoring and accountability. In fact, Chapter four revealed considerable evidence that municipalities continue to function below the norms and standards that guide waste management and that such poor practices are conducted with impunity.

Municipalities can employ several strategies to reduce the volume of waste reaching landfills. Rasimeni and Madyira (2019) elaborate on the waste management hierarchy and focus on waste prevention (less packaging and re-using products), recycling and composting (collecting, re-processing, and re-covering food and plant material), and disposal (landfilling and combustion). The waste recycling hierarchy suggests that the best strategy to control waste is to prevent generating it; however, this is difficult. Therefore, if waste has been generated, it should be recycled to ensure minimal volumes going to landfills.

Several projects that aim at reducing waste have been piloted in South Africa. For instance, the 'Pick it up' project was launched by a private company in Johannesburg. It operates a waste treatment facility with eleven depots, and this project has successfully reduced the waste generated in the targeted area. It also encourages people to deposit their garden refuse separately for compost manufacturing. The company also has an incinerator that converts solid waste into gas that is in turn converted to electricity, while a bag system encourages residents to separate waste at source. The World Bank funded another exciting project to turn waste into electrical energy. It was implemented in two phases: phase one installed one MWe, and phase two installed 6.5 MWe. The generated electricity benefits range from R10 to R95 million and generate in the region of 240 MWh of electricity (see Chapter 2).

6.3 A conceptual framework for sustainable and IMWM in South Africa

Sub-Saharan Africa produces approximately 62 million tonnes of waste per annum, but landfilling remains the main vehicle for waste disposal (Idowu *et al.*, 2019). Although South African waste policies prescribe the requirements for waste management (such as minimizing the use of natural resources, reducing waste generation, proper waste treatment, and awareness among inhabitants), its major weakness is that it permits waste management entities (i.e., municipalities) to use uncontrolled landfills (Godfrey and Oelofse, 2017). Additionally, it seems that current legislation gives too much power to municipalities to manage waste, as their inefficient operations lower the standards of waste management. Budgets are kept low, and the primary initiative is to collect waste and dump it on landfills, often without adhering to proper techniques. Unfortunately, this practice is not sustainable, and predictions suggest that major cities will run out of landfill space in a decade.

The waste hierarchy is one of the pivotal frameworks that has been used for decades for waste management promotion, prevention, reuse, recycling, recovery, and disposal (Figure 6.1).

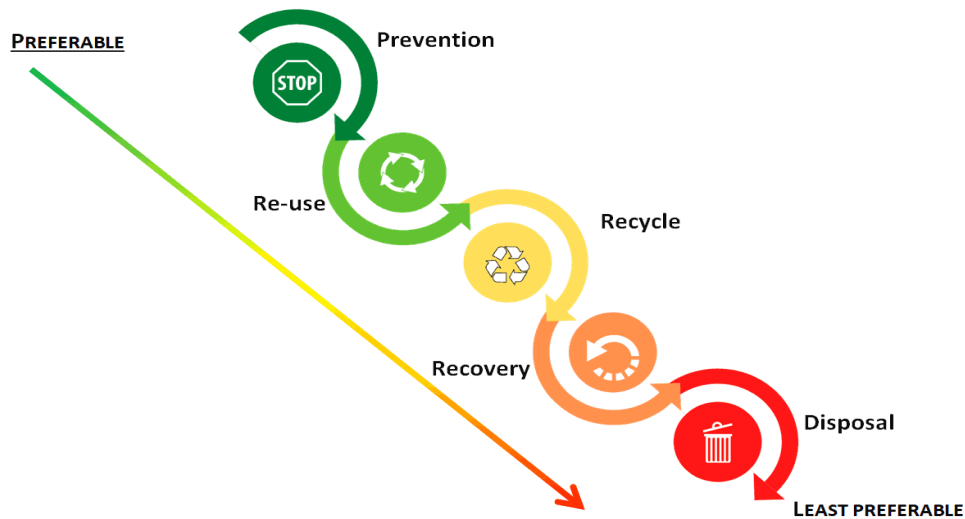


Figure 6.1: The waste management hierarchy

Source: Viable Alternative Energy, 2023

The waste management hierarchy has played a crucial role in waste management practices in both developed and developing countries where it has been applied to a greater or lesser extent depending on internal policies. However, its major weakness is the lack of a participatory approach that includes all stakeholders in the waste value chain. It was in this context that the current study sought to augment the current waste management framework so that it may be used by municipalities in South Africa and, with possible further amendments to suit internal requirements, by other struggling economies in the developing world. This framework needs to be sustainable while addressing integrated waste management principles. Initially, the process must start by addressing waste generation by stakeholders at source, and move on to address collection, recycling, reuse, energy generation, composting and, only as a last resort, dumping on landfills.

A key resource for the study was the framework (Figure 3.1) proposed by Batista *et al.* (2021). This framework is structured into four segments: primary stakeholder participation, critical success factors, implementation, and monitoring and evaluation. In addition, the framework recognises the importance of multidisciplinary skills as it urges the involvement of all major stakeholders such as government, industry, and local communities. Moreover, its foundation is the five pillars for sustainable waste management, namely public policy, disposal techniques, legal aspects, public-private partnerships, and energy recovery. For example, the public policy pillar acknowledges

that developing countries' governments lack the capacity and technologies to treat municipal solid waste in an improved manner. The framework thus proposes a strategy to optimise natural resources without neglecting economic and financial sustainability. On the other hand, the PPP pillar realises that developing countries have poor administration of PPP contracts, and by longer, it gives local communities the opportunity to respond by managing waste more effectively. Lastly, the energy recovery pillar stipulates that municipalities in developing countries should allocate enough funding for infrastructural development of landfills so that the waste-to-energy requirement can be addressed (Chapter 3).

6.4 The impact of unregulated landfills on groundwater resources in South Africa

A key finding was that South African municipalities must be in possession of an operating license to manage waste as stipulated by the National Environmental Management: Waste Act No. 59 of 2008. Only half of the municipalities under study had received approval before they constructed their landfills, which suggests that some municipalities might have a permit to operate, but that the design might not match the prescribed requirements. It was therefore not surprising that these municipalities faced several challenges. First, they lacked suitable equipment as only eight percent had a tractor, tipper, front-end loader, and compactor, whereas others had different equipment at various stages of functionality. Secondly, 29% of the waste disposal facilities did not follow proper design requirements as outlined in the National Environmental Management: Waste Act No. 59 of 2008 and the National Norms and Standards for Disposal of Waste to Landfill of 2013 (R636). This percentage might appear low, but it translates to nine out of 31 landfills that were improperly designed, thus suggesting that they are also severely flawed in their management operations, which can lead to various health and environmental risks.

The highest rate of daily waste disposal was 38 m³ per day, which translates to approximately 9 120 m³ of waste being disposed of on the landfills in the study area annually. It was obvious that most of the municipalities did not manage the landfill sites under their jurisdictions adequately. For instance, it was observed that gates were left unlocked, access was not controlled, and there was no compacting of waste and no

trenches at some landfills for stormwater control. Moreover, waste pickers roamed freely on these facilities without protective clothing, paper was blown haphazardly by the wind and burning or smouldering waste emitted traces of smoke-polluted air. It may also be averred that there is a high likelihood that groundwater resources are being polluted by the leachate from these landfills and that this threat will remain unchecked due to a lack of monitoring.

In terms of groundwater monitoring, it was calculated using a GPS system that the distance between some houses and landfill sites ranged from 100 m to 2 km. It was also surprising to find that waste management and waste volume reports were rarely submitted by most municipalities, and that approximately half of the municipalities under study did not submit geohydrology reports either. Leachate is naturally generated by landfills, but it was found that more than 60% of the landfills did not have a leachate collection or a gas monitoring/management system. It is therefore logical to argue that the groundwater resources near these unregulated landfills will continue to be highly exposed to pollution through uncontrolled leachate. Bearing in mind that South Africa is a water scarce country, cities such as Port Elizabeth and Cape Town had severe water problems in 2017 and 2018 respectively, and both approached day zero when water restrictions were at level 7 as dam levels supplying the cities had reached a level of 13.5% or even lower (Cape Town water crisis, 2023). Other major cities such as Pretoria and Johannesburg commonly impose water restrictions, often on a weekly basis (Venter, 2025). Water resources in South Africa have been constructed and are maintained to meet citizens' and industries' needs; however, when these water sources are polluted, the water is unfit for human and even animal consumption. A study conducted by Makhadi *et al.* (2020) showed that water resources near a non-engineered landfill was polluted with heavy metals, total dissolved solids, and coliforms, and these substances rendered the groundwater resources in the vicinity of the landfill unsuitable for human consumption.

Overall, the findings of the current study affirm that the municipalities under study mismanage the landfills they operate, and this suggests that there is a high probability that these unregulated landfills pollute groundwater resources. In this context, it is imperative that suitably qualified and trained personnel are employed to manage

landfills, yet the findings indicated that 68% of the surveyed municipal employees had not attended any training courses on environmental management, whereas 32% had not attended any training sessions at all. The duration of the majority of training sessions that had been attended ranged from one day to a month, which highlights the concern that training, when it is offered, is haphazard and ad hoc.

6.5 Guidelines to improve waste management by municipalities in South Africa

The guidelines that were sourced from the literature generally address conditions and requirements in developed countries, and it is therefore proposed that there is a need to augment these guidelines to address the South African waste management context. The foregoing sections indicated that landfilling remains the main vehicle for disposing of waste in developing countries, and South Africa is no exception. The data that were presented in Chapter 4 clearly showed that the landfills in the Upper Vaal water management area had been poorly designed and were inappropriately managed. These findings corroborate those of other studies conducted in South Africa that also found severe gaps in waste management and disposal practices in various areas across the country (Haywood *et al.*, 2021; Mangoro, 2020). Although the South African government developed guidelines for waste management, it seems prudent that they are augmented for more appropriate waste management practices by municipalities in the study area, and even across the country, as both the literature and the current study highlight this need (Nyika, Nyanga and Mafore, 2023). This chapter therefore presents these guidelines in tabular format to address both the design (Table 6.1) and the operational management (Table 6.2) of landfill sites in the South African context which the researcher taken into consideration as part of the outcome of the study.

Table 6.1: Several steps to be followed when designing landfills

Area for Attention	Description
Location	Landfills should be located at a minimum distance of 500 m from households, streams, rivers and dams. They should not be near an airport. A buffer zone should be constructed between a landfill site and households and this buffer should preferably consist of thick vegetation. Waste disposal facilities should not be too far from collection points due to high transportation costs. They should be far enough from local communities to reduce noise, automobile accidents, and air pollution.
Geological and hydrological conditions	Locate a landfill in a geological and hydrological setting where subsurface layers have lower hydraulic conductivity. Surveying groundwater flow direction is a necessity. Monitoring of current and future use of groundwater resources and other water bodies is also required. If the purpose of water in the vicinity is for drinking, the site should be deemed unsuitable.
Groundwater monitoring	Groundwater and borehole water near landfills should be monitored at least monthly or quarterly. Furthermore, formal reports detailing the water quality analysis and results must be compiled immediately following the monitoring exercise to allow for timely assessment and intervention. A dedicated lead authority must conduct compliance monitoring and regulation of municipal waste management activities, specifically focusing on landfills. This independent oversight is essential to ensure municipalities adhere to established environmental and water quality standards, preventing poor operational practices.
Covering waste and closing a landfill	Cover material should be spread daily or weekly over compacted waste to reduce volumes of waste carried by the wind, prevent birds and other animals from scavenging, and reduce fire risk. Once a landfill has been closed, a final cover should be added.
Leachate	Considering the geography of the area where a landfill is located is crucial. For example, if the topography is used in conjunction with appropriate landfill design to regulate leachate flow without pumping and by just relying on gravity flow, it is designed correctly. No landfill should be constructed or allowed to operate without proper leachate measurements, as indicated in construction guidelines.
Security	All landfills must be fenced off using a secure and strong fencing system that cannot be breached by waste pickers or roaming animals. Gates should be locked when no operations occur at the landfill.
Roads and infrastructure	Roads to the landfills must be maintained.

	Toilets and showers should be provided for regulated waste pickers working on site. Waste sorting areas with shaded covering must be provided for waste workers and pickers.
Weighbridge	Constructing a weighbridge at each landfill should be a primary consideration.

Regarding the operation of landfills, prerequisites are that daily working areas should be determined, daily compacting and cover material should be applied, waste layers should not exceed the planned height, and a landfill cell should have enough capacity to accommodate the estimated waste quantities generated daily.

Table 6.2: Several steps to be followed during landfill operations

Steps	Description
Unloading waste	Waste should be unloaded at specially designated areas on current landfills. Workers should be confined to working areas, which should be as small as possible to reduce the volume of daily covering material.
Waste compaction	Waste should be compacted daily to limit space needed for waste disposal. Compacted waste presents some benefits such as reduced odours, lower gas generation rates, the reduced risk of fire, and enhanced mechanical stability. Additionally, the number of compaction passes should be as many as possible to ensure efficient compacting. Compacted waste should also be monitored to prevent sliding.
Application of a daily cover	It is a prerequisite to alleviate odour nuisance, waste blowing, and vector presence. One essential role played by covering material is minimising the risk of groundwater contamination.
Leachate treatment	Locations receiving high rainfall tend to produce high volumes of leachate, and this leads to groundwater pollution if it is not well managed. Leachate generated should be stored in leachate ponds. After that, it should be treated using an anaerobic system before being discharged back to the water resource or being re-used.
Landfill gas management	When solid waste undergoes anaerobic degradation, landfill gas (LFG) is generated, and the end product is oxygen. Other emissions are methane and carbon dioxide, which are part of the greenhouse gases that accelerate global warming. LFG can be collected to generate electricity, or the gas can be channelled to a nearby industrial factory to be used as an energy source.
Security control	Access control is imperative. Waste truck drivers, workers, and waste pickers should be registered and only those carrying an official pass should be allowed to enter. NO CHILDREN should be allowed on any landfill site.
Waste records	Records of the waste being received should be available at all times in order to operate the site efficiently and effectively and to be able to determine the disposal space still available.
Waste types and recycling	Waste tyres should not be disposed of on landfills as they are non-biodegradable. Due to their size and structure, they take up too much space on landfill sites and are highly flammable.
Community involvement	The community and school children should be educated about the minimisation of household waste. Information about the dangers of residing on or near landfill sites should be disseminated. All stakeholders should be involved in information dissemination meetings prior to the development of new landfill sites.

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APPENDIX A: Landfill disposal requirements

Table 2.3A: Landfill disposal requirements (Part 1) (Department of Environmental Affairs, 2013).

Waste Type	Landfill Disposal Requirements
Type 0 Waste	The disposal of Type 0 waste to landfill is not allowed . The waste must be treated and re-assessed in terms of the <i>Norms and Standards for Assessment of Waste for Landfill Disposal</i> .
Type 1 Waste	Type 1 waste may only be disposed of on Class A landfill sites designed in accordance with section 3(1) and (2) of these Norms and Standards, or, subject to section 3(4) of these Norms and Standards, may be disposed of on landfill sites designed in accordance with the requirements for a Hh/HH landfill as specified in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998, 2 nd ed.).
Type 2 Waste	Type 2 waste may only be disposed of on Class B landfill sites designed in accordance with section 3(1) and (2) of the Norms and Standards, or, subject to section 3(4) of these Norms and Standards, may be disposed of at a landfill site designed in accordance with the requirements for a GLB+ landfill as specified in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998, 2 nd ed.).
Type 3 Waste	Type 3 waste may only be disposed of at a Class C landfill designed in accordance with section 3(1) and (2) of these Norms and Standards, or, subject to section 3(4) of these Norms and Standards, may be disposed of at a landfill site designed in accordance with the requirements for a GLB+ landfill as specified in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998, 2 nd ed.).
Type 4 Waste	Type 4 waste may only be disposed of on a Class D landfill site designed in accordance with section 3(1) and (2) of these Norms and Standards, or, subject to section 3(4) of these Norms and Standards, may be disposed of on a landfill site designed in accordance with the requirements for a GLB- landfill as specified in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998, 2 nd ed.).

Table 2.3B: Waste acceptance criteria for disposal on a landfill (Part 2) (Department of Environmental Affairs, 2013).

Listed Waste	Landfill Disposal Requirements
(i) Domestic waste (ii) Business waste not containing hazardous waste or hazardous chemicals (iii) Non-infectious animal carcasses (iv) Garden waste	Disposal is only allowed at a Class B landfill designed in accordance with section 3(1) and (2) of these Norms and Standards, or, subject to section 3(4) of these Norms and Standards, at a landfill site designed in accordance with the requirements for a GLB+ landfill as specified in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998, 2 nd ed.).
(v) Post-consumer packaging (vi) Waste tyres	Disposal is only allowed at a Class C landfill designed in accordance with section 3(1) and (2) of these Norms and Standards, or, subject to section 3(4) of these Norms and Standards, at a landfill site designed in accordance with the requirements for a GLB+ landfill as specified in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998, 2 nd ed.).
(vii) Building and demolition waste not containing hazardous waste or hazardous chemicals (viii) Excavated earth material not containing hazardous waste or hazardous chemicals	Disposal allowed at a Class D landfill designed in accordance with section 3(1) and (2) of these Norms and Standards, or, subject to section 3(4) of these Norms and Standards, at a landfill site designed in accordance with the requirements for a GLB- landfill as specified in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998, 2 nd ed.).

Table 2.3C: Waste acceptance criteria for disposal on a landfill (Part 3) (Department of Environmental Affairs, 2013).

Listed Waste	Landfill Disposal Requirements
Asbestos waste (ii) Expired, spoilt or unusable hazardous products. (iii) PCBs (or rather PCB-containing waste [>50ppm]) (iv) General waste, excluding domestic waste, which contains hazardous waste or hazardous chemicals (v) Mixed, hazardous chemical wastes from analytical laboratories and laboratories from academic institutions in containers less than 100 litres	Disposal is only allowed at a Class A landfill designed in accordance with section 3(1) and (2) of these Norms and Standards, or, subject to section 3(4) of these Norms and Standards, at a landfill site designed in accordance with the requirements for a Hh/HH landfill as specified in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998, 2 nd ed.).

Table 2.3D: Waste acceptance criteria for disposal on a landfill (Part 4) (Department of Environmental Affairs, 2013).

Waste	Disposal Requirements
Hazardous Waste - Hazard Rating 1 or 2	Disposal is only allowed at a Class A landfill designed in accordance with Section 3(1) and 3(2) of these Norms and Standards, or, subject to Section 3(4) of these Norms and Standards, at a landfill site designed in accordance with the requirements for a HH landfill as specified in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998, 2 nd ed.).
Hazardous Waste - Hazard Rating 3 or 4	Disposal is only allowed at a Class A landfill designed in accordance with section 3(1) and 3(2) of these Norms and Standards, or, subject to section 3(4) of these Norms and Standards, at a landfill site designed in accordance with the requirements for a Hh landfill as specified in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998, 2 nd ed.).
Hazardous Waste - Delisted	Disposal is only allowed at a Class B landfill designed in accordance with Section 3(1) and 3(2) of these Norms and Standards, or, subject to Section 3(4) of these Norms and Standards, at a landfill site designed in accordance with the requirements for a GLB+ landfill as specified in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998, 2 nd ed.).
General Waste	Disposal is only allowed at a Class B landfill designed in accordance with Section 3(1) and 3(2) of this Standard, or, subject to Section 3(4) of this Standard, at a landfill site designed in accordance with the requirements for a general waste site, G S/M/L B-/B+ as specified in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998, 2 nd ed.).

Table 2.3E: Waste disposal restrictions (Part 1) (Department of Environmental Affairs, 2013).

Waste Prohibited or Restricted in terms of Disposal	Compliance Timeframe
(a) Waste which, in the conditions of a landfill, is explosive, corrosive, oxidising (according to SANS 10234 or SANS10228).	Immediate
(b) Waste with a pH value of <6 or >12.	Immediate
(c) Flammable waste with a closed cup flashpoint lower than 61° Celsius.	Immediate
(d) Reactive waste that may react with water, air, acids or components of the waste, or that could generate unacceptable amounts of toxic gases within the landfill.	Immediate
(e) Waste of compressed gases (according to SANS 10234 or SANS 10228)	Immediate
(f) Untreated healthcare risk waste (HCRW)	Immediate
(g) (i) PCPs pesticides listed under the Stockholm Convention (ii) Other waste pesticides	Eight years Four years
(h) Lead acid batteries	Immediate
(i) Other batteries	Eight years
(j) Re-usable, recoverable, or recyclable used lubricating mineral oils, as well as oil filters, but excluding other oil-containing wastes.	Four years

Table 2.3F: Waste disposal restrictions (Part 2) (Department of Environmental Affairs, 2013).

Waste Prohibited or Restricted in terms of Disposal	Compliance Timeframe
(k) Re-usable, recoverable or recyclable used or spent solvents	Five years
(l) PCB containing wastes (>50 mg/kg or 50 ppm)	Five years
(m) Hazardous waste: electric and electronic equipment (WEEE) – Lamps	Three years
(n) Hazardous waste: electric and electronic equipment (WEEE) – Other	Eight years
(o) Waste tyres: Whole	Immediate
(p) Waste tyres: Quartered	Five years
(q) Liquid waste- (i) Waste which has an angle of repose of less than 5 degrees, or becomes free-flowing at or below 60 °C or, when it is transported, is not generally capable of being picked up by a spade or shovel; or (ii) Waste with a moisture content of >40% or that liberates moisture (iii) Waste under pressure in landfill conditions and which has not been stabilized by treatment	All six years
(r) Hazardous waste with a calorific value of: >25 MJ/kg >20 MJ/kg >10 MJ/kg >6% TOC	Four years Six years 12 years 15 years
(s) Brine or waste with a high salt content (TDS>5%) and a leachable concentration for TDS of more than 100 000 mg/l.	Eight years
(t) Disposal of garden waste: (i) 25% diversion from the baseline at a particular landfill of separated garden waste (ii) 50% diversion from the baseline at a particular landfill of separated garden waste.	Five years Ten years
(u) Infectious animal carcasses and animal waste	Immediate

Table 2.3G: Waste disposal restrictions (Part 3) (Department of Environmental Affairs, 2013).

Prohibited or Restricted Waste Disposal Activities	Timeframe
Disposal of— (i) Type 1 Waste that has been treated, with waste listed in paragraph (2)(a) of Annexure 1 to the Regulations; (ii) Waste classified as hazardous in terms of regulation 4(1), or waste listed in paragraph (2)(b) of Annexure 1 to the Regulations, with waste listed in paragraph (2)(a) of Annexure 1 to the Regulations; and (iii) Type 4 Waste with any waste other than Type 4 unless part of treatment.	Five (5) years Five (5) years Five (5) years
(b) Macro-encapsulation of waste, meaning the isolation (or long-term storage) of waste through containment in containers within a sealed or reinforced cell in a specifically prepared and engineered area within a permitted hazardous waste landfill.	Eight (8) years

APPENDIX B: RECOMMENDED GUIDELINE FOR LANDFILLING FOR DEVELOPING COUNTRIES

RECOMMENDATION FOR THE DEVELOPMENT OF A COST-EFFECTIVE INFRASTRUCTURE AT A DEVELOPING COUNTRY LANDFILL SITE WITHOUT COMPROMISING SAFETY, ENVIRONMENTAL COMPLIANCE OR OPERATIONAL EFFICIENCY

1. The recommendations are made to ensure a cost-effective development of a landfill which would not compromise safety, environmental compliance or operational efficiency. The aspects which will be included are:

- Access roads
- Access control (Perimeter fencing, manual gate)
- Sanitation facilities
- Weigh bridge alternatives
- Drainage channels
- Office block
- Signage boards
- Waste picker sorting area
- Covering and compaction of waste and
- Gas extraction.

1.1 Access roads to the landfill site

The roads can be built by compacted gravel to accommodate all weather conditions so that the landfill can operate without disturbances. To maintain the roads in good condition at all times, a simple grading device can be used.

1.2 Perimeter Fencing

Various types of fences can be used like mesh or barbed wire on poles to control unauthorised entry, illegal disposal of waste and control waste pickers access. The materials used for fencing is cheap and the landfill site owners can seek funding or partnerships with industry and government subsidies.

1.3 Gates

A manual operated gate made of metallic or wood material, can be installed to avoid usage of an electronic operated gate since electricity is expensive and load shedding would not compromise access control.

1.4 Sanitation-toilets (Basic)

Urine-diverting dry toilets or ventilated improved pit toilets can be used. They have a long-life span, are cheap and easy to maintain. Separate toilets for women and men, with hand wash basins must be available.

1.5 Weighbridge Alternatives

The feasible alternative to a full-scale weighbridge is a mobile weighing bridge for vehicles, a manual system of recording waste loads by using classical truck volumes, and a simple but effective system of ticket control.

1.6 Drainage Channels

Stormwater management channels can be constructed naturally to separate the dirty water, and clean water can be diverted to the environment. The channels must be cleaned regularly.

1.7 The office block

Shipping containers or “wendy houses” can be used for offices to avoid using expensive construction materials like cement bricks.

1.8 Signage around the landfill site

Place painted boards that display the rules of the landfill site, operating hours, what items can be disposed of and what items are not authorised. The name and contact details of a person in case of emergency. This would encourage safety and awareness by the people.

1.9 Waste pickers sorting area

The waste pickers must have a demarcated area to sort the waste. The area must be shaded and can be built from scrap roofing/material. This creates a more civilised safer working area.

1.10 Covering and compaction of waste

Manual compactors, tractors or rollers can be used to compact the soil used for the covering of the waste on daily basis. The area where the cover material is collected from, must be nearby.

1.11 Gas extraction

Passive gas extraction equipment with polyvinyl chloride (PVC) or high-density polyethylene (HDPE) pipes can be used.

2. Cost effective waste containment system constructed from bottom to top to protect the environment particularly the groundwater and the surface water resources

2.1 The first step is the preparation of the in-situ soil and compaction to a minimum depth of 0.5 meters. The soil material needs to be of low permeability and the surface must be sloped at 2.5 percent to facilitate proper drainage of leachate.

2.2 Above the in-situ soil, a compacted clay liner (CCL) should be installed. This should be 0.6-1.0 meter thick with hydraulic conductivity of no greater than or equal to 1×10^{-7} cm/s. The material should be sourced locally to avoid expensive transportation but work effectively for the prevention of leachate seepage and run-off.

2.3 If the landfill site owners are financially strong, a geosynthetic clay liner (GCL) can be used instead of the compacted clay liner. This layer contains bentonite clay sandwiched in between the geotextiles which enhances containment.

2.4 Above the CCL or GCL, there is an HDPE geomembrane liner of 1.5-2.0 mm. It provides a solid major wall that cannot be permeated and prevent leakages of welding seams occurring.

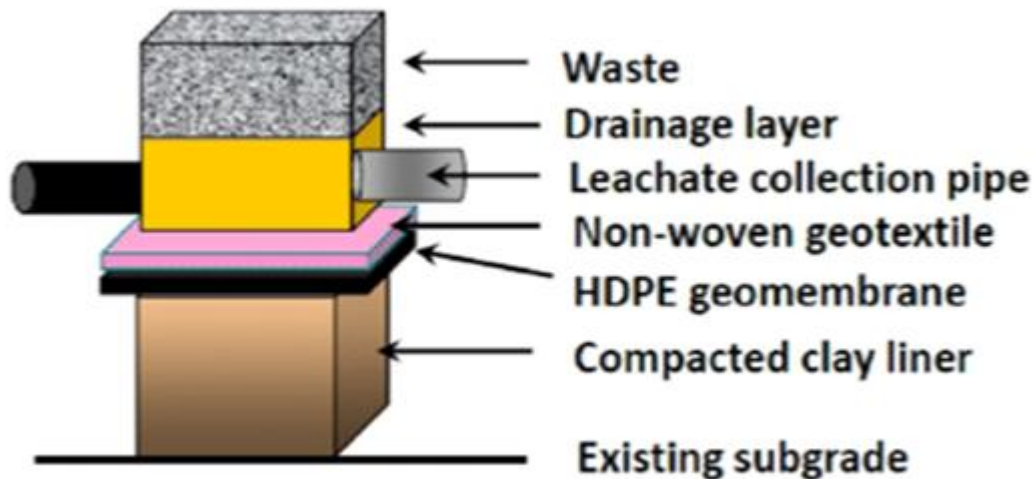


Figure 1.1: Typical cross section of the barrier containment system for the developing country landfill site

Source: Onyelowe, Obianyo, Onwualu, Onyia & Moses, 2021

2.5 On top of the geomembrane, after the placement is completed, a protection geotextile layer follows, usually at 200-400 g/m², to avoid puncture of the geomembrane by gravel or waste during operation.

2.6 The leachate collection system has a gravel drain layer comprising of perforated HDPE pipes on a 300 mm gravel drainage. The length of pipes between each other (10-20 meters) is wrapped with a filter fabric. The collection pipes transport the leachate to the storage tank gravitationally.

2.7 Other storing options are (in case of dry climate) leachate evaporation beds or (in case of humid climate) recirculation of leachate to optimize decomposition in the waste mass in the HDPE or concrete holding tanks above or underground.

2.8 The drainage layer is shielded by an operations layer of coarse sand or gravel of approximately 300 mm thick.

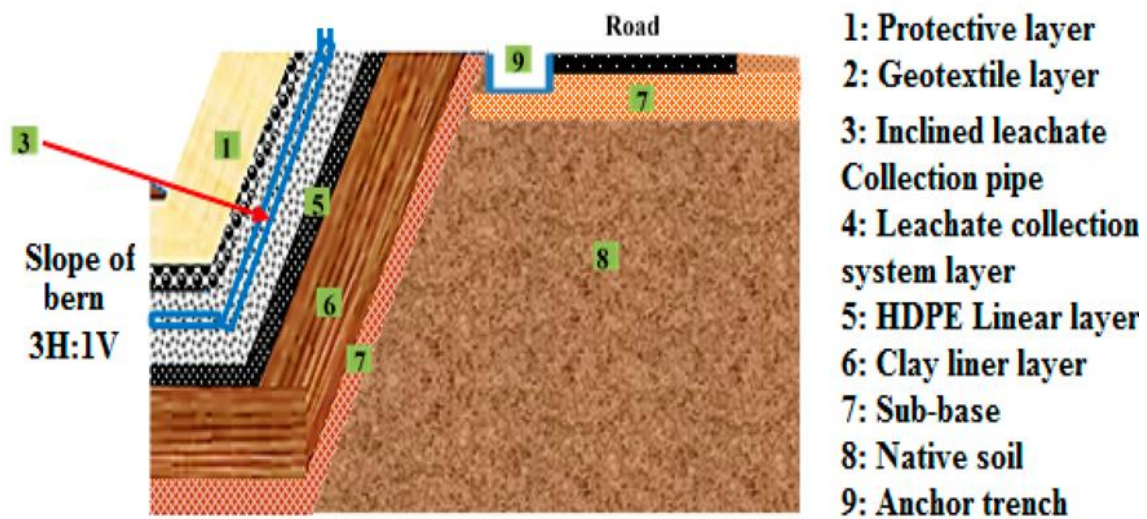


Figure 1.2: Cross-section of designed landfill liner system with leachate collection and anchor trench

Source: Chabuk *et al.*, 2018

3. Different leachate storage systems other than a pond or a dam

The following types of leachate storage systems are discussed, namely leachate holding tanks, leachate evaporation beds and bio-reactor landfill leachate circulation.

3.1 Leachate holding tanks

Tanks are made of concrete or HDPE and stored above grounds or buried in the ground. Affordable and easy to buy and always available on the market. May operate by gravity-flow or pumped up out of the sumps.



Figure 6.3: Leachate holding tank

3.2 Leachate evaporation beds are applied in the areas of low rainfall

Sand gravel-narrow lined basins. Covered over them with black geomembrane. The sun will assist with the leachate evaporation. The method is cheap and very effective especially in dry regions.

3.3 Bioreactor landfill leachate circulation

The collected leachate is sprayed on top of the waste body. This method increases the waste decomposition process and reduces the amount of the leachate.

References

- Onyelowe, K. C., Obianyo, I. I., Onwualu, A. P., Onyia, M. E. & Moses, C., 2021. Morphology and mineralogy of rice husk ash treated soil for green and sustainable landfill liner construction. *Cleaner Materials*, 1(1),1-12.
- Chabuk, A., Al-Ansari, N., Ezz-Aldeen, M., Laue, J., Pusch, R., Hussain, H.M. & Knutsson, S., 2018. Two Scenarios for Landfills Design in Special Conditions Using the HELP Model: A Case Study in Babylon Governorate, Iraq. *Sustainability*, 10(1),125.

APPENDIX C: SURVEY QUESTIONNAIRE



FACULTY OF HEALTH AND ENVIRONMENTAL SCIENCES

WASTE DISPOSAL FACILITIES COMPLIANCE QUESTIONNAIRE

The aim of this study is to investigation of non-compliance at municipal-owned waste disposal facilities and their impact on water resources in South Africa. In addition, the researcher wants to find out what constitutes statutory compliance of waste disposal facilities in South Africa; what is the full cost of waste disposal by landfill in South Africa; what is the cost of alternative waste disposal methods in South Africa; what are the factors associated with the prevalence of non-statutory compliance of municipal owned waste disposal facilities in South Africa.

The purpose of this questionnaire is to understand the knowledge of the interviewee when it comes to the management of the waste disposal facilities and to assess their compliance with the waste management regulations.

I, Mr H.M. Noe, student number, 9707964 declare that I am a PhD student at the above-mentioned institution and that the information received from the questionnaires will only be used for the purpose of the study and all names and contact details will be used for verification purposes. The information that you supply cannot be traced back to you.

The questionnaire to be completed is not a test but contains questions to determine the understanding of waste managers on the management of the waste disposal facilities.

There are no right or wrong answers.

To ensure the best value from the results, you should answer the questionnaire truthfully and as accurately as possible.

Please provide your contact details:

Cell number:
Office number:
E mail address:

PERMISSION:

I,in my capacity of, hereby give permission for information gained by the completion of the questionnaire to be used in the study.

.....
Signature

.....
Date

.....
Position at the site

Official Use

Questionnaire number:

--	--	--

Name of the Respondent:

Date:

Instructions:

Mark the applicable box with an 'X' or write your answer in the space provided.

Please be honest when answering the questions.

SECTION A: BIOGRAPHICAL INFORMATION

Question 1: What is your gender?

Male	1	
Female	2	

	1
--	---

	2
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Question 2: What is your age? _____ years.

Question 3: How long have you been working at this facility

Less than 6 months	1	
6 to 12 months	2	
1 – 2 years	3	
2 - 5 years	4	
More than 5 years	5	

	3
--	---

Question 4: What is your highest qualification obtained?

No education	1	
Primary Education	2	
Secondary Education	3	
Matric Certificate	4	
Tertiary qualification	5	
Post graduate qualification	6	

	4
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Question 5: Have you attended any training on the management of waste facilities?

Yes	1			5
No	2			

Question 5.1: If YES, what is the name of the course?

	6

Question 5.2: If YES, how long was training?

		7
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SECTION B: GENERAL INFORMATION ABOUT THE WASTE DISPOSAL FACILITY

Question 6: Indicate the province where the waste disposal facility is located:

Northwest	1		8
Free State	2		
Gauteng	3		
Mpumalanga	4		

Question 7: Indicate the town where the waste disposal facility is located:

	9
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Question 8: What is the name of the waste disposal facility?

	10
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Question 9: Does the waste disposal facility have a permit/waste licence:

Yes	1		11
No	2		
Do not know	3		

Question 10: What is the name of the municipality where the waste disposal facility is situated?

	12
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Question 11: Which legislation was used when compiling the application for this waste disposal facility?

Environment Conservation Act, 1989 (Act 73 of 1989)	1		13-16
National Environmental Management: Waste Act, 2008 (Act 59 of 2008)	2		
Don't know	3		
No legislation was used	4		

Question 12: Is the waste disposal facility build according to the approved designs?

Yes	1		17
No	2		
Don't know	3		

Question 13: Which regulations/law was followed when designing the waste disposal facility?

Minimum Requirements series of documents as published by the DWAF	1		18
Regulation 634, 635 and 636, 635 National Norms and Standards as published by Department of Environmental Affairs dated 23 August 2013	2		

Don't know	3	
None	4	

Question 14: Which materials specifications standard was used to construct the waste disposal facility?

GRI GM13	1	
GRI GCL3	2	
SANS 1526:2003	3	
None of the above	4	
Don't know	5	

19

Question 15: Were the South African Drinking Water Quality Standards used for groundwater quality monitoring?

Yes	1	
No	2	
Don't know	3	

20

Question 16: How many cells does the waste disposal facility have currently?

One	1	
Two to four	2	
Five and more	3	

21

Question 17: How many cells does the waste disposal facility plan to have in future?

One	1	
Two to four	2	
Five and more	3	

22

Question 18: Until what height will the cells be operated in the future?

20m and less	1	
Between 20 and 29m	2	
Between 30 and 50m	3	
Don't know	4	

23

Question 19: How much waste is disposed per day (in m³)?

0 m ³ to 20 m ³	1	
21 m ³ to 30 m ³	2	
31 m ³ to 50 m ³	3	

24

51 m ³ or more	4	
Don't know	5	

Question 20: What is the planned life-span of the waste disposal facility?

1-5 years	1	
6-10 years	2	
11-15 years	3	
16-more years	4	
Don't know	5	

	25
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Question 21: What is the remaining life span (air space) before closure?

Already closed	1	
6 months to a year	2	
More than a year but less than 2 years	3	
More than 2 years but less than 5 years	4	
More than 5 years	5	
Don't know	6	

	26
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Question 22: What will be the end use of the waste disposal facility?

Sports facility	1	
Vegetable garden	2	
Buildings	3	
Don't know	4	
If, other specify:	5	

	27-31

Question 23: Which of the following equipment are Available from the facility?
(Please select all the relevant options)

None	1	
Tractor	2	
Tipper truck	3	
Front end loader	4	
Compactor	5	
If, other specify:	6	

	32-37

SECTION C: GENERAL INFORMATION ABOUT THE WASTE DISPOSAL FACILITY

Question 24: Is the waste disposal facility registered in South African Waste Information Centre?

Yes	1			38
No	2			

Question 25: Indicate the classification of the waste disposal facility

		39
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Question 26: Indicate the type of waste being disposed at the waste disposal facility?
(Please select all the relevant options)

Plastics	1			40
Paper	2			41
Glass	3			42
Tins	4			43
Food waste	5			44
Tyres	6			45
Wood waste	7			46
Construction and demolition waste	8			47
Garden waste	9			48
Sewage sludge	10			49
Other, please specify:	11			50

Question 27: Does the municipality keep records of the disposed waste?

Yes	1			51
No	2			

Question 28: Is the waste disposal facility fenced?

Yes	1			52
No	2			

Question 29: If the waste disposal facility is fenced, please indicate type of fencing

		53
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Question 30: Is access to waste disposal facility controlled?

Yes	1			54
No	2			

Question 31: If you answered yes to question 30, please indicate how access is controlled?

Staff	1			55
Boom gate	2			56
Lock and key	3			57
Other Specify:	4			58

Question 32: Indicate the distance between the waste disposal facility and the closest residences

Less than 50 meters	1			59
More than 50 metres less than 100m	2			
Less than 1km	3			
More than 1 km less than 2 km	4			
If further, indicate approx. distance to residences	5			

Question 33: Indicate the distance (in meter) of waste disposal facility to closest water source:

			60
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Question 34: What is the reliability of the water resource close by?

Water always present	1			61
Frequently dry	2			
Dry during certain seasons	3			

Question 35: Is the groundwater monitoring done?

Yes	1			62
No	2			

Question 36: How many groundwater monitoring boreholes are present?

None	1			63
One	2			
Two to Three	3			
Four and more	4			
Don't know				

Question 37: What is the position of groundwater monitoring boreholes?

Upgradient	1	
Down gradient	2	
Upgradient and Down gradient	3	
Don't know		

64

Question 38: How many times in a year is groundwater monitoring done?

None	1	
Monthly	2	
Quarterly	3	
Twice a year	4	
Once a year	5	
Don't know		

65

Question 39: Do you compile a geohydrology report after groundwater monitoring?

Yes	1				66
No	2				
Don't know					

Question 40: How many times per annum is the compliance audits conducted?

Four times	1	
Twice	2	
Once	3	
Never	4	
Don't know		

67

Question 41: What do you do with the geohydrology report compiled after groundwater monitoring?

Nothing	1	
File it	2	
Submit to Authorities	3	
Don't know		

68

Question 42: Indicate if leachate is generated on the waste disposal facility?

Yes	1			69
No	2			
Don't know	3			

Question 43: If leachate is generated on site, does the site have leachate collection system/dam?

Yes	1			70
No	2			
Don't know	3			

Question 44: If yes, what type of leachate collection system is installed in the cell/s?

		71
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Question 45: Is the waste disposal facility having gas management system?

Yes	1			72
No	2			
Do not know	3			

Question 46: Is waste burned at the waste disposal facility?

Yes	1			73
No	2			

Question 47: If waste is burnt on site, please indicate who is burning it.
(Please select all the relevant options)

Municipal workers	1			74
Waste pickers	2			75
Community members	3			76
Other Specify:	4			78

Question 48: Is waste compacted at the waste disposal facility?

Yes	1			78
No	2			

Question 49: Is the working cell waste covered each day?

Yes	1			79
No	2			
If Yes, specify:	3			

Question 50: Is litter (papers, plastics etc.) blowing around on site?

Yes	1			80
No	2			

Question 51: Are there trenches/berms around waste disposal facility to manage stormwater?

Yes	1			81
No	2			

Question 52: Are there waste pickers/recyclers collecting waste at the waste disposal facility?

Yes	1			82
No	2			

Question 53: Are there any community members living on the waste disposal facility?

Yes	1			83
No	2			

Question 54: Is recycling of waste taking place on the waste disposal facility?

Yes	1			84
No	2			

Question 55: Is there a disaster management plan when the waste disposal facility is burning?

Yes	1			85
No	2			
Do not know	3			

Question 56: Do you think that the waste at the waste disposal facility is handled in the manner prescribed by legislation?

Always	1			86
Sometimes	2			
Never	3			
Do not know	4			

Question 57: How do you rate your knowledge of the waste disposal practices in operation at this facility on a scale of 1-5?
(1 being low, and 5 being very knowledgeable)

Low						High		87
	1	2	3	4	5			

Question 58: Indicate what types of Environmental Impact could be caused by the facility.
(Please select all the relevant options)

Air pollution	1			88
Soil pollution	2			
Water pollution	3			
Bad odours	4			
Disease due to vermin/pests	5			
Do not know	6			

Geographic location of the waste disposal site

Latitude

S								
---	--	--	--	--	--	--	--	--

Longitude

E								
---	--	--	--	--	--	--	--	--

APPENDIX D: OBSERVATIONAL CHECKLIST



water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

**Investigation of non-compliances at
municipal owned waste disposal facilities and their impact on water
resources in South Africa study check list**

Name of the site	Date

Weather Conditions	
Sunny	
Cloudy	
Hot	
Cold	
Dry	
Rainy	

	Parameters	Ye s	No	Comm ent
1.	When approaching the site, was the site causing the following excessive nuisance conditions?			
1.1	Dust			
1.2	Odours			
1.3	Wind-blown litter			
1.4	Other, please specify: _____			
2.	What type of waste is disposed of at the waste disposal site			
2.1	Plastics			
2.2	Paper			
2.3	Glass			
2.4	Tins			
2.5	Food waste			
2.6	Tyres			
2.7	Wood waste			
2.8	Construction and demolition waste			

2.9	Garden waste			
2.10	Sewage sludge			
2.11	Other, please specify:			
3.1	Is there gate present?			
3.2	If yes, is the gate manned during office hours?			
4.1	Is there signage at the entrance?			
4.2	If yes, is it bearing the name of the contact person, name and classification of the waste disposal site			
5.1	Is the weighbridge present?			
5.2	Is the weighbridge working?			
6.1	Is there running water present?			
6.2	Is there electricity present?			
7.	Is waste sorting on the waste disposal site?			
8.	Is disposal controlled on site (vehicle directed)?			
9.	Is there a water resource near the site?			
10.	Is the waste sufficiently covered?			
10.1	If yes, with what?			
10.1.2	Soil			
10.1.2	Ash			
10.1.3	Gravel			
11.	Is the excessive waste scattered around the site?			
12.	Is the sufficient stormwater control (diversion berms)?			
13.	Is contaminated stormwater (water that came into contact with the waste) sufficiently managed?			
14.1	Does the site produce leachate?			
14.2	If yes, is leachate managed properly (lined leachate ponds?)			
15.	Are the access roads in good conditions?			
16.	What is the road type?			
16.1	Gravel			
16.2	Paved			
16.3	Tar			

17.	Does the site pose unacceptable health risks (uncovered carcasses)? If yes, what type?			
18.	Are there wastes pickers/recyclers present on site?			
18.1	If yes, from where?			
18.1.1	Municipality			
18.1.2	Private company			
18.1.3	Community			
19.	Is the waste disposal facility fenced, if yes by:			
19.1	Steel fence			
19.2	Wire mesh fence			
19.3	Steel palisade fence			
19.4	Concrete palisade			
20.	Are waste pickers/recyclers managed on the waste disposal site?			
21.	Are waste pickers/recyclers wearing protective clothing?			
22.	Are there sanitation facilities on site? If yes what type?			
22.1	Pit Latrine			
22.2	Flushing system			
22.3	Chemical toilet			
23.1	Are there boreholes in the area?			
23.2	If yes in 20.1, are the monitoring boreholes maintained (capped)?			
23.3	If yes in 20.1, are the monitoring boreholes positioned according to the monitoring plan?			
24.	Is record being kept (volumes or mass) of the waste disposed of on the waste disposal facility?			
25.	Are/Was constructions done according to approved plans and designs?			
26.	Is the site within the boundaries as indicated in the waste licence?			
27.	Is there erosion on walls slopes?			
28.	Is the working cell well managed?			
29.	Other			

APPENDIX E: WASTE DISPOSAL FACILITIES COMPLIANCE QUESTIONNAIRE



water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

FACULTY OF HEALTH AND ENVIRONMENTAL SCIENCES

The aim of this study is to investigate the non-compliances at municipal owned waste disposal facilities in South Africa, in addition to find out what constitutes statutory compliance waste disposal facilities in South Africa; what is the full cost of waste disposal by landfill in South Africa; what is the cost of alternative waste disposal methods in South Africa; what are the factors associated with the prevalence of non-statutory compliance of municipal owned waste disposal facilities in South Africa.

The purpose of this questionnaire is to understand the knowledge of the interviewee when it comes to the management of the waste disposal facilities and also check their compliance with the waste management regulation

I, Mr H.M. Noe, student number, 9707964 declare that I am a PhD student at the above-mentioned institution and that the information received from the questionnaires will only be used for the purpose of the study and all names and contact details will be used for verification purpose and published.

1. **The questionnaire to be completed is not a test but contains questions to determine the understanding of the waste managers on the management of the waste disposal facilities.**
2. **There are no rights and wrong answers.**
3. **To ensure the best value from the results, you should answer the questionnaire truthfully and as accurately as possible.**

Please provide your contact details:

Cell number:

Office number:

E mail address:

PERMISSION:

I,in my capacity of, hereby give permission for information gained by the completion of the questionnaire to be used in the study.

.....
Signature

.....
Date

.....
Position at the site

Questionnaire number:

Official Use

--	--	--

Name of the interviewer:

Date:

Instructions:

- Please answer the questions to the best of your ability.

SECTION A: BIOGRAPHICAL INFORMATION

Name of the Province: _____

Name of the facility: _____

Question 1: What type of training or course do you think can be beneficial for you to improve the standard of the site?

SECTION B: GENERAL INFORMATION ABOUT THE WASTE DISPOSAL FACILITY

Question 2: What type of authorisation does the site have?

Question 3: When did the site start operating?

Question 4: What can you introduce to improve the status of the site?

Question 5: Which equipment would you need to operate the site effectively?

Question 6: How do you control the community from accessing the site?

Question 7: Who is conducting the groundwater monitoring?

Question 8: How is the groundwater monitoring conducted?

Question 9: Which laboratory do you use to analyse the water quality samples?

Question 10: Who is writing the report after the results have been received from the laboratory?

Question 11: Is the municipal council aware of the site and it's functioning?

Question 12: What do you think can the leachate cause to the environment/ groundwater?

Question 13: What method do you use to measure the gas produced by the site?

Question 14: How do you manage the stormwater within the facility?

Question 15: To keep the stormwater channels in a good working state how do you manage them?

Question 16: What is the role of the recyclers on site?

Question 17: What type of waste is recycled?

Question 18: Where are the recyclers taking their recyclables?

Question 19: Explain what the disaster management plan entails?

Question 20: What can be done to improve the standard of the site?

Question 21: What type of pollution is worse and who can be affected?

APPENDIX F: ETHICAL APPROVAL AND DOCUMENTS



water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Faculty of Health and
Environmental Sciences/CAFSaB

Malise Noe

F - 0866345998

(012) 336 7639

E - noem@dws.gov.za

Dr Kenneth Kaunda District Municipality
Private Bag X 5017
Klerksdorp
2570

Attention: Mr T. Chanda

REQUEST FOR PERMISSION TO CONDUCT A RESEARCH AT THE MUNICIPALITIES WASTE DISPOSAL FACILITIES

I'm a doctoral student from Central University of Technology, Free State and the research I wish to conduct involves the performance of the municipal waste disposal facilities. The title of the thesis is "Investigation of non-compliances at municipal owned waste disposal facilities and their impact on water resources in South Africa"

I would like to ask your permission to allow me to conduct a survey on the municipal waste disposal sites under the Upper Vaal Catchment Area which cover the municipalities in the Dr Kenneth Kaunda District Municipality.

Upon completion of the study, I undertake to provide the municipality with a report. If you require any further information, please do not hesitate to contact me.

Thank you for your time and consideration in this matter.
Yours sincerely,



Malise Noe
Date: 24/9/2018

CUT, FS • Private Bag X20539 • Bloemfontein • SOUTH AFRICA • 9300
•Website:<https://www.cut.ac.za>

Noe Malise

From: Noe Malise
Sent: Wednesday, 26 September 2018 07:38
To: Mr T Chanda
Subject: Dr Kenneth Kauda DM Permission
Attachments: Dr kk permission letter.doc

Good morning

I'm a student doing a research on the municipal waste disposal facilities, so I would like to ask your permission to conduct such a study at your municipality. Attached find a letter requesting a permission to conduct a study at the municipalities waste disposal facilities.

Your assistance will be highly appreciated.

Should you need further clarity, don't hesitate to call me.

Kind regards

Noe Malise

Department of Water and Sanitation
Resource Protection and Waste
Zwamadaka Building 124
Private Bag X313, Pretoria, 0001
Fax to E-mail: 086 634 6888
Tel: +27(0)12 336 7689
Cell: 079 511 4174



Health Sciences Research Ethics Committee

29-Oct-2018

Dear Herbert Noe

Ethics Clearance: Investigation of non-compliances at municipal owned waste disposal facilities and their impact on water resources in South Africa

Principal Investigator: Herbert Noe

Department: CUT - Central University of Technology

APPLICATION APPROVED

Please ensure that you read the whole document

With reference to your application for ethical clearance with the Faculty of Health Sciences, I am pleased to inform you on behalf of the Health Sciences Research Ethics Committee that you have been granted ethical clearance for your project.

Your ethical clearance number, to be used in all correspondence is: **UFS-HSD2018/0123/2711**

The ethical clearance number is valid for research conducted for one year from issuance. Should you require more time to complete this research, please apply for an extension.

We request that any changes that may take place during the course of your research project be submitted to the HSREC for approval to ensure we are kept up to date with your progress and any ethical implications that may arise. This includes any serious adverse events and/or termination of the study.

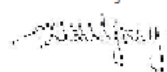
A progress report should be submitted within one year of approval, and annually for long term studies. A final report should be submitted at the completion of the study.

The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act, No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

For any questions or concerns, please feel free to contact HSREC Administration: 051-4017794/5 or email EthicsFHS@ufs.ac.za.

Thank you for submitting this proposal for ethical clearance and we wish you every success with your research.

Yours Sincerely



Dr. SM Le Grange
Chair : Health Sciences Research Ethics Committee

Health Sciences Research Ethics Committee
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