

ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS OF WASTE IN THE FREE STATE PROVINCE

by

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DECLARATION OF INDEPENDENT WORK

I, Mamello Agnes Motaung, student number _____, hereby declare that this research document submitted to the Central University of Technology, Free State, is my independent work and has not been submitted before to any institution by me or any other person to any other institution in fulfilment of any requirement for the attainment of any qualification.

05/ 11/ 2025

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ABSTRACT

Developing countries, including South Africa, continue to face significant challenges in achieving effective and sustainable waste management, despite progressive legislation. Weak institutional capacity, poor enforcement, inadequate infrastructure, and rapid urbanisation contribute to the growing burden of unmanaged waste. In South Africa, these challenges are especially evident in the Free State province, where municipalities struggle to comply with national waste management standards. This study assessed the environmental and public-health impacts of waste exposure among residents living near landfill sites in the province and explored ways to minimise these impacts through a One Health approach, which recognises the interconnection between environmental integrity, human well-being, and animal health.

The research adopted a quantitative, non-experimental, cross-sectional design. Primary data were collected from residents, municipal officials, and waste pickers living near selected landfill sites using structured questionnaires, observational checklists, and field mapping supported by Global Positioning System (GPS) devices. Study sites were purposively selected based on prior evidence of operational deficiencies and exposure risks. Quantitative data were analysed using descriptive and inferential statistics to determine associations between environmental exposure and reported health outcomes, as well as to capture residents' perceptions, lived experiences, and coping mechanisms.

The findings revealed that most landfill sites in the Free State operate below the minimum standards prescribed by the Department of Forestry, Fisheries and the Environment (DFFE). Waste loads were largely uninspected and mixed, leading to the indiscriminate disposal of hazardous and general materials such as healthcare waste, e-waste, absorbent hygiene products, and food waste. Open burning, leachate seepage, and vector proliferation were common across sites. Due to inadequate fencing and limited monitoring, school-age children and domestic animals were frequently observed scavenging at landfills for food or reusable items.

The study further highlights operational inconsistencies in landfill classification, as several sites continue to accept mixed waste streams, despite the provisions of the Gauteng Pollution Buffer Zones Guidelines. Residential dwellings were found on seven landfill sites (38.9%), and three sites (16.7%) were located within 2 km of water bodies, the closest being approximately 140 m away, posing a substantial risk of water contamination.

Sociodemographic analysis showed that most respondents were low-income earners with an average household income of R1 877,85. The majority were unemployed (57.9%), while 32.2% were employed in low-paying jobs, and 19.8% were waste pickers. A significant proportion (62%) engaged at least occasionally in waste picking, while 9.9% relied on social grants or pensions. Most respondents lived in substandard housing, such as shacks (38.8%), Reconstruction and Development Programme (RDP) houses (29.8%), or backyard dwellings (19%), with limited access to clean water, sanitation and healthcare. The association between limited municipal water access and reliance on wood as a primary energy source was statistically significant ($p = 0.026 < 0.05$), reflecting poverty-driven adaptive choices.

Waste pickers and informal recyclers face heightened occupational hazards due to inadequate personal protective equipment (PPE) and the absence of occupational health monitoring. The ecological dimension of exposure was also evident: reports of sick or dead livestock and increased rodent and mosquito infestations indicated that waste mismanagement extends beyond human health, threatening both animal health and environmental stability. While 62.8% of respondents had never been hospitalised, 21.5% reported admissions due to illnesses related to poor air quality, pathogen exposure and environmental stressors, primarily respiratory ulcers, bronchitis, diarrhoeal infections and tuberculosis. The association between healthcare visits and disease prevalence ($p = 0.004 < 0.05$) reinforces the environmental health burden faced by communities near landfill sites.

Using the One Health framework, the study demonstrated the interconnectedness of environmental degradation, human ill-health, and animal exposure, all driven by weak waste governance systems. The absence of multi-sectoral monitoring

perpetuates cycles of vulnerability and exposure. To address this gap, the study proposed a Digitised Community Awareness and Self-Monitoring Tool (DCASMT), an innovative participatory mechanism for real-time environmental and health monitoring, local reporting, and interdepartmental coordination. This model seeks to enhance accountability, data-driven decision-making, and proactive health responses.

The study concludes that waste management in the Free State is both an environmental and public health crisis with deep social-justice implications. The ongoing exposure of vulnerable populations to waste-related hazards constitutes a violation of the constitutional right to a safe and healthy environment. To mitigate these risks, the study recommends:

- Revising landfill classifications and strengthening compliance monitoring systems;
- Enforcing segregation, treatment, and safe disposal of hazardous waste;
- Integrating environmental health surveillance into municipal waste management plans;
- Institutionalising the DCASMT as part of a broader One Health implementation strategy; and
- Promoting waste diversion in alignment with the waste management hierarchy and Sustainable Development Goals (SDGs).

By linking environmental quality, public health, and community participation, the study underscores the necessity of multi-level policy coordination and the ethical imperative of protecting both human and ecological health in developing country contexts.

Keywords: solid waste, environmental exposure, public health impact, One Health, Free State Province, digital monitoring, environmental justice, landfill sites.

LIST OF ACRONYMS

C&DW	Construction and Demolition Waste
DEA	Department of Environmental Affairs
DFFE	Department of Forestry, Fisheries and Environment
DWAF	Department of Water Affairs and Forestry
DSI	Department of Science and Innovation
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organisation
FSPSDF	Free State Provincial Spatial Development Framework
HCRW	Health Care Risk Waste
ILO	International Labour Organisation
MSW	Municipal Solid Waste
NEMWA	National Environment Management Waste Act No. 58 of 2009
NIEHS	National Institute of Environmental Health Sciences
OECD	Organisation for Economic Co-operation and Development
OIE	Office International des Epizooties
PAGE	Partnership for Action on Green Economy
PAHO	Pan American Health Organisation
PPE	Personal Protective Equipment
REDISA	Recycling and Economic Development Initiative of South Africa
UN	United Nations
UNICEF	United Nations International Children's Emergency Fund
UNEP	United Nations Environment Programme
UNITAR	United Nations Institute for Training and Research
SAPs	Superabsorbent Polymers
WOAH	World Organisation for Animal Health
WEEE	Waste Electrical and Electronic Equipment
WHO	World Health Organisation

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CHAPTER ONE – GENERAL BACKGROUND

1.1 Background

Waste is a global concern that reflects deep-rooted environmental, socioeconomic and governance challenges; yet its definition remains fluid across regulatory, disciplinary and institutional contexts. Although definitions vary, they commonly converge on the notion of discarding or disposing of materials that no longer serve their original function or value. The Working Group on Environmental Auditing (WGEA, 2016), the Environmental Protection Agency (EPA), and scholars such as Zibara et al. (2016), Ali and Bella (2016), and Deghani et al. (2021) emphasise this foundational perspective. The World Health Organisation (WHO, 2024a) defines waste as any substance or object that the holder discards, intends to discard, or is required to discard. Similarly, South Africa's National Environmental Management Act 59 of 2008 (RSA, 2008) defines waste as any unwanted material or object intended for disposal, including items listed in Schedule 3 or officially declared as waste by the Minister. However, once such materials are reused, recycled, recovered, or formally exempted, they cease to be classified as waste.

Waste is commonly categorised by source (e.g. household, industrial, healthcare), type (e.g. plastic, organic, electronic), physical state (solid, liquid, gaseous), and characterisation (general, hazardous, or mixed) (Olaoke & Popoola, 2017; WHO, 2024a). According to NEMA (2008), waste is primarily divided into general and hazardous categories. General waste includes domestic, business, construction, demolition and inert waste that does not pose an immediate threat to human health or the environment. In contrast, hazardous waste contains organic or inorganic compounds that, due to their chemical, physical, or toxicological properties, present significant environmental and health risks (RSA, 2012; Olaoke et al., 2017; EPA, 2019). The Hazardous Substances Act 15 of 1973 further enforces the precautionary principle by presuming waste to be hazardous until proven otherwise (RSA, 1973). Solid waste, although primarily composed of tangible materials, may also include sludge from wastewater treatment and certain chemical waste – though interpretations vary across jurisdictions (Hoornweg & Bhada-Tata, 2012; EPA, 2019). This study focuses specifically on solid waste. As Jansen et al. (2017) caution, definitional inconsistencies, fragmented legislation, and differing waste classifications can

complicate waste management practices, escalate operational costs, and undermine coherent environmental governance.

Demographic and socioeconomic factors play a significant role in shaping global waste-generation patterns (Fan et al., 2025). Rapid urbanisation, economic growth, industrialisation, consumerism, and both internal and cross-border migration continue to pose significant challenges to solid-waste management systems. The global population is projected to increase from 8 billion in 2025 to approximately 9.3 billion by 2050 (World Bank, 2018; African Union Development Agency [AUDA], 2021; Abubakar et al., 2022; Alabi et al., 2023). South Africa has mirrored this trend, with its population rising from 46 million in 2002 to 59 million in 2020 (Stats SA, 2020). Correspondingly, global annual waste generation is expected to grow by 73%, from 2.24 billion tons in 2020 to 3.88 billion tons by 2050. In Africa alone, waste is projected to rise from 174 million to 516 million tons within the same period (World Bank, 2021; AUDA, 2021). Asia and Africa, home to most of the world's population, are experiencing particularly rapid urban expansion (Tacoli et al., 2015; Kundu et al., 2023). In 2020, only 29% of Eastern Africa's population was urbanised, compared to 64.6% in Southern Africa, largely driven by South Africa's historically high rates of urban development (Kundu et al., 2023).

As the largest economy in the southern African region, South Africa exhibits several traits associated with developed nations, including advanced infrastructure and relative wealth. However, these benefits are unequally distributed across its population (World Bank, 2018). Africa is also the only region where both the youth population and unemployment rates are projected to grow significantly in the foreseeable future, factors that contribute to increased rural–urban and cross-border migration in search of opportunities (International Labour Organisation [ILO], 2021). These migration patterns are often linked to the growth of informal settlements, urban poverty, inadequate sanitation, crime, and increased pressure on municipal services (Mohapi, n.d.; Nor et al., 2019). However, Tacoli et al. (2015) argue that migration is not the primary driver of these challenges and that not all migrants live in poverty. Rather, the urban outcomes of migration differ across contexts and are shaped by national policies, planning frameworks, and localised sociopolitical dynamics.

In recent years, the integration of emerging technologies, particularly artificial intelligence (AI), has significantly enhanced countries' capacity to forecast municipal solid waste (MSW) generation and inform more effective planning and budget allocation strategies (Fan et al., 2025). Even in contexts where direct measurement tools and consistent records of waste generation are lacking, estimates are typically derived from demographic trends and economic activity at municipal level. Industrial waste, in contrast, is frequently approximated based on production data – especially in cases where waste-related figures are sensitive, confidential, or inaccessible due to permit restrictions (DEA, 2012; Eberhard, 2018). Sadan and De Kock (2021) highlight that South Africa's waste data remain largely unreliable, due to inconsistent reporting by municipalities and waste operators through the South African Waste Information System (SAWIS). Nonetheless, during a parliamentary portfolio committee briefing held on 15 February 2022, the Department of Forestry, Fisheries, and the Environment (DFFE) estimated that South Africa generates approximately 107.7 million tons of waste annually. Alarming, about 92.7% of hazardous waste and 65% of general waste are still disposed of in landfills (Parliamentary Monitoring Group [PMG], 2022).

The number, capacity and design of existing disposal facilities are unlikely to evolve rapidly due to the prolonged and contested processes associated with securing new regional landfill sites. Yet, as consumption and industrialisation continue to rise, the volume of waste requiring disposal is expected to increase, placing additional strain on an already overburdened system (Vani et al., 2017; Ndukwe et al., 2019). Waste management is among the most critical public service responsibilities in developing countries, where municipalities allocate between 20% and 50% of their budgets to waste-related activities. Of this, approximately 80–95% is spent on collection and transportation alone (World Bank, 2021). However, inefficiencies persist. It is estimated that around 70% of urban waste in developing countries is either not collected or improperly disposed of (Zibara et al., 2016). The situation is more severe in low-income contexts, where over 90% of waste is dumped in open, unregulated sites, or incinerated in open practices that have devastating health and environmental consequences (Abubakar et al., 2022).

In South Africa, the legislative framework guiding waste governance is anchored in the NEMA: Act 59 of 2008, which mandates DFFE to establish national norms and standards, while provincial departments are responsible for licensing waste facilities.

Municipalities, in turn, are tasked with delivering waste collection and disposal services (Kalina & Schenck, 2024; Polasi et al., 2020). However, municipalities face significant challenges, including limited financial resources, equipment failure, political instability, corruption, labour unrest and institutional inefficiencies (Godfrey & Oelofse, 2008; DEA, 2012; Polasi et al., 2020; Kalina et al., 2024). Although major strides have been made since 1994 to expand waste services to underserved communities, current systems remain inadequate to meet the demands of South Africa's growing and urbanising population (Kalina et al., 2024). According to StatsSA (2022), only about 62.9% of waste is collected weekly in South Africa residential areas while 38.1% does not receive waste collection.

Waste collection and final disposal are two key stages in the solid waste management hierarchy and continue to present major obstacles. Nearly 90% of all collected waste in South Africa is disposed of via landfilling, which is the least-preferred option in the waste hierarchy (Local Government Bulletin, 2023; Rodseth et al., 2020). In Sub-Saharan Africa, over 75% of waste is openly burned or deposited in unlicensed landfills. These dumping sites carry immense public health and socioeconomic costs – costs that remain largely unquantified by governments, industries, and affected households (Salam, 2010; Madaleno, 2018; Farah, 2019).

Despite the development of technologies that enable recovery and reuse, approximately 70–80% of MSW in Africa is technically recyclable. Yet only around 10% is recovered in practice, with South Africa reflecting similarly low recycling rates (AUDA, 2021; Local Government Bulletin, 2023). A staggering 87% of municipalities lack the financial capacity or infrastructure to implement waste minimisation strategies, including source separation and resource recovery (DEA, 2019). The absence of clear, enforceable guidelines on household waste segregation has led to indiscriminate disposal, including the mixing of hazardous and general waste streams (Du Toit & Bodenstein, 2014; Jansen et al., 2017). Recyclable materials are often landfilled or dumped, including an estimated 10 million tonnes of food waste annually, despite the prevalence of food insecurity in the country (WWF, 2017).

This improper handling of waste not only exacerbates pressure on limited landfill space, but also contributes to significant environmental and health risks, particularly for those living close to disposal sites, informal waste pickers and municipal workers.

In response, the DEA (2018) published draft guidelines for the separation of waste at source, urging that such measures be aligned with municipal Integrated Waste Management Plans (IWMPs) and local waste by-laws. These guidelines aim to slow the depletion of landfill airspace and reduce pollution and environmental degradation. Jansen et al. (2017) further recommend that healthcare risk waste (HCRW) be integrated into broader waste systems rather than treated as a separate stream to ensure comprehensive and efficient management.

Environmental degradation resulting from poor waste management practices poses one of the most pressing sustainability issues of our time. The environment comprises both biotic (living organisms) and abiotic (soil, air and water) components, and landfill sites interact with these elements through processes such as leachate percolation, which can contaminate groundwater and surface water sources (Manisalidis et al., 2020; The Green Guardian, 2023). Landfills also emit significant quantities of greenhouse gases, including methane and carbon dioxide, which contribute to global warming and climate change (Ziraba et al., 2016; Yousafza et al., 2017; WHO, 2024a). These environmental impacts are linked to declines in biodiversity, ecological health, and the quality of human life (Ogundele et al., 2018; Gwibi et al., 2020; Krecl et al., 2020).

Populations residing near landfill sites are especially vulnerable to health risks, including poor sanitation, exposure to contaminated water and food, respiratory illnesses, rodent infestations, and vector-borne diseases (Salam, 2010; Alam & Ahmade, 2013; Ziraba et al., 2016; Scarponi et al., 2019). Children are particularly at risk due to their underdeveloped immune and metabolic systems, which limit their ability to eliminate environmental toxins (Cointreau, 2006; Inghels Vasina, 2018). According to the World Health Organisation (2024b), an estimated 13.7 million deaths, approximately 24% of global mortality, can be attributed to modifiable environmental risk factors, with noncommunicable diseases such as cardiovascular illnesses, chronic respiratory conditions, and cancers being the most prevalent outcomes. These statistics underscore the urgent need for targeted interventions that prioritise environmental justice and protect the health of the most vulnerable communities.

1.2 Rationale of the study

In South Africa, the waste management sector in South Africa is characterised by the presence of progressive national policy frameworks yet continues to face consistent implementation difficulties both at provincial and municipal levels (DEFF, 2020a). Section 24 of the Constitution of the Republic of South Africa (Act 106 of 1996), found in the Bill of Rights, guarantees the right to an environment that is not harmful to health or well-being, and mandates environmental protection for present and future generations. This protection is to be achieved through reasonable legislative and other measures that prevent pollution, promote conservation, and ensure sustainable development (RSA, 1996). The NEMA: Waste Act (Act 59 of 2008) provides a legal basis for an integrated policy framework for the environment, yet its effectiveness varies across provinces due to differences in institutional capacity, resource allocation, and enforcement (DEA, 2012; Polasi et al., 2020). The unequal distribution of waste management services in South Africa, particularly the Free State, raises concerns about restoration, environmental and social justice, particularly for low-income and historically marginalised communities (Rodseth et al., 2020; Kalina et al., 2024), including those working on and living in the vicinity of landfills.

The drivers of improper waste disposal in the Free State are exacerbated by poverty, rapid urbanisation, and population explosion. The Free State municipalities, such as the Mangaung Metro Municipality, Lejweleputswa, Xhariep, Fezile Dabi and Maluti-a-Phofung, have experienced rapid urbanisation and population pressure, exacerbating the increase in waste generation (Matjhabeng Local Municipality, 2024; Mangaung Metropolitan Municipality, 2022; Center of Scientific and Industrial Research [CSIR], 2023; Fezile Dabi Municipality, 2022; Cooperative Governance & Traditional Affairs [COGTA], 2020). The Free State province is the third-largest province in South Africa, located on the high central plains, and represents 10.6% of the total land area of the country, but is one of the least economically active provinces in South Africa (OECD, n.d; Toerien, 2015). According to the Department of Statistics South Africa (2020), the largest employment decrease of 29 000 was recorded in the Free State province in the year 2020, and it remains the second province with the highest unemployment rate in the country after North West. The high unemployment rate in South Africa is one factor leading to interprovincial migration and a rise in the proliferation of informal sector activities such as waste picking, driven by poverty (Uhunamure *et al.*, 2021;

AUDA, 2021). Despite the existing human settlement allocation disparities, these are the populations that usually settle informally in environmentally insecure places such as landfills without basic amenities such as water, toilets, and electricity, accounting for about 5 million in South Africa (International Budget Partnership, 2021; Schenck et al., 2022). This further influences the reliance of residents on social grants and free services. Health insurance coverage in the Free State is estimated at 17.8%, which leaves over 2.2 million of the uninsured population to be fully or partially dependent on the public health service, which is already overburdened due to insufficient human resources undermining the quality of healthcare services provided in the province (Department of Health [Free State], 2016; Ritshidze, 2021). Vulnerability reduction would require an understanding of the underlying social, economic and political context, and then addressing the factors that increase risk and vulnerability (Dintwa et al., 2018).

According to the latest landfill audit of 153 landfills by AfriForum in South Africa, it was identified that only 27 (14.3%) sites met 80% or above of the minimum requirement audit, and the worst-performing provinces were the Free State and Northern Cape. The report further revealed that none of the landfill sites in the Free State passed the audit for compliance with the minimum requirement (AfriForum, 2021; Burger, 2024). The Free State district coordinator of Africa described the conditions of the province as below:

A lot of the machinery is broken, and the landfill sites hold great health and safety risks for people who work there and for the community that has to use the sites. It is clear that the municipality is mismanaging this department. – Christo Groenewald, AfriForum's District Coordinator for Bloemfontein (AfriForum, 2021)

The Free State has 73 landfill sites, whose capacities are already stretched and are operated like dumpsites (Roberts 2013; AfriForum, 2021; The Green Guardian, 2023). Even though MSW services are mostly underpriced, residents and businesses fail to pay, which has a direct impact on a municipality's budget and ability to render services or improve infrastructure (DEA, 2010; DEA, 2012; Polasi et al., 2021). Due to the lack of a hazardous landfill site in the Free State, e-waste and healthcare risk waste are disposed of at general waste landfill sites (MMM, 2016). There is a paucity in the

scientific literature investigating the impacts on health and the environment of municipal landfill sites in the Free State and on sustainable solutions relevant and appropriate for all South African communities, including the marginalised groups. The available studies focus on respiratory health in those living near illegal dumpsites (Maluleka et al., 2025) and water quality, soil quality, and food security (Ololade et al., 2019; Makhadi et al., 2020), and waste pickers' socioeconomic context (Schenck et al., 2016). Most studies were based on the Mangaung Metropolitan Municipality.

Despite the urgent need for waste valorisation to reduce the waste burden and its impacts on the environment and health, recycling was not listed as an essential service and waste pickers were not recognized as essential workers during COVID-19 lockdown in South Africa and such restrictions prohibits the country to reaching the potential of a R10 billion estimated turnover through recycling (DEA, 2012b; Polasi et al., 2020). Even though the Department of Forestry, Fisheries and Environment (DFFE) & Department of Science and Technology (DSI). Developed a waste picker integration guideline in 2020 (DFFE & DSI, 2020), there is a need for the development of a comprehensive guideline tool that integrates legal, social, and health dimensions, specifically targeting disparities in waste management and vulnerabilities of marginalised groups working or living near landfill sites. This study contributes to promoting sustainable, inclusive and health-conscious practices through United Nations Sustainable Development Goals (SDGs), including SDG3 Good Health and Well-being, SDG6 Clean Water and Sanitation, SDG8 Decent Work and Economic Growth, SDG10 Reduced Inequality, SDG13 Climate Change, SDG15 Life on Land, and SDG12 Responsible Consumption and Production.

1.3 Problem statement

The communities living in the vicinity of landfill sites in the Free State province face significant health and environmental risks due to exposure to environmental waste and living in the vicinity of poorly managed waste facilities. Despite the presence of national waste management policies, there is insufficient scientific data on holistic environmental, health and social impacts, leaving a critical gap in addressing the environmental injustices and public health vulnerabilities affecting marginalised groups in the Free State.

1.4 Aim and Objectives

1.4.1 Aim

The study aims to:

1. Assess the impact of the environmental waste on the health of residents living in proximity to the landfill sites in the Free State province.
2. Investigate environmental risks linked to waste exposure.

1.4.2 Objectives

1. To assess the perception of residents on the environmental, health, and social risk factors affecting their livelihood.
2. To evaluate the environmental conditions and risks linked to living in the vicinity of landfill sites.
3. To develop a digitised community awareness and self-monitoring tool aimed at minimising environmental exposure and health implications for affected populations using the One Health approach.

1.5 Structure of the thesis

This study is structured into six chapters following the format below:

Chapter 1: Introduction

This chapter provides the background to the study, presenting waste, socioeconomic, and demographic factors, as well as municipal governance factors influencing waste management and disposal globally, regionally, and in the country. The environmental and health impacts of waste and waste facilities are highlighted. This section provides the rationale and significance of the study. The aims and objectives of the study are presented, along with the most important delimitation that affected the study.

Chapter 2: Literature review

Key concepts and definitions are discussed in the literature review. The waste exposure patterns in the environment and different population groups are described. Health risk assessment and legislative framework are discussed in detail. The

theoretical and conceptual frameworks are described and illustrated to guide the study.

Chapter 3: Methodology

In this chapter, the empirical review is conducted to justify the choice of methodology. The research design, study area, sampling techniques, data collection instruments, collection methods, data management, and ethical considerations used to test objectives are detailed.

Chapter 4: Interpretation of Results

The findings of the study are interpreted and presented concerning the research objectives.

Chapter 5: Discussion

Based on the findings presented in Chapter 4, the discussion summarises results and incorporates their meaning to the study and the innovation that has come out of the work. Limitations of the study are also addressed in this section.

Chapter 6: Conclusion

This is the final part of the research study report. Conclusions are drawn based on the findings pertaining to the objectives of the study and recommendations to address environmental and health impacts in the Free State.

1.6 Delimitations of the study

The waste that the researcher refers to is waste in its solid state. The study is geographically limited to selected landfill sites within the Free State, depending on previous reports, their conditions, and operation. The environmental and health impacts of residents are based on their self-examination and perceptions. The environmental conditions were observed rather than quantified, and no environmental measurements (no exposure gradients or dose–response patterns) are explored.

1.7 Conclusion

The waste mismanagement in South Africa, particularly in the Free State province, poses serious environmental, health, and social risks that disproportionately affect

marginalised communities living near landfill sites. Despite the existence of progressive legislative and policy frameworks, weak implementation, limited municipal capacity, and inadequate infrastructure continue to undermine effective waste governance. Rapid urbanisation, poverty, unemployment, and population pressures further exacerbate improper waste disposal and environmental exposure. The heavy reliance on landfilling, low recycling rates, and poor source separation practices intensify environmental degradation and public health vulnerabilities. These challenges highlight critical gaps in data, enforcement, and inclusive planning, especially regarding communities and waste pickers operating around landfill sites. Addressing these gaps requires integrated, context-specific interventions that align environmental protection, public health, and social justice to promote sustainable and equitable waste management outcomes.

CHAPTER TWO – LITERATURE REVIEW

2.1 Introduction

The generation, composition and management of waste are not purely statutory, but deeply influenced by the sociodemographic issues of the source. MSW is the major component of solid waste managed by local municipalities (DEA, 2013). Globally, MSW generation has increased substantially in recent decades, accompanied by an increasing presence of hazardous waste streams originating from households (Gutberlet & Uddin, 2018). Some of the key factors influencing the effectiveness of solid waste include the household size, cumulative income range, urbanisation of the areas, population density, and location of the region (Zibara et al., 2016; Fadhullah et al., 2022). Since the last century, shifts in consumption patterns and rapid urbanisation have led to notable changes in the waste stream and environmental pressures (Alabi et al., 2023).

Waste can also be categorised based on its source and physical state. Organic waste is waste derived from biodegradable material. It can be categorised into three parts: putrescible, fermentable and non-fermentable (Zibara et al., 2016). Putrescible waste includes materials such as food scraps that decompose rapidly, often accompanied by unpleasant odours and potential health risks. Fermentable waste also decomposes quickly, but without the offensive byproducts of putrefaction. In contrast, non-fermentable waste is more resistant to decomposition and therefore breaks down at a much slower rate (Zibara et al., 2016; Vu, 2023). Organic waste can include food scraps, agricultural residues and garden waste such as vegetable trimmings, branch pruning, leaf sweepings and animal manure (Repsol, 2023). Inorganic waste refers to non-biodegradable waste that does not decompose naturally by microbial activity. Inorganic waste categories are ceramics, concrete, asphalt, bricks, polyethene containers, cellophane wrap, synthetic textiles, metal, glass, and e-waste (Fiveable, 2024; Vu, 2023). Because the waste is not composed of material that is required by nature, the inorganic waste categories are likely to accumulate longer in the environment and produce hazardous residuals; therefore, deliberate efforts to reintegrate into new finished products are essential to minimise environmental impacts (Fiveable, 2024; Asri, 2025).

In South Africa, waste is classified into two categories: general and hazardous (DEFF, 2020b). A solid waste is classified as hazardous if it is specifically listed as a known hazardous waste or exhibits one or more characteristics of hazardous waste (EPA, 2024). Hazardous waste is considered more dangerous than general waste, as it often contains potent biological constituents, contaminants and toxic chemicals resulting from the processing and conversion of raw materials into finished products (Olaoke & Popoola, 2017; Roy et al., 2022). It is categorised under hazardous waste according to Annexure 1(2)(b)(iii) of the Draft Waste Classification and Management Regulations. This category may include disinfectants, pesticides, bleach, battery acids and thinners. Wastes exhibiting ignitability include liquids with flash points below 60 °C, non-liquids capable of spontaneous ignition, flammable compressed gases, and oxidising agents. Corrosive wastes are typically aqueous with a $\text{pH} \leq 2$ or ≥ 12.5 or have the ability to corrode steel. Wastes showing reactivity are unstable under normal conditions, may react with water, release toxic gases, or detonate when exposed to heat or pressure. Toxic waste poses significant health and environmental risks when ingested or absorbed, as they can leach contaminants into groundwater sources (EPA, 2024). A report by the DEA suggests that South Africa produces and disposes of slightly higher amounts of hazardous than general waste as out of the estimated 12.9 million tons of waste generated in 2017, approximately 57.5% was considered hazardous and 42.6% was classified as general waste (DEA, 2018; Nyika et al., 2021). The environmental and health impacts of MSW may vary according to its composition and management procedures followed (Chen et al., 2020). The quantity and special distribution of mismanaged waste data are also crucial for the development of more effective National Waste Management Plans.

2.2. Major solid waste streams of environmental concern in South Africa

According to the Recycling and Economic Development Initiative of South Africa [REDISA] (2023), South Africa has 38 waste streams. However, in this section, the focus will be on common peculiar waste that constitute MSW or finds its way into the MSW stream and their management challenges.

2.2.1 Food waste

Food waste is a major component of organic waste (Zibara, 2016). This waste category is generated when edible food is spilt, spoiled, or incurs a reduction in quality

or value at any point in the food supply chain before reaching its final product stage during production, post-harvest handling, processing and distribution (Stancu et al., 2016; UNEP, 2021; Kooiman et al., 2023). In developing countries, most of this waste is disposed of in landfill sites, which generally lack proper moisture or oxygen levels to promote the breakdown of organic materials as quickly as required (Rathe & Murphy, 2001; Kooiman et al., 2023). Globally, approximately one-third of the world's food is lost or discarded, amounting to roughly 1.3 billion tons and valued at about US\$990 billion (Food Loss and Food Waste, 2019). According to the UN World Food Programme, worldwide, approximately 1 in 10 people face hunger, and eliminating current levels of food loss and waste could preserve sufficient food to feed up to two billion people (UN World Food Programme, 2023). The most affected food categories are usually perishable foods, which include 45% of fruits, vegetables, roots and tubers, 35% seafood (fish, shellfish and seaweed), and 30% cereal (wheat, maize and barley). Each year, approximately 18 billion land animals are discarded, and an estimated 40% of those caught or killed for food are left to rot (Clark, 2022). In developing countries, the largest proportion of food waste occurs during the initial stages of the food supply chain, where developing countries experience significant food loss at the final stages, which include food markets and food outlets, due to the expiration period or simply because of the ejection due to unawareness of consumer intervention (Arsand & Parry, 2019; Seberini, 2020). The disposal of food in landfills is a source of food ailments for people who live on or in the vicinity of landfill sites who, because of impoverishment, consume food waste (Etea, 2021). The post-harvest residues such as straw, husks and stalk have lignocellulosic material (plant-based biomass), which is associated with the emission of high concentrations of polycyclic aromatic hydrocarbons (PAHs) (Oskina et al., 2024). An estimate of 170 million metric tons of greenhouse gases is attributed to food waste in the United States, representing 16–18% of total emissions from the national food system and 6% of global greenhouse gas emissions, which greatly influence climate change in the world (Read et al., 2020; Kooiman et al., 2023).

2.2.2 Absorbent hygiene product waste

This category of waste, including disposable diapers, incontinence products, and menstrual sanitary items, constitutes a significant share of the global waste problem (UNEP, 2021; Schenck et al., 2023). The absorbent hygiene product waste category

is usually made up of a combination of organic material, including wood-derived pulp, cellulose and cotton, corn starch, and itaconic acid from sugars through fermentation. Inorganic materials such as fossil-based polymers, including superabsorbent polymers (SAPs) and non-woven polyester layers, usually constitute 65.2% of the mass product (College of Charleston, 2017; Demichelis et al., 2023; Chitaka et al., 2024).

Single-use baby diapers constitute an important category of childcare products due to their convenience and effectiveness, and mothers are largely responsible for their purchase (Plotka-Wasyika et al., 2022; Kordecki, 2021; Kordecki et al., 2022). In South Africa, approximately 1.1 million tons of disposable diaper waste are generated yearly (Khanyile et al., 2020). A study conducted in Mpumalanga province reported 80% of respondents using disposable diapers, which was associated with the lack of access to basic water, sanitation, hygiene, and waste removal services in the area (Chitaka et al., 2024). Globally, the disposable nappy industry is valued at approximately US\$71 billion, and due to the population of newborns each year, about 300 000 disposable nappies are either incinerated, disposed of in landfills, or indiscriminately dumped in the environment, especially in developing countries such as South Africa, Kenya (; Newswire, 2018; Ntekpe et al., 2020; UNEP, 2023; Schenck et al., 2023). The traditional terry-cotton cloths have recently resurged as an alternative, environmentally friendly option; however, unlike the disposable nappies, they are prone to leakage and require more water and energy usage for soaking, washing and drying purposes (UNEP, 2023). To show that disposable nappies will be here for the foreseeable future, in the year 2019, an archipelago in the South Pacific comprising 65 islands with a population of approximately 300 000, named Vanuatu, announced plans to ban disposable nappies due to their perilous environmental impacts. However, the proposal faced swift resistance from local communities, who emphasised the limited availability of practical alternatives (Radio New Zealand, 2020). Disposing of diaper waste generation, coupled with poor municipal service delivery, has caused division in communities as a contentious dispute among neighbours regarding the disposal of used nappies was reported by Environmental and Rural Solutions (ERS), a social enterprise non-governmental organisation NGO dedicated to improving ecosystem health and human well-being in the Eastern Cape. The NGO has made efforts to

launch a pilot programme with young mothers but met with some resistance (The Green Guardian, 2023).

Similar to disposable diapers, the use of sanitary pads constitutes a significant aspect of women's lives. A woman typically menstruates from puberty (around ages 11–14) until menopause (approximately aged 45–55), experiencing an estimated 459 cycles over her lifetime (WHO, 2024g). As much as sanitary pads are needed every cycle or month, socioeconomic factors are determinants of access to these products, and disparities are usually seen in both urban and rural settings (Rossouw & Ross, 2021). Single-use pads and tampons continue to be the predominant menstrual hygiene products, especially in high-income countries (Aujla et al., 2024). The current sanitary-napkin market is expanding, as the growing female population, particularly in developing countries, increases the potential consumer base. In 2024, North America dominated the global market, accounting for over 40% of revenue with a market size of USD\$860.48 million and an expected CAGR of 2.2% from 2024 to 2031. Europe followed with more than 30% of the market, valued at USD\$7 374,36 million. The Asia Pacific region held approximately 23% of global revenue, with a market size of USD\$5 653,68 million and a projected CAGR of 6.5%. Latin America and the Middle East & Africa represented smaller shares, around 5% (USD\$1 229,06 million, CAGR 3.9%) and around 2% (USD\$43,02 million, CAGR 3.7%), respectively (Singh, 2025). The indoctrinated taboos around menstruation and misconceptions from the past in the African culture perpetuate prioritising discretion while dealing with menstrual waste over menstrual health management (sanitation, health and safe disposal) (Phillips-Howard et al., 2016; Elledge et al., 2018). Globally, the absence of clarity and consensus regarding the classification of menstrual waste, whether as solid, hazardous, or biomedical waste, creates challenges in establishing how best to discard this waste category and usually ends up in landfills and water systems (Hartmann et al., 2015; Elledge et al., 2018; Aujla et al., 2024). In Dar es Salaam, Tanzania, an average of 150 sewer blockages occur each month, costing the Dar es Salaam Water and Sewerage Corporation approximately US\$25 000, and menstrual waste was attributed as a common contributing factor (Sommer et al., 2013). Europe, which produces over 200 million tons of sanitary pad waste per year, and the United States dispose of more than 80% of menstrual products in landfills (Aujla et al., 2024).

2.2.3 Healthcare Risk Waste (HCRW)

Waste emanating from healthcare facilities has two categories. General waste, also known as solid waste, is similar to household waste, consisting of food scraps, paper, plastic materials and packaging wraps, while HCRW refers to any solid material generated from activities related to health promotion, medical diagnosis, treatment, scientific research, and dental and veterinary services (Kasuku et al., 2016; Udofia et al., 2017; Mehta et al., 2018; Miamilitis & Talias, 2024). HCRW is ranked as the second-most hazardous waste after radioactive waste in terms of toxicity and regardless of quantity (Jansen et al., 2017; Zithathile & Atagana, 2018a). Drawing on research conducted across 30 Brazilian cities, about 35% of medical waste was inadequately treated before disposal during the COVID-19 pandemic, thereby presenting significant risks to public health, including the potential transmission (Urban & Nakada, 2021; Abubakar et al., 2022). Although the disposal of HCRW in landfills and open environments is universally prohibited due to its perilous nature, there are still incidents of illegal disposal of this waste category (Motaung et al., 2024; WHO, 2024b). Over a decade ago, tons of highly infectious raw medical waste, including bloody swabs, body parts, filthy bandages, used needles, vials and discarded medication, were unearthed in the backyard of a brick factory in Welkom, Free State (Magner, 2014). A study conducted in the City of Tshwane reported that even government officials provided inconsistent procedures to follow when an illegal HCRW disposal is reported to them, indicating a lack of a legal framework to address HCRW management directly (Ngobeni, 2021). Household HCRW, also referred to as household medical waste by other authors, is typically generated during the provision of domiciliary care, the treatment of injuries, and the management of chronic diseases such as diabetes (Zithathile & Atagana, 2018b). It may include syringes, sharps (such as razors and needles), blood-stained bandages and absorbents, sanitary towels and faecal-contaminated nappies. In Ghana, 47 respondents (7.8%) reported taking the placenta home after delivery, where it was often buried in the ground (Udofia et al., 2017).

In South Africa, the improper classification and disposal of household HCRW pose a growing threat to environmental integrity and public health. According to SANS 10248-1:2008, untreated healthcare-risk waste must be classified in accordance with Annexure D, which outlines various hazard classes, and SANS 10228, which specifies

the identification and classification of dangerous goods for road and rail transport. The residues resulting from treatment processes must also be classified under SANS 10228 and tested in compliance with the relevant requirements and provisions of applicable national legislation (SABS, 2008). The management of HCRW is enacted by the NEMA Act of 2008, in the Draft Health Care Risk Waste Management Regulations also defines HCRW as the portion of the health care waste that is deemed hazardous and includes: laboratory waste, anatomical waste, cytotoxic waste, infectious waste, sanitary waste, and nappy waste (RSA, 2013a). However, domestic or household-level HCRW is disregarded in the regulation and therefore excluded from the general prohibitions guiding its management (Rodseth et al., 2020).

A hazardous constituent of household medical waste is pharmaceutical waste, which may be described as expired, unused and contaminated medicines discarded at household level. It includes prescription drugs, over-the-counter pills, syrups and ointments. Pharmaceutical waste is a significant environmental pollutant, arising both from human excreta after drug consumption and from the improper disposal of expired drugs, unused medicines, nutraceuticals, and other discarded wellness products (OECD, 2022; Magagula et al., 2022). In many developing countries, where designated hazardous waste landfills or safe waste treatment facilities are lacking, medical facilities often use a small, restricted burial pit specifically for infectious clinical waste, or dispose of such waste in general landfill sites (Mochungong, 2011; WHO, 2024b). According to SANS 10248-1: 2008, this waste category is classified as and needs to be treated as healthcare-risk waste; however, a loophole is noted, where generators are only regarded as healthcare facilities and practitioners (SABS, 2008). The Health Care Risk Waste Management Regulations further state that pharmaceutical waste needs to be effectively minimised or entirely avoided whenever feasible, for instance, by meticulously verifying the expiration dates of goods upon delivery, prioritising the distribution of older inventory, engaging in the recycling or repurposing of packaging materials, and facilitating the return of empty gas cylinders to the respective suppliers. Waste generated must be properly segregated at the site of generation within a pharmacy, with healthcare-related waste distinctly separated from general waste and other waste categories (SABS, 2008; RSA, 2013a; Du Toit & Bodenstein, 2014).

2.2.4 Plastic waste

Plastics are synthetic polymers widely utilised across diverse sectors of goods, including textiles, medical supplies, food and beverage packaging, electrical components, and construction materials (Proshad, 2018; Adeniran & Shakantu, 2022). The rise of the fast fashion industry has led to a global increase in the consumption of textiles made from polyester fibre, which is also a significant contributor to plastic waste that is usually discarded in landfills (Motaung, 2020; Sadan & De Kock, 2021; Makgato, 2024). Some plastic bags contain toxic chemical additives, including persistent organic pollutants (POPs) and brominated flame retardants (BFRs), which are resistant to environmental degradation and can accumulate in ecosystems (Barra & Leonard, 2018; Njoku et al., 2019; Nahman et al., 2022). The accumulation of waste in landfills is also uncontrollable because, unlike other waste, plastic can withstand ultraviolet (UV) exposure and wave action, allowing it to remain intact for extended periods and forming a higher proportion of macro-debris (Chitaka & Von Blottnitz, 2019; Beaumont et al., 2019; Arabi & Nahman, 2020). With a population of approximately 1.3 billion, Africa generated an estimated 400 million tons of plastic waste in 2020, representing roughly 4% of global plastic production (UNEP, 2018). Several African coastal countries, including Algeria and Morocco, rank among the top 20 global contributors to marine plastic pollution. In addition, nations such as Egypt, Nigeria and South Africa are major importers of plastic into the continent (Jambeck et al., 2018). Most of the plastic, however, is produced in China (28%), North America (19–21%), and Western Europe (18–19%) (Sadan & De Kock, 2021).

In Africa, numerous countries, including Mali, Kenya, Zimbabwe, Guinea-Bissau, Ethiopia, Eritrea, Tanzania, Chad, Cameroon, Mauritania, Morocco, Niger, Somalia, Rwanda, Tunisia, Mozambique, Botswana and, have enacted legislation banning plastic bags. However, plastic-bag pollution continues to pose a significant challenge, and poor enforcement and the need for amendment of laws are hindering effective plastic-waste management (Chasse, 2018; Behuria, 2019; Nyathi & Togo, 2020). However, in South Africa, no single intervention strategy implemented in isolation is sufficient to meaningfully reduce plastic pollution (Stafford et al., 2022). South Africa has not implemented a total nationwide ban on all plastic but it has introduced several including single-use plastic, targeted bans on specific types of plastic including single-use plastic and microbeads (George, 2025). Despite the implementation of the

Extended Producer Responsibility (EPR) Regulations, current collection and recycling targets are projected only to stabilise pollution levels, with 2040 outcomes likely to mirror those of the present, given the anticipated rise in plastic production and consumption (World Bank & CSIR, 2022; Nahman et al., 2022).

2.2.5 Tyre waste

The automotive sector remains one of the most dynamic and rapidly growing industries globally, and so is its waste (Czama-Juszkiewicz et al., 2023). The outcomes of such consumption are that 1.5 billion waste tyres are generated in the world annually, and only 15–20% are processed for reuse, while the rest becomes unmanaged waste that ends up in landfill sites (Donnelly, 2023; Czama-Juszkiewicz et al., 2023). A tyre is a pneumatically inflated rubber covering, which can sometimes be infused with fabric, wire, carbon black, and chemical compounds, designed to provide a cushion around a wheel, providing a stable and soft contact with the road surface (Harrison-Obi, 2019). The global tyre market reached US\$2 268 million in 2021 and is projected to reach US\$2 665 million in 2027, driven by the accelerating sales of passenger vehicles, particularly in developing countries (Businesswire, 2022). The waste tyre generation is from the replacement of old tyres with new tyres or removal from vehicles before scrapping. The tyres can be segregated into two categories, namely partly worn tyres that are still fit for road use, or end-of-life tyres that can no longer be used further for their original purpose (Czarna-Juskiewicz et al., 2023).

To address the waste tyre problem in South Africa, the Recycling and Economic Development Initiative of South Africa (REDISA) was gazetted in 2013 to create, monitor and support industry waste management plans in terms of Section 34D. Its mandate included promoting the circular economy through the waste management hierarchy, establishing a national network of collection depots and tyre processors, creating employment opportunities in the informal sector, and stimulating the growth of small businesses in the waste-tyre industry. Waste tyres were managed by REDISA until 2017, however, following the cessation of the producer-paid levy in 2017, REDISA was forced to shut down (Scott, 2017; REDISA, 2023). Since then, the Waste Bureau (Part of DFFE) has mandated to managing waste tyres. Annually, South Africa sells an average of 13 million tyres through a network of 1 400 to 2 000 dealerships (DFFE, 2022). Waste tyres are regulated under the National Environmental Management:

Waste Act 59 of 2008 (RSA, 2008), the National Norms and Standards for the Disposal of Waste to Landfill (RSA, 2013a), and the Waste Tyre Regulations, 2017 (R1064) which placed a landfill ban on waste tyres as of 29 September 2017 in South Africa (CSIR, 2020). Between 2017 until 2024 the DFFE drafted a new Industry Waste Tyre Management Plan (IndWTMP) which was then again withdrawn in 2025. The DFFE is drafting a new plan at the moment (Schenck & Blaauw, 2025).

When tyres are not properly managed, they cause significant problems in the environment. Tyres have a large mass and are non-biodegradable because of their complex physical nature; therefore, they occupy a large proportion of space in where they are disposed, particularly landfills (Harrison-Obi, 2019). Tyres rank among the most flammable forms of waste, which can be a problem if not managed. The dense rubber composition of tyres burns at extremely high temperatures, often exceeding 1 000 °C, while the embedded steel belting contributes to complex fire dynamics that resist conventional firefighting methods (Donnelly, 2023; Murphy, 2025). Since the REDISA closure, incidents of illegal burning have occurred in parts of Gqeberha in the Eastern Cape, Freedom Park in Soweto, and Baden Powell in Cape Town (Burger, 2025). When tyres burn, they release an alarming array of toxic compounds that persist in the environment for years. When tyres burn, the combustion process transforms ordinary rubber into a complex array of toxic compounds. Harmful gases such as carbon monoxide (CO), carbon dioxide (CO₂), and sulphur oxides (SO_x) are released into the atmosphere, causing long-term damage to both human health and ecological systems (Donnelly, 2023).

2.2.6 E-waste

The growing global demand for electronic products has intensified the consumption of natural resources for their manufacture (Huisman et al., 2007; Mmereki et al., 2016; Tomita & Slotow, 2020). Information Communication and Technology (ICT) products, among many electronic appliances, are the fastest growing in the market, and older products rapidly become obsolete, escalating the generation of electronic waste (Awasthi & Li, 2017). The manufacturer of one mobile phone uses between 60 and 64 elements and metals that constitute between 50 and 60% of the product (Nuwer, 2014; Tansel, 2017). A study reported that, when compared to their counterparts, the Black middle class exhibits high consumption patterns, particularly regarding household

assets such as stoves, microwaves, televisions and other appliances, profiling the biggest consumers (Zondi et al., 2023). In 2022, global e-waste generation reached approximately 62 million tons. Of this total, an estimated 31 million tons consisted of embedded metals, 17 million tons were plastics, and 14 million tons comprised other materials such as minerals, glass and composites (Kuehr et al., 2024). E-waste constitutes the fastest-growing waste stream in South Africa; however, recycling rates remain notably low. Although an estimated 6–7 kg of e-waste is generated per capita annually, only about 360 000 tons per year are officially placed on the market (AST Recycling, 2022).

Despite its role in regulating transboundary movements of hazardous waste, the Basel Convention does not address the emerging environmental problems associated with the recycling of e-waste sufficiently (Oliveira et al., 2012; Mmereki et al., 2016). In recent years, developing countries have been recipients of waste originating from developed nations (Tomita & Slotow, 2020). The major problem with e-waste is that while its transboundary movement from affluent Western nations to transitioning and developing countries is for legitimate, second-hand product usage, it is due to the lack of consumer end-use responsibility and regulation (Roy et al., 2023). When second-hand electronic products reach these countries, particularly India and China, and are purchased by consumers, they rapidly reach the end of their useful life and contribute to electronic waste, and a significant amount is illegally dumped and forced into the informal sector (Breivik et al., 2014; Awasthi & Li, 2017; Liu et al., 2023; Fawole et al., 2023). About 14 million tons (22.3%) of e-waste were discarded, predominantly through landfilling, and the challenge in developing countries is the lack of adequate financial resources, which poses a significant barrier to the development of essential infrastructure, including sanitary landfills and recycling facilities (Kuehr et al., 2024; Faisal et al., 2025). Where e-waste is processed for recycling to extract valuable and scrap metals that serve as a source of inexpensive raw material, unsafe, informal methods are used to liberate the materials from each other by physical force where metals, fumes and aerosols are exposed at the same time, leading to severe health and environmental consequences (Van Schaik & Reuter, 2012; Tansel, 2017; Tomita & Slotow, 2020; Liu et al., 2023). Some of the elements found in e-waste are technology-critical elements, which refer to a group of materials that are gaining growing societal and economic importance due to their indispensable roles in both

existing and emerging technologies, and this makes e-waste the most sought-after type of recycling item by waste pickers (Schenck et al., 2019; Takyi et al., 2021).

2.2.7 Construction and demolition waste (C&DW)

Construction and demolition waste (C&DW) is one of the significant types of solid waste, as the economic development of any country is largely dependent on construction projects (Husnain et al., 2017; Shakirov et al., 2024). Construction waste refers to any material generated during construction, refurbishment, maintenance and demolition, whether from residential projects or large-scale commercial infrastructure developments. It typically includes packaging materials, debris from demolition, and surplus building supplies (Zhao, 2021; EMR recycling, 2023). According to Eurostat data of 2020, the European member states amounted to 2 153 million tons, of which 37.5% was from C&DW projects (Eurostat, 2023). Most C&DW items, including aggregate, bricks, tiles, plastic, timber, aluminium, glass and metals, can be reused for other purposes other than the original use, recycled, resold, or kept for future use. However, hazardous waste items such as latex paint, adhesives and chemical solvents need precautionary handling (Otasowie et al., 2024). South Africa faces growing challenges related to landfill space shortages, driven by the closure of older sites, rising operational costs, and constraints in developing new facilities. These challenges are compounded by the significant share of C&DW, which accounts for up to 30% (7.8 million tons) of the 26 million tons of municipal solid waste generated annually (GreenCape, 2022; Govender et al., 2023; Simon et al., 2025). Within the context of sustainable development, construction waste management should adopt an approach that balances economic, social, and environmental considerations (Spišáková et al., 2021). A study conducted in Surabaya, Indonesia, found that the impact of construction and demolition waste (C&DW) on sustainable development was quantified as 28.5% for the social dimension, 39% for the economic dimension, and 52.6% for the environmental dimension (Beatrix et al., 2024).

2.2.8 Household chemical waste (HCW)

Household chemicals refer to non-food substances that are commonly utilised within household environments, specifically engineered to facilitate sanitation, pest management, and overall hygiene maintenance (Rudd, 1970). The SANS 10234 provides the framework for classification and labelling of waste aligned with the

Globally Harmonised System (GHS) (SABS, 2008; RSA, 2013d). Many household chemical waste falls under Class 3 (flammable liquids), Class 8 (corrosive), and Class 6.1 (toxic substances) and need to be handled and treated as hazardous substances due to their nature. However, there is a lack of infrastructure (hazardous landfills) and programmes that support the *duty of care* to handle, store, transport, or dispose of waste in an environmentally sound way in communities and therefore are treated similarly to the general waste category. The amounts and significance of this disposal are poorly understood. Generally, it is assumed that amounts are small and therefore the risks of disposal are negligible, but are consequently found in landfill leachate (Alabi et al., 2023)

When evaluating the disposal of HHW, the conditions within the landfill must be acknowledged to determine the nature of the components and the likelihood of occurrence in leachate (Alabi et al., 2023). Household chemical waste has many terms by many authors and regions, including household hazardous waste (Environmental Protection Agency [EPA], 2019). Domestic hazardous waste, home-generated special materials, chemical waste, and general toxic waste, with a description of waste containing chemical composition in the household, with a potent ability to cause harm if not handled with care. Hazardous waste refers to waste that can ignite, undergo chemical reactions, explode under certain conditions, or have corrosive properties (EPA, 2019). The terms 'chemical waste' and 'hazardous waste' cannot be used interchangeably, because chemical waste constitutes a specific category of waste derived from discarded chemical substances, while hazardous waste is a broader classification encompassing any waste that poses a potential threat to human health or the environment (Purcell, 2024). The middle-income group generates the highest proportion of hazardous components in their waste compared to both lower- and higher-income groups (Zondi et al., 2023; Alabi et al., 2023). Factors like the weather and the season are known to affect how people purchase insecticides (Alabi et al., 2023).

The amount and significance of proper chemical waste disposal are poorly understood. With the lack of efficient waste separation strategies at households, these wastes are mixed with MSW and follow the general waste management handling, storage, transportation and disposal, which is mandated to local municipalities (Machete & Shale, 2015; DFFE, 2020). Mixed waste is classified as hazardous waste

in Annexure 1, section 2(b)(i) in the Waste Classification and Management Regulations (RSA, 2013d). However, its definition invalidates its inclusion of hazardous household-level waste. Mixed waste is described as general waste, excluding domestic waste, which contains waste or hazardous chemicals, and mixed, hazardous chemical wastes from analytical laboratories and laboratories from academic institutions in containers less than 100 litres (RSA, 2013d). Even when disposed of in smaller quantities, chemical waste can still be traced in landfill leachate, and factors such as temperature, humidity, barometric pressure and seasonal changes can influence the rate at which these substances are absorbed into the environment (Misra & Pandey, 2005; Alabi et al., 2023).

2.3 Landfill suitability and risk analysis

One of the persistent challenges in municipal solid waste (MSW) management in developing nations is the identification of suitable sites for waste disposal (Akinrogunde et al., 2019). Similar to many other developing countries, South Africa has experienced a recurring history of poorly sited, designed and operated landfill facilities (Department of Water Affairs and Forestry [DWAF], 1998). The landfill site selection process is often constrained by numerous environmental, social and political factors that must be addressed carefully to ensure successful implementation. As such, achieving a viable siting outcome requires not only technical and regulatory compliance, but also the support of decision-makers across municipal, governmental and environmental sectors, as well as public acceptance of the proposed landfill location (Torabi-Kaveh et al., 2016).

According to the Minimum Requirements for Waste Disposal by Landfill, site selection is influenced by three key considerations, i.e. economic feasibility, environmental suitability, and public acceptability (DWAF, 1998). The design phase is guided by Sections 6, 7, and 8 of the relevant legislation, which align with the outcomes of the Environmental Impact Assessment (EIA). The EIA establishes the procedural framework for application submission, interdepartmental consultation, and project approval, and its outcomes determine the appropriate authority for application submission, the extent of consultation with relevant government bodies, and the guidance provided to applicants on potential environmental impacts. These procedures aim to minimise risks to public health and prevent environmental

degradation (DWAF, 1998; RSA, 2014). Operational requirements are detailed in Section 10, which specifies daily procedures for the compaction and covering of waste (DWAF, 1998). Despite these frameworks, landfill siting remains a major obstacle for waste management planners due to the stringent criteria required for environmentally sound operations (Oyinloye & Fasakin, 2013). Several studies identify the variables influencing site selection, including land use, investment cost, proximity to surface water and aquifers, distance from urban settlements and transport routes, elevation, slope, soil characteristics, and geological composition (Oyinloye & Fasakin, 2013; Torabi-Kaveh et al., 2016).

According to Section 4(2) of the National Environmental Management: Waste Act 59 of 2008 (NEM:WA) Norms and Standards for Disposal of Waste to Landfill, landfills are classified into four main categories, which define waste acceptance criteria based on waste type and associated risk (RSA, 2013a). Class A landfills accommodate high-risk hazardous (Type 1) waste; Class B landfills are designated for moderate-risk (Type 2) waste, such as domestic, business, and packaging waste not containing hazardous substances or chemicals, as well as non-infectious waste, garden waste and expired consumer products. Class C landfills are intended for low-risk (Type 3) waste, including post-consumer packaging and used tyres, while Class D landfills accept low-risk inert (Type 4) waste, such as construction and demolition debris and uncontaminated excavated material (RSA, 2013a & 2013d).

A buffering distance between the landfill and the immediate environment can also determine the environmental and health implications caused a landfill. A landfill buffer zone constitutes an undeveloped area surrounding the landfill, designed to protect both the public and the environment from adverse effects. The buffering distance (BFD) between the landfill and groundwater supply wells plays a critical role in preventing contamination of drinking water by hazardous pollutants. Underestimating the buffering distance, particularly as leakage risks increase towards the end of a landfill's operational lifespan, can compromise drinking-water safety (Qiu et al., 2023). Buffer-zone dimensions vary according to regional, national and local regulatory frameworks, as they are established through site-specific risk assessments; consequently, there is no single global standard for landfill buffer zones.

2.3.1 Status Quo of the South African residential areas and waste management

The current spatial landscape of the South African residential areas continues to be shaped by the apartheid-era divisions and inequalities (Marutlulle, 2021). The Group Areas Act of 1950 and the Promotion of Bantu Self-Government (1959) demanded that different racial groups had to inhabit separate areas (Terreblanche, 2002), where white dominance was maintained in economic and residential centres, and other non-white groups (Black, Coloured and Indian South African groups) that were displaced and forced into under-resourced and underdeveloped designated townships in peri-urban and distant rural areas. (Sekhampu, 2013; Mapa et al., 2024) These disparities linked to the apartheid era laws which banned people of colour from receiving services offered to whites in the country, resulting in people from low-income areas such as townships receiving poorer municipalities than those in high income areas (Govender et al., 2011; Adeniran & Shakantu, 2022), still haunt and shape predominantly non-white communities to date.

The status quo is driven by alarming population growth, poverty, rapid urbanisation and poor service delivery. The diverse settlements, which were previously disadvantaged in South Africa, such as traditional, township and informal settlements, still do not have opportunities associated with the cities, not only because of their geographical location, but also materially and psychologically (Rameni & Madyira, 2019; Zondi et al., 2023). South African studies report that the average household size in townships is 3.1 people, with 28% of the community living in overcrowded conditions. Johannesburg, for instance, accommodates over 5 million people within an area of 1 643 km², serving as South Africa's economic hub and representing approximately 8% of the total population (Ma & Hipel, 2016; Makgato, 2024). There are 76 of the largest townships in South Africa, which alone constitute over a quarter of the South African population, exacerbated by the inter-migration due to their transition to peri-urban (Ngeleka, 2010). This has led to overcrowding in townships, resulting in increased waste and pollution, which affects service delivery due to limited and ageing infrastructure (Ngeleka, 2010; Mabunda, 2023). Although municipalities in South Africa have made significant progress in service delivery, townships continue to experience marked disparities – particularly in access to waste management services. Even three decades into democracy, Reconstruction and Development Programme (RDP) housing developments have not addressed the persistent poverty in these

areas effectively. Moreover, the housing structures and related infrastructure are often of poor quality and require increasing maintenance (Language et al., 2016; Kalina & Schenck, 2024). Impoverished communities in townships still face minimal to no waste collection, increasing vulnerability to exposure to airborne and waste-borne diseases (Makgato, 2024).

Informal settlements accommodate more than half of the urban poor in developing nations, representing approximately 61.7% of the urban population in African cities (UN-Habitat, 2015). Demographic pressures have led to the proliferation of informal settlements, which now constitute a significant component of the township landscape. Informal settlements refer to areas lacking secure land tenure rights, typically situated within the transitional zones between urban peripheries and rural regions. These settlements often develop illegally and are characterised by inadequate infrastructure, including limited access to roads, electricity, water and access to healthcare, education, and other social infrastructures that form part of the National Development Plan 2030 (Aydamo et al., 2020; Ojo-Aromokudu et al., 2020; Parikh et al., 2020). In South Africa, informal settlements also represent a continued economic separation and the government's failure to address injustices of the past, as housing is limited and slow, despite various governmental departments' drive to meet the increasing housing demand (Ojo-Aromokudu et al., 2020; Parikh et al., 2020; Mabunda, 2023). Backyard dwellings remain a widespread and rapidly growing form of informal settlement in township contexts, defined by self-contained apartments erected within the yards of formal residential properties, often constructed from corrugated iron or wooden material (Brown-Luthango, 2021; Nyakabawu & Schenck, 2025). Additionally, the informal settlements are usually excluded in geospatial data and other statistical data on sociodemographic are not widely available (Socio-Economic Rights Institute of South Africa [SERI], 2018).

2.4 Waste exposure routes

This section outlines the patterns of waste exposure within the environment and identifies the groups most vulnerable to these exposures.

2.4.1 Exposure to the environment

Environmental degradation resulting from inadequate and poorly managed waste disposal facilities is primarily characterised by the contamination of surface water, groundwater and soil through leachate infiltration (Njewa et al., 2025). Municipal landfills and open dumps are recognised as major sources of hazardous substances that pose serious risks to environmental integrity, wildlife and human health (Njewa et al., 2025). Hazardous landfill activities such as the co-disposal of industrial, medical and electronic waste with domestic refuse, improper leachate management, and uncontrolled gas emissions intensify environmental exposure (Oskina et al., 2024). These activities release toxic metals, persistent organic pollutants and volatile compounds into surrounding ecosystems, thereby contributing to long-term soil and water contamination as well as air pollution. The environment plays an essential role in sustaining public health, encompassing both living and working spaces (Marutlhule, 2021). It represents an interconnected system comprising biotic components such as plants, animals, and microorganisms and abiotic components, including the hydrosphere, lithosphere and atmosphere (Manisalidis et al., 2020). Environmental degradation arising from waste mismanagement has become one of the most pressing global challenges. An item is classified as waste once it is perceived to lack further use or value and is consequently discarded (Ali & Bella, 2016).

Waste poses significant environmental and public health threats primarily through human activities associated with its management. Globally, nearly half of all household solid waste is subjected to uncontrolled open burning each year, a practice undertaken by both communities and municipal authorities (Alam & Ahmed, 2013; Wiedinmyer et al., 2014; Krecl et al., 2020). Fires and explosions at landfill sites may occur due to human error, poor waste segregation, methane accumulation, or electrical faults, and are increasingly recognised as contributors to wildfires and air quality deterioration (Ibrahim et al., 2013; Jakhar et al., 2023). Exposure to landfill-derived pollutants occurs through multiple routes, including ingestion of contaminated food or water, dermal absorption, and inhalation of polluted air (Wiedinmyer et al., 2014). Moreover, hazardous waste runoff and airborne particulates can bioaccumulate within the food chain, heightening long-term ecological and human health risks. In marine environments, plastic debris contributes additional hazards, with organisms exposed through ingestion and entanglement (Krecl et al., 2020).

2.4.2 Exposure to the housing and health of residents near landfill sites

Housing quality and its surrounding environmental context represent key dimensions of environmental inequality. Poorly planned or informal housing is often located near landfills due to lower land values, urban sprawl, or lack of affordable alternatives (Mottelson, 2023). According to the WHO (2018), healthy housing is defined as shelters that promote holistic physical, mental and social wellbeing, and encompass not only the structural integrity of the dwelling, but also its capacity to protect physical health by providing protection against environmental elements and excess moisture, maintaining comfortable indoor temperatures and ensuring adequate sanitation, ventilation, illumination and road infrastructure (Bonney, 2007; WHO, 2018). Additionally, healthy housing offers sufficient living space. Despite the function of the house structure to provide a healthy living environment, the adverse effects of living in proximity to such areas are mainly influenced by the presence and activities of the disposal sites (Kaza et al., 2018). Much of the housing provided for the poor majority in South Africa during the apartheid era failed to meet the World Health Organization's (WHO) standards for healthy housing. Township dwellings were frequently characterised by environmental and health hazards, including the use of bucket toilets, asbestos roofing and lead-based paint (Mathee & Wright, 2014).

Housing is a critical determinant of health, and substandard living conditions represent a major public health issue (Kriger & Higgins, 2002). People living close to unsanitary landfills and burning areas are more prone to health and safety hazards (Mahajan, 2023). In recent years, about one billion people live in undesirable housing settings referred to as slums or informal settlements that lack a coherent urban strategy globally, especially within low-income communities, as affordable housing becomes scarcer for them (WHO, 2018; Rahelinina et al., 2024). Children are particularly vulnerable to household chemicals, as their frequent hand-to-mouth behaviour and ongoing physiological development increase their susceptibility to toxins. They may ingest up to five times more contaminated dust than adults, about 100 mg per day (Alabi et al., 2023). Informal settlements may face additional hazards, as they lack basic infrastructure and services, making them more prone to contamination from landfill leachate, flooding, intrusion by rodents and vectors, and diminished ambient air quality (Kriger & Higgins, 2002; Brahimi et al., 2019; Abubakar et al., 2022; Aydamo

et al., 2023; Mottelson, 2023; Grangxabe et al., 2023; Raheliniina et al., 2024; Ezell, 2025).

Whether at household level or from disposal sites, residents are exposed to conditions that impede their well-being, but the infiltration of housing into buffer zones around landfills increases direct exposure risks. Udofia et al. (2017) observe that adverse effects from solid medical waste are more frequently reported within households (4.8%), compared to those documented at community level in Ghana (2.7%), indicating the dangers of inadequate and mismanaged waste at household level. In addition to the open incineration of waste at disposal sites and illegal dumps, waste collection trucks are often poorly maintained and left uncovered, releasing exhaust fumes and generating dust during transportation. From a social perspective, these practices expose nearby communities to significant discomfort and potential health risks (Deffinika et al., 2021; Abubakar et al., 2022; Sagan & Mach, 2025). Due to the lack of reliable data, emissions from the open burning of household solid waste are often omitted from emission inventories at regional, national and global scales (Wiedinmyer et al., 2014).

2.4.3 Waste exposure to waste generators

Establishments and individuals that produce waste, including healthcare centres, industrial plants and residential households, are directly exposed to various risks associated with the handling, storage and initial disposal of their waste. South African legislation describes a waste generator as any person whose actions, production processes, or activities, including waste management activities, result in the generation of waste (RSA, 2013d). This includes commercial establishments, government institutions, healthcare facilities, and industrial firms or residents whose actions first make waste subject to regulations, even if they are not the ones who physically produce it. Waste generators produce various types of waste, depending on their activities, which may be classified as hazardous, such as infectious, chemical, or radioactive waste, and non-hazardous, commonly referred to as general waste and the extent to which each type of generator is regulated is dependent upon the amount of hazardous waste each generator produces (DEFF, 2020b) which within the South African context is 20 kg per day. Hazardous waste streams are prioritised not only by their volume, but also by their toxicity and the environmental risks posed by their

treatment and disposal. Substances such as asbestos, oils, mercury, lead, Healthcare Risk Waste (HCRW), and persistent organic pollutants (POPs) are of particular concern due to their high toxicity and potential environmental impact (DEFF, 2020a). Only about 15% of hazardous waste is produced from healthcare activities, but this is one of the significant contributors, due to the nature thereof, of waste (Janik-Karpinska et al., 2023; WHO, 2024e).

The accelerated industrialisation generates employment, reduces youth restiveness, increases per capita income, and enhances both domestic and foreign revenue, especially in major cities. However, industrial and commercial producers are vulnerable to exposure to industrial waste, usually in the form of chemicals or hazardous substances, if not correctly labelled or managed (Olaoke & Poopola, 2017). One of the most significant dangers associated with hazardous waste is its often-invisible nature, as many toxic substances cannot be detected by the naked eye (Safelec, 2024). In South Africa, coal-fired electricity generation is the dominant source of hazardous waste, with flying ash alone representing about 66% of the total and bottom ash contributing an additional 9%. Collectively, these by-products account for roughly three-quarters of all hazardous waste produced (DEFF, 2020a). Compliance, training and education of workers in sectors that generate hazardous waste are essential for safeguarding both environmental quality and human health. Inadequate storage and handling of such waste can result in serious accidents and exposure incidents. Improper disposal practices, leaks, or spills may further lead to chemical exposure, fires, explosions and long-term environmental contamination, thereby posing significant risks to workers, surrounding communities and ecosystems (Safelec, 2024). A study conducted in a hospital facility in Cyprus reports that most challenges in the management of infectious medical waste (IMW) arise from non-compliance with established directives, legal frameworks and regulatory guidelines. Survey findings further indicate that 82.9% of respondents acknowledged their essential role in managing infectious waste, while approximately 70.7% of participants believed that failure to properly handle infectious waste would lead to serious consequences. Poorly managed hazardous waste not only compromises workers' health but may also cause their productivity to decline (Olaoke & Poopola, 2017; Janik-Karpinska et al., 2023).

2.4.4 Waste exposure to waste collectors

Waste collection is a necessary activity all around the world for inhabitants' health and living conditions (Gutberlet & Uddin, 2018). Waste collectors collect accumulated solid waste, organic waste and compost, as well as recycle goods and multiform items from residential areas, business centres, industrial companies and public parks, especially in urban areas (Salvaraji et al., 2020; Tshivhase et al., 2022). In South Africa, adequate collection of waste is the initial step in fulfilling the constitutional right of citizens to a healthy environment and preserving the environment for future generations (RSA, 1996). However, waste collectors are among groups that work under stringent conditions, including workers in facilities producing toxic and infectious material (Alam & Ahmade, 2013; Nor et al., 2019). In many developing countries, MSW is handled manually in its mixed form by cheap, unskilled labourers with limited protective gear and limited knowledge of the risk involved in handling solid waste (Abd El-Wahab, 2014; Ephraim et al., 2021).

Waste-collection workers are at risk for diseases resulting from exposure to various work hazards and fatal and nonfatal occupational accidents (Awad, et al., 2013). The International Labour Organisation (ILO) reports that 270 million accidents and diseases related to occupation occur every year, and about 3 400 000 are disabling, work-related injuries (ILO, 2005; Ephraim et al., 2021). Some of the many duties carried out by an MSW collector that expose them to risks include sweeping and picking waste, lifting and pushing of heavy waste bags, and emptying of waste bins into waste vehicles without hydraulic lifts (Tshivhase et al., 2022). Waste collectors are prone to injuries. Workers with open wounds or skin diseases, such as lesions on the skin or on the mucous membrane of the mouth, nose and eyes, provide entry sites into the human body for biological hazards (Rachiotis et al, 2012; Poole & Basu, 2017; Rachiotis et al., 2016; WHO, 2017). Reports indicate that the faecal-oral route of exposure can be contributed to by improper work practices, such as smoking and eating during work without adhering to universal sanitary precautions (Rachiotis et al., 2016).

According to the International Labour Organisation and the Republic of South Africa's Constitution (RSA, 1996), all employees have a right to work in an environment that is free of hazards that are detrimental to their health (ILO, 2005; WHO, 2017). To

minimise the risk of infection, one or more control measures should be implemented to interrupt the transmission chain. The proper and consistent application of these measures helps to safeguard both the physical and mental well-being of workers, ensuring their health is maintained at optimal levels (Soni et al., 2025). Carrying out medical surveillance is highly recommended in order to establish and maintain the positive physical and immune state of workers and, in contrast, using personal protective equipment is the least effective control method in the hierarchy; yet it is widely practised (NES Global, 2019; Salvaraji et al., 2020).

2.4.5 Waste exposure to waste pickers and recyclers

Contemporary global socioeconomic challenges, including the lack of opportunities, unemployment and poverty, have contributed significantly to the proliferation of informal sectors as a means of survival (Etim & Daramola, 2020). This trend has been pronounced particularly post the COVID-19 pandemic (International Labour Office [ILO], 2018; Babaola & Maila, 2021; Sepadi & Nkosi, 2022). The term ‘waste picker’ comes from a provisional consensus that emanates from the First World Conference of Waste Pickers held in Colombia in 2008 and describes individuals who collect reusable and recyclable material, whether segregated or mixed from residential and commercial waste bins, large generators, dumpsites and public spaces, to repurpose them or channel them into recycling as a means of livelihood (WIEGO, n.d). Waste picking and recycling form part of the incentives that drive the informal sector. Despite the health and environmental effects of landfill sites on the inhabitants in the vicinity, waste dumpsites are still beneficial for their livelihood (Ololade et al., 2019; Akinrogunde et al., 2019; Tomita & Slotow, 2020). The Department of Environment, Forestry, and Fisheries recognises that waste pickers perform strenuous manual duties in the harsh weather conditions of South Africa, influenced by climate change (DFFE, 2025).

Recycling can be categorised into two forms, formal and informal, which differ in terms of institutional support, access to resources, and the extent to which the health and safety of participants are prioritised (Lofty, 2024). Formal recycling, governed and regulated by institutional or governmental bodies, adopts a systematic approach to waste management within an environmentally safe and sustainable framework where waste segregation from source is upheld and both public and private entities are

involved (Rautela et al., 2021; Fawole et al., 2023). Formal recycling is conducted in industrialised countries, but on a smaller scale (Adam et al., 2021). It is usually rare in developing countries such as Latin America, Africa and the Middle East, and well adopted in most European countries (Austria, Wales, Germany, Belgium, Netherlands, Denmark, Slovenia, Northern Ireland and Switzerland), followed by some Asian countries (Taiwan and South Korea) (Tomra, 2024; Lofty, 2024).

Informal recycling is predominantly common in developing nations. It operates outside the formal regulations and typically relies on primitive methods such as open burning and dismantling for the extraction and recovery of valuable waste items, and which release and expose the environment and workers to POPs, heavy metals and acid leaching (Cesaro et al. 2019; Okwu et al. 2022; Ghulam & Abushammala 2023; Fawole et al., 2023). In South Africa, informal waste pickers are found in urban, peri-urban and rural areas (Littlewood et al., 2022). Waste pickers rarely have PPE and, even where provided by landfill management, compliance is very low (Schenck et al., 2019). The waste is processed manually, such as dismantling with bare hands, open burning, and acid digestion to extract valuable metals from electrical and electronic goods that often contain large amounts of plastic materials (Cesaro et al., 2019; Moeckel et al., 2020; Okwu et al., 2022). A study conducted in Ghana reported that the most common activities of waste pickers on an average of four days a week are the burning of e-waste (34%), burning of wires (25%), removing covering off wires (10%), sorting e-waste (9%), and dismantling of e-waste equipment (6%) (Takyi et al., 2021). These methods usually fail to recover valuable materials efficiently, resulting in significant resource loss (Abalansa et al., 2021; Lofty, 2024). Due to fierce competition for valuable recyclables, waste pickers are often pushed to engage in increasingly risky practices (Schenck et al., 2019).

2.5 Waste Impacts on the environment and health

In this section, the components and contaminants of different solid waste categories are presented in tabular form, along with their specific environmental and health impacts. The general effects of waste on environmental quality and human health are also outlined.

Table 1: Waste categories, their composition and associated environmental and health impacts

Waste type	Components/Contaminants	Environmental/Health Impact	Authors
E-waste	Base metals: copper (Cu), tin (Sn), Special metals: lithium (Li), cobalt (Co), indium (In), and antimony (Sb) are found in rechargeable batteries, LCDs of mobile phones and laptops, hard drives, and mobile phones. Precious metals- silver (Ag), gold (Au), and palladium (Pd) are found in switches and solders, multilayer capacitors, and integrated circuits. Metalloid selenium (Se), Silicon (Si), and Germanium (Ge), which exhibit semiconducting properties, are used in circuit boards, solar cells, and light meters. Heavy metals- arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg) are found in circuit boards, cathode ray tubes, displays, and cables. Organic compounds and fumes- polychlorinated biphenyls (PCBs) found in transformers, hydraulic fluids and lubricants, polybrominated biphenyls	Environmental impact - Seeping of elements from leaching and storm water runoffs into the ground can contaminate surface and groundwater. - Release of greenhouse gases and damage to the ozone layer, which contribute to climate change. - E-waste elements can alter soil properties and soil structure, influencing nutrient availability, water retention, and microbial activity, which impact plant development, biome composition, and overall fauna. - Poisoning animals (domestic, marine, and wildlife) with high levels of toxins, trapping, injury, and direct inhalation or ingestion can lead to depopulation. - Reduced biodiversity, an unstable ecosystem, and disruption of the food chain. Health impact - Vomiting, diarrhoea, and stomach ulcers.	(Shao et al., 2008; Blass et al., 2006; Chancerel et al., 2009; Liu et al., 2009; ; Xu et al., 2012; Needhidasan et al., 2014; Mmereki et al., 2016; Cayumil et al., 2016; Twagirayezu et al., 2021; Gwimbi et al., 2020; Roy et al., 2022; Adam et al., 2021; Ankit et al., 2021; RebootTech, 2024; ; Fawole et al., 2023).



	(PBBs) are flame retardants in synthetic fibres and moulded plastics, poly-brominated diphenyl ethers (PBDEs) flame retardants used in casings, cables and printed circuit boards, brominated flame retardants (BFRs), polycyclic aromatic hydrocarbons (PAHs) found in plastic material of e-waste; and Chlorofluorocarbons (CFCs) are used in refrigerants and insulating foams. Polyvinyl chloride (PVC)- found in cables and casings.	- Chemical compounds such as BFRs and PVC trigger allergies. - Injuries from the dismantling of e-waste - Damage the reproductive system and cause birth abnormalities (DNA alterations). - Hormonal disturbances and damage to the neurologic system (impaired nerve signalling). - Damage and diseases of organs, namely, the skin, eyes, thyroid, lungs, liver, heart, stomach, spleen, and kidneys.	
Health Care Risk Waste (HCRW) from health care centres	Infectious waste- contaminated with blood and other body fluids. Pathological waste- human tissues, organs, or fluids, body parts, fetuses, unused blood products. Pharmaceutical waste- expired or unwanted pharmaceutical products. Cytotoxic waste- containing chemicals (laboratory reagents, film developer, expired or no longer needed disinfectants, mercury-filled thermometers).	Environmental impacts - Air pollution due to the emission of greenhouse gases. - Alteration of water quality by dumping expired, deteriorated, and/or excess medications and substances used in any type of procedure. - Direct impact on water and soil quality due to atmospheric contamination with corrosive substances, which become incorporated into the water cycle and are used for soil treatment.	(Udofia et al., 2017; Nemathaga et al., 2008; Ghali et al., 2023; Trujillo-Moscoso & Paredes-Schmidt, 2024).



	Radioactive waste- containing radioactive substances (unused liquids from radiation therapy or laboratory studies). Sharps waste- Used or unused needles, syringes with needles, knives, blades, broken glass. General waste- any biological, chemical, radioactive, or physical hazard (plastic, cardboard, paper, food scraps).	Health impact - Injury and spread of disease from handling or contact with sharp waste. - Exposure to infectious biological agents from blood-contaminated and soiled waste, skin penetration, direct skin contact, ingestion, or inhalation, such as hepatitis A, B, and C, and HIV. - Some of the health impacts from exposure to hazardous hospital wastes include mutagenic, teratogenic, and carcinogenic damage, respiratory damage, central nervous system effects, and reproductive system damage. - Accumulation of pathological waste in unsuitable locations is an eyesore and traumatic.	
Absorbent hygiene products waste (Menstrual hygiene waste)	Polyethene and polyester Containers and absorbents- menstrual cups, cotton fibres, and cloths used to hold blood and bodily secretions. Pesticides- atrazine, pyrethrum, and procymidone, which may also originate from natural fibres like cotton.	Environmental impact - Air pollution emission of potentially toxic monomers and/or additives from the polymer network. - Leaching of microorganisms and toxins into waterways. - Blockage of the sewage drainage system.	(Udofia et al., 2017 Kaur et al., 2018; Elledge et al., 2018; Anand et al., 2022).



	Adhesives contain hazardous chemicals like methyl dibromo glutaronitrile. Fragrances and antibacterial chemicals- containing organochlorines Paper- toilet paper and paper wraps contaminated with blood and bodily secretions.	- Compromised aerobic and anaerobic digestion in sewage ponds and pit latrines. Health impact - Urogenital infections: infection of the lower genital tract and endotoxin accumulation in the menstrual fluid. - The psychosocial impact that menstrual hygiene waste can have on adolescents and unprivileged societies.	
Household pharmaceutical waste (human and livestock)	Human pharmaceuticals - Used or expired pills (e.g. painkillers/ analgesics, anti-allergics, antibiotics, oestrogen, and antineoplastic). - Used or expired ointment (e.g. creams, medicinal oils, and gels). - Used or expired liquid (e.g. cough syrups and solutions). - Used or unused sharps (e.g. needles, syringes). - Wellness products (e.g. slimming pills, mixtures, and herbs). - Health-monitoring devices (e.g.	Environmental impact - Chemical contamination of sewage water and additional expenses in purification. - Water contamination – Ecotoxicity, especially for pharmaceuticals with high water affinity/solubility, through drainage systems and run-offs into nearby water sources. - Soil contamination through fertilisation with raw animal manure and gradual degradation from direct land disposal.	Constantino et al.,2020; Manyi-Loh et al., 2018; Wood et al., 2015; Schoeman et al., 2015; Magagula et al., 2022; OECD, 2022)



	autoinjectors, inhalers, and nebulisers). - Contaminated supplies- empty liquid or pill medication, soiled bandages, masks, and gloves, and utensils that were in contact with medications and biological materials. Veterinary pharmaceuticals - Unused, expired, and surplus medications in the form of liquid drops, powder, or capsules (e.g. antibiotics, antiparasitic, anti-inflammatory, vaccines, sedatives, and hormone-inducing medication). - Used or unused sharps (e.g. needles, syringes, scalpels). - Personal Protective Equipment (PPE) (e.g. gloves, masks, and bandages that have become contaminated with medicines or other biological materials).	- Air pollution by dust contaminated with antibiotics from farms and emissions from waste burning at sites. - Antibiotics can also lead to mutations in animals. Health impact - Teratogenic, drug hypersensitivity reactions, mutagenic, reproductive disorders, nephropathy, hepatotoxicity, and carcinogenic effects in animal and human populations. - Humans are exposed to pharmaceutical residues by drinking contaminated water or ingesting contaminated food, such as fish, dairy and meat. - Accidental poisoning in children due to improper storage and disposal. - Disruption of the normal flora of the intestines through direct ingestion or contaminated water, food and products. - Exposure to endocrine disruptors is linked to reproductive and endocrine issues (e.g. infertility, certain cancers, diabetes) and may also affect the	
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		immune, cardiopulmonary, and nervous systems. - Antibiotic resistance in both humans and animals affects the immunology of the body system.	
Absorbent hygiene products waste (diapers)	Inner and outer layer- Propylene (PP), polyethylene (PE), and viscose rayon. Acquisition and distribution layer (ADL)- cellulose-based fibres such as cotton and wood pulp. Absorbent core- Sodium polyacrylate (SAP), Polyacrylate acid (PLA), and protein-based fibres). Outer layer- Elastics, Propylene (PP), polyethylene (PE). - Faecal and urine components after usage.	Environmental impact - Air pollution from urine and faeces exposure, biodegradation, and burning. - Leaching organic compounds into the groundwater and soil. - Animal gastrointestinal issues and infections from ingestion of non-biodegradable polymers and human pathogens (bacteria, viruses, parasites and helminths) from faeces and urine. - Global warming potential resulting from emissions of (CO₂, CH₄ NO_x) in production and disposal. - Ozone depletion of the stratospheric layer. - Freshwater eutrophication and ecotoxicity. - Terrestrial acidification and ecotoxicity- SAP and PP are the main contributors to these impacts.	Plotka-Wasyłka et al., 2022; Chitaka et al., 2025; Tesfaye et al., 2019; Kordecki et al., 2023; Schenck et al., 2023).



		- Soil biological and chemical contamination that disrupts the biodiversity of soil microbiota. Health impact - Waterborne diseases- microbial contamination of drinking water can cause diseases such as diarrhoea, cholera, typhoid, hepatitis A, and E. coli infections. - Vector-borne diseases- diaper moisture and soiled waste may act as food for various vectors, such as flies, mosquitoes, which transmit disease (e.g. malaria, dengue fever, yellow fever). Diapers contain human faeces, which can harbour pathogenic viruses, bacteria, and protozoa during direct contact.	
Rubber and Tyre waste	Used vehicle rubber components may include tyres, body seals, suspension system elements, wires, and seals. Natural rubber- harvested from rubber trees. Synthetic rubber- styrene-butadiene	Environmental impact -- Spontaneous ignition- they are highly flammable and can pose a fire hazard when stored in heaps. - Air pollution from the emissions of hazardous gaseous emissions (CO, CO₂, SO_x), including thick black smoke	(Harrison-Obi, 2019; Czarna-Juszkiewicz, 2023; Murphy, 2023; Hashamfirooz et al., 2025).



	rubber and polybutadiene rubber are processed from chemical reactions. Silicon dioxide (SiO₂)- enhances the anti-crack strength. Plasticisers- consist of polycyclic aromatic hydrocarbons (PAH), increase weight, durability, and rolling resistance on various surfaces. Sulphur- added during the vulcanisation process for strength and elasticity. Metals- steel is used to preserve the correct shape and stiffness of the tyre. Textile- nylon and polyester are used for the reinforcement of the rubber.	into the atmosphere during the burning process. - Due to their large sizes, they take up too much land in landfills and anywhere they are disposed of, and do not decompose. - When in contact with leachate, it can release heavy metals and organic compounds that contact the ground or surface water and disrupt ecosystems. Health impact - Burning releases PAHs and particulate matter, which are carcinogenic to humans. - Stagnant water or leachate in waste tyres is an ideal breeding ground for vectors such as mosquitoes that transmit diseases such as malaria, encephalitis, and Zika virus. Tyre fires are difficult to extinguish and can release harmful gases for months, affecting the respiratory health of surrounding communities. - Light irradiation, ambient temperature, and ventilation rate may have an impact on the chemical exposure from	
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		crumb rubber, which mostly children may be exposed to during hand-to-playground contact, leading to poisoning.	
Construction and demolition waste	Inert construction waste- includes non-reactive and non-decomposable waste such as concrete slabs, bricks, graphite rocks, sand, and ceramic and cement. Non-inert construction waste- includes organic and non-organic waste with varied reactivity, such as wood planks, plastic pipes or packaging, broken or cut-out window glass, and insulation material. Metal waste- construction metals include congregated iron sheets, steel nails and pipes, copper wiring and aluminium. Hazardous waste- spilt or damaged materials and chemicals containing polycyclic aromatic hydrocarbons (PAHs) or inherently harmful, including asbestos, vanishes, paint, adhesives, chemical solvents and sealants.	Environmental impact - Emission of toxic fumes and greenhouse gases. - Contributor to global warming by releasing greenhouse gases such as CH₄, CO₂ and CO. - Takes up too much land in landfills and anywhere they are disposed of, and most components do not decompose. - Contribute to the depletion of soil quality in the immediate environment. Health impact - Inhalation of suspended particulate matter (PM) from construction dust in the air can lead to long-term respiratory diseases and increase the risk of premature death in waste pickers, waste collectors, and residents. - Noise and vibrations from heavy machinery, transportation, and disposal can contribute to discomfort and hearing loss for those in the vicinity.	(ETM Recycling, 2023; Sagan, 2018; Otasowie et al., 2024).



		- Hazardous waste such as asbestos is associated with asbestosis, and some construction waste contains carcinogenic PAHs.	
Plastic waste	Polyethene terephthalate (PETE) used in water and soft drink bottles may contain acetaldehyde and xylene. Polyvinyl Chloride (PVC) used in plastic pipes, cabling insulation, and roof sheeting may emit polychlorinated dibenzo-dioxin, Polychlorinated dibenzofuran, vinyl chloride and lead (Pb). Polypropylene (PP) used in ropes, bottle tops, and food tubs may emit carbon monoxide (CO) and carbon dioxide (CO₂). Polystyrene (PS) used in plastic cutlery may emit polycyclic aromatic hydrocarbons (PAHs), styrene and carbon dioxide (CO₂). High-density polyethene (HDPE) used in shampoo bottles, milk cartons, and cleaning agents' containers may emit acetone and benzaldehyde. Low-density Polyethene (LDPE) used in	Environmental impact Air pollution – especially when burned, plastic toxins can be emitted and reach the atmosphere, and contribute to climate change. Water pollution affects surface water bodies, and microplastics leach into the groundwater, where the groundwater is the main source of drinking water supply. Microplastics affect marine animals. Soil pollution reduces soil quality and plant growth. Climate change increases greenhouse gases, causes impacts on ozone production, acidification and global warming. Health impact Headaches, weakness, dizziness, nausea anaemia. Irritation of the eyes, skin and nose.	(Tesfaye et al., 2025; Zhang et al., 2021; Gwimbi et al., 2020; Lomonaco et al., 2020; Royer et al., 2018)



	plastic bags and food wrappings may emit CO ₂ , toluene, ethylene and methane (CH ₄).	Respiratory– coughing, asthma, pulmonary oedema, shortness of breath, suffocation, erythema. Neurological system – mood changes and depression, nerve impairment, slurred speech, decreased consciousness, limits brain function, and causes permanent brain damage. Damage and cancer of the lung, thyroid, kidney, liver and eyes.	
Organic waste	Food waste Avoidable food waste: expired, spoiled, or leftover food, e.g. cooked meals, fruit, vegetables, grains, meat, dairy products. Unavoidable food waste: during and after food preparation, e.g. vegetable peels, eggshells, and bones. Biodegradable packaging waste Paper wraps Office paper Card boxes Animal farming waste Urine Dung Blood Condemned the whole carcass	Environmental impact - Eutrophication contributes to the production of algae in fresh waters. - Greenhouse gases: CO₂, H₂S, methane (CH₄), Nitrous oxide (N₂O), and particulate matter (PM_{2.5}) emitted from mainly food and manure. - Climate change: glacial melting in the Arctic Circle. - Desertification, especially in Africa, and West Coast Forest fires. - Microbial contamination of drinking water sources (surface and groundwater). - Ammonia emissions from animal droppings and decomposition cause	(Utah State University, n.d.; Rudziak et al., 2023; & Muth, 2021; Kooiman et al., 2023)



	Condemned material or trimmings Garden waste Pruned branches Grass cutting Weeds and leaves	Health impact - Nutritional deficiencies in populations in need of food. - Spread of food-borne diseases from improper food waste management. - Respiratory problems from the inhalation of gases, such as those from decomposing organic matter. - Spread of diseases, e.g. Listeriosis, Leptospirosis, Salmonellosis, Brucellosis and Vibriosis, from animal excreta and waste carcasses.	
Chemical waste	By-products of manufacturing processes (industrial spills/leaks), discarded used materials, or expired or discarded unused commercial products of: Household detergents/solvents (e.g. oven and drain cleaners, wood and metal polishes, ceramic cleaners, and bleach). Automotive products (e.g. motor oil, fuel additives, automotive batteries, transmission and brake fluid, antifreeze). Pesticides, insecticides, and herbicides (e.g. rodent and vector pests and baits,	Environmental impact - Flammable or reactive HCWs can release toxic fumes or even explode when disposed of together in a compartment. - Contributes to landfill spontaneous fire and wildfires. - Chemical contamination of ground and surface waters, ruining drinking water and killing fish and wildlife. Health impact - Fatigues and headaches.	(Alabi et al., 2023; EPA, 2019; Gulma, 2025; New Hampshire Department of Environmental Sciences, 2020; Singh, 2025).



	weed killers, moth repellents, and pet care products. Painting supplies (e.g. adhesives, oil or enamel paint, latex or water paint, paint strippers, and thinners. Flammable products (e.g. compressed gas cylinders, paraffin, polish, and cigarette butts). Miscellaneous (e.g. thermometers, fluorescent light bulbs, discarded PVC, and computer components).	- Irritation of the eyes, respiratory tract, and skin. - Corrosive HCW, such as acids and aerosol burns from acids and exploding aerosols, can cause injuries. - Reproduction conditions: - Development conditions: prenatal exposure and childhood are also vulnerable to neurotoxic and other effects. - Neurodegenerative diseases.	
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2.5.1 Air pollution (indoor and outdoor)

Air pollution consists of a mixture of harmful substances originating from both human and natural sources (NIEHS, 2025a). Air pollution from disposal sites (landfill emissions, dust and waste burning) forms part of the broader category, ambient or outdoor pollution, which also includes traffic-related pollution, wildfire smokes and volcanic eruptions, which are problematic in urban areas (Pan American Health Organisation [PAHO], 2018). Air pollution in a landfill can instantly be identified by a brown haze or fire smoke in the area. However, other air pollutants may not be visible, but their pungent smell confirms their presence (National Institute of Environmental Health Sciences [NIEHS], 2025b).

About 92% of the world's population is exposed to ambient air pollution levels that exceed World Health Organisation recommended limits (WHO, 2017; Coker & Kizito, 2018). In South Africa, air quality is the second-greatest environmental concern after water quality and scarcity, contributing to an estimated 25 800 premature deaths annually (DFFE, 2025). Although air quality in high-income countries such as the United States of America has generally improved over recent decades, the persisting impacts of particulate matter emissions remain a global public health concern even at low concentrations (PAHO, 2018; Njoku et al., 2019). South Africa has also experienced some improvements in air quality over the years through inventory; however, particulate (PM₁₀ and PM_{2.5}) matter is still a potent pollution constituent, leaving many South Africans to continue to breathe air that may be detrimental to their health and well-being (DFFE, 2025).

Indoor air pollution is a significant problem in low-income households and those situated near disposal sites, mainly resulting from the inadequate or poor infrastructure (Language et al., 2016; WHO, 2024d). Globally, about 2.1 billion people are without clean fuels and technologies and use solid fuels (wood, dry crop waste, dung, charcoal and solid waste) and kerosene in open fires, fireplaces and inefficient stoves for cooking and heating in their households (IEA, IRENA, UNSD, World Bank, WHO, 2024d; WHO, 2024b). In addition to heating methods, studies report that the presence of mould, lead and radon exposure in poor ventilation, including lifestyle choices such as tobacco smoke and electronic cigarettes, contributes to the presence of indoor air pollution (NIEHS, 2025b; Liu et al., 2025). A study designed to evaluate particulate

matter associated with residential areas in Mpumalanga revealed that residents were exposed to increasingly high respirable particulate matter within the indoor environment compared to ambient concentrations (Language et al., 2016). However, household air pollution remains the predominant form in African countries in general, while ambient air pollution has increased significantly in recent years (WHO, 2024b).

2.5.2 Water pollution

Rapid population growth and subsequent increase in waste have numerous negative impacts on water resources in terms of quantity and quality (Deffnika et al., 2021). The WHO and UNICEF Joint Monitoring Programme reports highlight that approximately 2 billion people lack access to safely managed drinking water supplies, and 3.6 billion people lack adequate sanitation services (WHO/UNICEF, 2021). Furthermore, 785 million people globally still lack access to clean and reliable drinking water (United Nations, 2019; Aydamo et al., 2022). Studies confirm that the removal of chemicals, pharmaceuticals, and their metabolites from contaminated water bodies has become increasingly costly for water treatment facilities and management programmes (Fernández et al., 2014; Shraim et al., 2017; Nieto-Juárez et al., 2021). A study conducted in South Africa also revealed that traces of anti-retroviral drugs (ARVs) were found in both surface water bodies (Bouwman et al., 2020) and water treatment plants; however, studies conducted in South Africa have not indicated the challenges involved in the clean-up of such products in water intended for human consumption.

Irregularities in waste collection practices are a significant driver of marine pollution, and the lack of properly engineered landfills further exacerbates environmental risks. Leachate produced from unsanitary landfills can infiltrate groundwater systems, posing long-term contamination problems as aquifers require extensive time for natural recovery (Deffnika et al., 2021). Ammonia derived from the landfill leachate within landfills will migrate through the soil horizons, where it is gradually converted into nitrite and nitrate, a process that contributes to algae production in surface waters. Excessive algal growth adversely affects aquatic populations in lakes by reducing light penetration into the water column (Danthurebandara et al., 2013; Gwibi et al., 2020). It is estimated that 192 coastal nations collectively produced 275 million metric tons of plastic waste, of which approximately 12.7 million metric tons ultimately entered marine ecosystems (Jambeck et al., 2015; Abubakar et al., 2022). Over time, the

plastic materials degrade into microplastics, which are consumed by marine species, thereby threatening aquatic ecosystems (The Green Guardian, 2023).

2.5.3 Soil pollution and plant health

The soil is one of the most important components of the biosphere, as it supports the majority of living organisms. Soil pollution refers to the introduction of foreign substances that alter the soil's physical and chemical composition. In a landfill site setting, soil contamination often occurs when pollutants such as hazardous chemicals and heavy metals leach into the soil (Njewa et al., 2025). Acid rain, which is an effect of environmental pollution, also causes secondary contamination of soil (Hassan Al-Taai, 2021; Panneerselvam et al., 2022). Soil is a non-renewable resource whose loss and degradation are not recoverable within a short period of time, and its health affects the food we eat, the water we drink, the air we breathe, and the health of all living organisms (FAO, 2018; Njewa et al., 2025).

South African studies have reported the contamination of soils near landfill areas; however, the impacts on local communities have not yet been properly established. A study conducted in the Illuvo DSW landfill in KwaZulu-Natal sampled soil in all cardinal directions of the site and found that heavy metals, particularly cadmium (Cd), chromium (Cr), lead (Pb) and zinc (Zn), exhibited higher concentrations in soil than water samples in nearby streams (Adu & Aneke, 2025). The study that profiled soil from the Bloemfontein Southern landfill reported that the mean heavy metal concentrations were below normal; however, chromium (Cr) was 150% from upper horizons and posed a potential risk for the near-surface environment (Mavimbela et al., 2019). Another study that was conducted in Roundhill landfill, Berlin, Eastern Cape found chromium (Cr), copper (Cu), magnesium (Mn), nickel (Ni), cobalt (Co), vanadium (V), zinc (Zn), arsenic (As) and iron (Fe) to be above WHO and DEA permissible limits (Nyika et al., 2019). Heavy metal contamination of soil reduces healthy soil flora (bacteria, fungi and actinomycetes), faunal (nematodes, insect larvae, earthworms and insects), and burrowing animal populations (moles, rats, badger, rabbits and squirrels) by reducing their population and disrupting their diversity and activities (Panneerselvam et al., 2022), ultimately having an impact on the growth of indigenous plants in the affected areas. Soil microbial properties such as air

circulation and enzyme activity are influenced by soil pH, organic matter and chemical properties, which are affected by soil contamination (Stefanowicz et al., 2020).

Soil contamination increases salinity, nutrient loss and food contamination. The loss of soil fertility, which ultimately contributes to poor plant production, is a significant agricultural problem that affects both subsistence and commercial farmers (Njewa et al., 2025). One of the most detrimental effects on plants is the suppression and eventual destruction of root development and vegetation cover, resulting from anaerobic soil conditions caused by elevated concentrations of sulphides that laterally leach from landfill sites (Danthurebandara et al., 2013; Panneerselvam et al., 2022). Chemical constituents such as Zn, Cd, Pb, As and certain POPs in soil can accumulate in crops (leafy vegetables, tubers and legumes), depending on soil chemistry, with consequent dietary exposures through the food chain (Rezapour et al., 2018).

2.5.4 Animal health and productivity

Waste causes great harm to the terrestrial and marine organisms, regardless of size (Sadan & De Kock, 2021). Solid waste presents a wide range of environmental pollutants such as natural toxins, pesticides, heavy metals and microplastics, which can potentially be harmful to animal health (Poppenga, 2000; Gwimbi et al., 2020; Sadan & De Kock, 2021; Kordecki et al., 2023; Abdullah & Abdeen, 2022). Environmental toxicants are defined as chemicals, man-made or naturally occurring, that are released into the environment because of human activities and that pose a direct threat to food animal health and productivity, or that potentially contaminate animal products intended for human food consumption (Poppenga, 2000; WHO, 2024d). The disposal and excessive environmental accumulation of human waste (including excreta, urine and other bodily fluids) through disposal nappies, sanitary pads and open defecation can facilitate the proliferation of antimicrobial resistance (AMR) genes and the emergence of novel pathogens posing risks to vulnerable and endangered wildlife populations (Kordecki et al., 2023; WHO, 2024d). Diseases like plague that are associated with cellular and metabolic waste exhibit distinct characteristics in its many forms, and all share an epidemiological cycle in which mammals act as reservoirs and fleas serve as vectors. Globally, the disease is capable of infecting more than 200 mammalian species, and 60 species of fleas can transmit a plague. Wildlife plays a central role in the epidemiology of most plague outbreaks,

acting as key reservoirs that facilitate the transmission of the pathogen to domestic animals and humans (Plaza & Lambertucci, 2017; Rahelinirina et al., 2024).

Studies have found that some of the most invasive waste pollutants that contribute to the death of many animal species are e-waste and plastic waste (Priyanka & Dey, 2018; Sadan & De Kock, 2021). Although plastic ingestion is predominantly infamous among marine organisms, the findings indicate that terrestrial and freshwater species are equally affected (Ho, 2021). Cases of terrestrial fauna, such as camels and cattle suffering mortality due to the ingestion of plastic materials have been documented in many parts of the world, including American, Arabic, African, European and Asian countries (Priyanka & Dey, 2018; Ho, 2021). A study conducted at the Maqalika Dam in Maseru, Lesotho, revealed that concentrations of mercury (As) and lead (Pb) in the gills of *Cyprinus carpio*, a species harvested for local consumption and sale, exceeded the WHO permissible limits of 1 mg/kg and 0.2 mg/kg, respectively. These findings indicate potential health risks for residents arising from the ingestion of these metals through fish consumption (Gwibi et al., 2020; Motaung et al., 2024). In Egypt, El-Sappah et al. (2022) investigated the presence of five trace elements, zinc, manganese, copper, cadmium and lead in Nile Tilapia (*Oreochromis niloticus*) collected from three regions (Alexandria, Cairo and Aswan), using the species as a bioindicator of environmental pollution and elements such as cadmium, and lead were higher than the safe levels recommended by many international organizations such as the FAO, WHO and the European Commission (Abdullah et al., 2022). For bird species such as white storks, landfill sites constitute a major source of toxic metal exposure, with elevated concentrations of lead, mercury, cadmium and arsenic detected in the blood of chicks raised in nearby nesting areas (Plaza & Lambertucci, 2017).

2.5.5 Rodent and vector proliferation

Waste provides a conducive environment for the proliferation of rodent and vector species. Waste piles can become habitats and nesting areas for rodents, whereas water trapped in improperly disposed waste materials, such as tins, tyres and plastic containers creates favourable breeding grounds for mosquitoes and flies (Nor et al., 2019; Krystosik et al., 2020; Salvaraji et al., 2020; Fadhullah et al., 2022). According to Rahelinirina et al. (2024), the spread of vector-borne diseases is influenced by how humans manage water storage, stagnant water in rainy seasons, and wastewater

systems. The continued presence of rodents in certain households or buildings is attributed to the structural characteristics and the level of environmental sanitation; however, soil type and land-use patterns such as landfilling can also regulate this abundance (Hieronimo et al., 2014; Kimaro et al., 2014; Dimkpa et al., 2025). A study conducted in Ethiopia documented that solid waste dump sites in Asella town provided favourable conditions for the retention of various arthropods and carnivorous animals, with 14.6% of the sites occupied by mosquitoes, 18.4% by rats, 8.9% by carnivores, and 42.6% by houseflies recorded. The presence of these organisms poses significant public health concerns, particularly for populations residing near dump sites (Eshete et al., 2024).

The increased presence of vectors also leads to higher incidences of vector-borne diseases in nearby communities. *Aedes* mosquitoes (*Aedes albopictus* and *Aedes aegypti*) that transmit such illnesses such as dengue (DENV), Zika (ZIKV), and chikungunya (CHIKV) viruses thrive well in solid waste and the rainy season and threaten the lives of half a billion people in populated areas such as Delhi, India and Brazil (Vikram et al., 2015; Eder et al., 2018; MacCormack-Gelles et al., 2018; Krystosik et al., 2020). Studies conducted in India have reported that there is a correlation between poor SWM practices and the proliferation of *Trypanosoma cruzi*, which transmits Chagas disease/Trypanosomiasis, uses waste material as a burrow, source of food and breeding site (Rosecrans et al., 2014; Sasi & Lal, 2024). Malaria, spread by the bite of infected female *Anopheles* mosquitoes, remains a major public-health challenge and is endemic in 19 sub-Saharan African countries, particularly in underdeveloped regions where poor waste management, housing and socioeconomic factors drive its transmission. In 2023, the World Health Organisation (WHO) reported approximately 263 million cases and 597 000 deaths related to malaria, with Africa accounting for 94% of cases and 95% of deaths (WHO, 2024f; Yitageasu et al., 2025; Dimkpa et al., 2025). Flies act as vectors, carrying pathogenic microorganisms on their bodies after immersion in waste and transferring them to food, water and surfaces that may subsequently be consumed by humans (Nor et al., 2019). The most common fly species, *Musca domestica* (housefly), is a major vector responsible for transmitting gastrointestinal disease – causing bacterial pathogens such as *Salmonella enterica*, *Escherichia coli*, *Listeria monocytogenes*, *Klebsiella* and *Campylobacter* spp (Shahanaz et al., 2025).

The problem of rodent proliferation is closely intertwined with matters of public health, human rights and social justice. Whether manifested through disease, malnutrition or infrastructure, the rodent proliferation represents a global, multisectoral challenge with costs estimated at 23 billion euros annually (Colombe et al., 2019). Among many existing rodents, the house mouse (*Mus musculus*), black rat (*Rattus rattus*), brown rat (*Rattus norvegicus*), and field mouse (*Apodemus* spp.) of the family Muridae, along with cotton rats (*Sigmodon hispidus*) and woodrats (*Neotoma* spp.) of the family Cricetidae, are small rodent species that are well adapted to landfill sites. They commonly coexist in proximity to human populations and cause havoc in households (Plaza & Labertucci, 2017; Hamidi, 2018). In the United States, besides the significant property damage rodents cause, they are suspected to be linked to electrical wire damage that is responsible for about 25% of house fires of unknown origin, resulting in roughly 171 deaths annually (Illinois Department of Health – Division of Environmental Health, 2019; Zano, 2023). The economic burden of rodent-related production losses attributed to urine and faecal contamination and disease transmission to livestock by rodents have been estimated at approximately AUD200 million crop damage in Australia, US\$1.9 billion in Asia, US\$45 million in the United Republic of Tanzania, US\$19 billion in the United States, and US\$60 million in Australia (Brown et al., 2002; Hamidi, 2018; Colombe et al., 2019; Brown & Henry, 2022). Implementing effective rodent control measures could prevent approximately 280 million cases of malnutrition globally each year, as about 50% of agricultural resources are affected when they are harvested and 5–20% after harvesting (Gonga et al., 2022).

2.5.6 Climate change

In the past three decades, increasing attention has been directed towards environmental concerns, with a particular emphasis on climate change (Habib et al., 2023; Hayati et al., 2018; Abdul-Nabi et al., 2025). Climate change presents an existential threat to humankind and our planet; therefore, South Africa is not exempt from the vulnerability of its impacts (DFFE, 2025). Some of the catastrophic events that have been evident in South African provinces, including the Free State, due to climate change include severe storms, droughts, floods, wildfires and landslides. Global heating is already having other direct and measurable impacts (DFFE, 2025). Studies have shown that climate change threatens freshwater availability throughout

the world as it increases the already existing scarcity. Since the 1950s, South Africa has experienced a steady rise in the frequency of 'hot days', defined as days when maximum temperatures exceed 30 °C or surpass thermally comfortable conditions. Beyond its ecological implications, excessive heat constitutes a significant environmental and occupational health risk, especially for people whose jobs are outdoors (DFFE, 2025).

The improper management, disposal and treatment of MSW have been identified as some of the anthropogenic contributors to greenhouse gas (GHG) emissions (Yu & Chen, 2009; Mahajan, 2023). Open burning of waste frequently occurs at poorly managed disposal sites, and because of the high temperatures generated during the combustion, the resulting smoke is typically lifted and dispersed at elevations far above ground level (Oleniacz et al., 2022; Jakhar et al., 2023). The burning of waste, along with emissions from the naturally occurring decomposition of organic matter, releases chemical compounds such as carbon monoxide (CO), sulphur dioxide (SO₂), nitrogen dioxide (NO₂) and methane (CH₄). These compounds combine with atmospheric moisture, lowering the pH value of precipitation and resulting in acid rain, which in turn causes significant damage to ecosystems, soil structure and infrastructure (Njoku et al., 2019). Nitric acid affects plant physiology negatively by disrupting stomatal regulation, reducing photosynthetic efficiency, inhibiting enzymatic activity, altering metabolic pathways, and ultimately suppressing growth and crop yield (Danthurebandara et al., 2013). Moreover, the emissions also contribute to atmospheric pollution that exacerbates climate change by altering air quality, atmospheric chemistry, and the balance of greenhouse gases (Abubakar et al., 2022). Methane and carbon dioxide are greenhouse gases of global significance, exhibiting higher reactivity, while carbon dioxide is generated in substantially larger volumes. Landfills and wastewater together account for approximately 17% of the total methane (CH₄) emissions (Krupa, 1996; Hoornweg & Giannelli, 2007; Olczak et al., 2023).

Ozone depletion (thinning of the protective ozone layer can cause increased amounts of ultraviolet (UV radiation), and global climate change, whereby the activities of humans have disturbed greenhouse gases from the decomposition of wastes in disposal sites, causing the earth's average temperature to rise (Krecl et al., 2020). Health sciences are playing an increasingly important role in advancing climate justice and human rights initiatives. However, a major policy and legal gap persists in

implementing a transdisciplinary health framework and in addressing the interconnectivity between biodiversity and health (Willettts et al., 2025).

2.5.7 Waste-related injuries, diseases, and health conditions

Exposure to environmental pollutants can cause a range of health effects, from immediate (acute) to long-term (chronic) illnesses (Jakhar et al., 2023). The exposure to waste does not affect everyone equally, as some groups, such as children, pregnant women, senior adults, and immunosuppressed individuals with pre-existing health conditions, are more vulnerable to serious health impacts than others (Texas Department of State Health Services, 2025). According to Stats SA (2018), respiratory disease, cardiovascular disease, and HIV/AIDS constitute three of the five leading causes of death in South Africa. South Africa has to deal with multiple, simultaneous burdens of disease: communicable, non-communicable, perinatal and maternal, and injury-related disorders (Mayosi et al., 2009; Mathee & Wright, 2014). Despite increasing evidence of health and safety hazards among impacts on health in South African literature, limited information exists regarding such risks within the Free State.

Injuries related to waste exposure represent a significant occupational and public-health concern (Tshivhase et al., 2022). Repetitive movements associated with lifting, carrying, pulling and throwing can cause musculoskeletal injuries, including strains, tears and sprains of muscles and ligaments (Berger & Michelena, 2023). Chemical burns are also common amongst waste workers and waste pickers when exposed to chemical waste (Tshivhase et al., 2022). Globally, waste slides in landfills continue to claim the lives of those living in the vicinity or working on and near it (EJAtlas, 2021). The landfills attract both domestic and wildlife, and the increasing presence of animals at landfill sites located near human settlements can exacerbate human–wildlife antagonism, leading to direct attacks on humans and predation on livestock (Plaza & Lambertucci, 2017). Unsafe needle and sharps management practices spread blood-borne diseases and account for over 23 million new infections of hepatitis B, hepatitis C and HIV each year (WHO, 2017; Udofia et al., 2017; Zithathile & Atagana, 2018a). The improper co-disposal of medical and municipal waste heightens occupational health risks, rendering waste collection workers and waste pickers particularly susceptible to infectious diseases.

The transmission pathways of waste-related communicable diseases are airborne,

water-borne, foodborne, vector-borne and direct skin or intravenous contact (Zibara et al., 2016; Twagirayezu et al., 2021; Tshivhase et al., 2022). Enteric infections have consistently had the highest disease burden in low-income countries, largely as a result of poor sanitation (Li et al., 2024). The spread of diseases like cholera and typhoid that are both typically understood as waterborne infections, and other health issues have long been related to water pollution (Eshete et al., 2024). Around 94% of the burden of diarrhoeal disease and 42% of lower respiratory infections may be prevented through environmental health interventions, which could be essential within the South African context to promote equity by addressing the needs of the most vulnerable and marginalised populations (Mathee & Wright, 2014). One of the most significant pathways linking waste to disease transmission is the proliferation of mosquitoes, which serve as vectors for dengue fever, Zika virus, chikungunya, yellow fever and malaria (Krystosik et al., 2020; MacCormack-Gelles et al., 2018). Respiratory diseases attributable to both chemical and biological agents have been closely associated with waste exposure. Several studies have demonstrated a significant correlation between poor air quality and the prevalence of respiratory conditions such as shortness of breath, sore throat, chest pain, nausea, asthma, bronchitis and lung cancer (Rim-Rukeh, 2014; Kaza et al., 2018; Turyahabwe et al., 2022; Motaung et al., 2024). The exposure to gaseous emissions such as methane, carbon dioxide, sulphur dioxide and nitrogen dioxide can trigger inflammatory responses and bronchoconstriction, thereby compromising immune cell activity. Furthermore, hydrogen chloride and hydrogen fluoride emitted from waste sources may, upon deposition in the respiratory system, result in symptoms such as coughing, chest constriction and shortness of breath (Fadhullah et al., 2022).

Prolonged exposure to pollutants emanating from landfill sites contributes to the onset and progression of non-communicable diseases. According to a Swedish cohort study, diabetes seems to be induced after long-term air pollution exposure (Eze et al., 2014). Heavy metals have been reported to cause the mutation of inner organs, disturb immune reactions and reduce their adaptation and resistance to diseases in humans (Gwibi et al., 2020). Traces of microplastics that usually contain persistent organic pollutants (POPs), and heavy metals such as mercury have been reported to be detected in human faeces, with the majority being excreted. However, a proportion of particles can migrate from the gastrointestinal tract into lymphatic and circulatory

systems where they can reach cellular tissues and the immune nervous, endocrine and reproductive systems (Department of Environmental Quality, 2017; Yong et al., 2020; Barboza et al., 2020; Adeniran & Shakantu, 2022). Approximately 19% of all cancers are estimated to be attributable to the environment, including work settings (Mathee & Wright, 2014). Plastic waste has persistent organic pollutants (POPs) that are linked to several cancers, impairment of the nervous system and vision impairment, as well as reproductive and developmental diseases (Barra & Leonard, 2018; Adeniran & Shakantu, 2022). Synthetic organics, notably benzene and related petrochemicals, can induce carcinogenesis through mechanisms involving DNA damage and oxidative stress (Department of Environmental Quality, 2017). According to the developmental origins of health and disease concept, environmental stressors could result in brain structural and functional changes in the developing foetus and cause birth defects (Gómez-Herrera et al., 2025). Statistics South Africa/Census 2001 surveyed the prevalence of disabilities in the country and found that there were more than 2 million people with various forms of disability (Statistics South Africa, 2005).

2.5.8 Waste-related social and psychological impacts

Historically, waste has instigated conflicts or waste wars among generators, waste workers and the local authorities. A study conducted on waste collectors in Johannesburg, South Africa, documented that they were verbally abused with insults, or labelled with derogatory terms by people in the streets when collecting waste. However, they never responded, in order to avoid an escalation of physical attacks (Tshivhase et al., 2022; Made et al., 2023). Studies have also reported that problems like depression and anxiety are common among waste pickers and waste collectors, which are caused by stigmatisation and inherent developmental disabilities of mental health diseases (Abubakar et al., 2022). Waste pickers are usually implicated (wrongfully or rightfully) in criminal offences, whether in the streets, neighbourhoods, and disposal sites where they pick waste recyclables (Made et al., 2023). One of the most common referrals by courts of law to the Forensic Units in South Africa is for an assessment of both the competency to stand trial and the criminal responsibility of people deemed to exhibit an intellectual disability, which influences complex factors, including developmental disability, and social and economic influences (Mosotho et al., 2020). People with intellectual disabilities may be more susceptible to simultaneously becoming both the perpetrator and the victim of a crime, considering

their diminished level of functioning (Nixon et al., 2017). While neurodevelopmental toxicity is implicitly recognised in the most vulnerable groups, such as waste pickers, usually in developing countries, it is also noteworthy that ageing also contributes to neurodegenerative diseases (Delobel-Ayoub et al., 2015; Rizvi, 2025).

Studies have documented concerns of residents about their culture and social well-being in relation to environmental waste. Improper waste disposal of medical or human waste not only contributes to an eyesore environment, but also undermines the beliefs, norms and culture of communities. The community in the study conducted in KwaZulu-Natal revealed a concern about the contamination of their freshwater ecosystems, which are important for fulfilling some of their traditional and religious rituals and activities (Zondi et al., 2023). Studies conducted at Tsosane landfill in Maseru, Lesotho, documented the previous incidences of spontaneous fires at the disposal sites, which not only affected their respiratory health but also caused residents to live in fear of losing their lives, property, business opportunities and social lives because of their living conditions (Bulane, 2007; Mokoka, 2022; Motaung et al., 2024). Waste burning can affect other aspects of residents' lives; they are unable to spend time outside, have sleeping disorders because of air pollution, or must leave their residences during fire outbreaks, and even receive fewer visits from family and friends (Mokoka, 2022; Owusu-Sekyere, 2022). In some studies, residents reported that they constantly moved to a different location to avoid the potential health effects of open burning of waste, which was a solution (Mokoka, 2022; Phelan et al., 2020).

2.5.9 Waste impacts on the social economy

The negative externalities associated with economic classification and proximity to a landfill are well documented. However, if properly managed, waste can contribute to positive impacts on people's lives, which will be stated in subheading 2.6. The burden of morbidity and mortality linked to waste exposure results in increased healthcare expenditure, reduced workforce productivity, and loss of household income (Deffnika et al., 2021). Community living in the vicinity of disposal sites and low-to middle-income households are especially vulnerable to these atrocities, which can hinder their economic development and reinforce cycles of poverty (Mokoka, 2022; Muzvondiwa, 2021; Deffnika et al., 2021; Owusu-Sekyere, 2022). Municipalities also bear the financial burden of waste fires on waste management sites, as these incidents damage

infrastructure such as recycling plants and landfills, requiring costly repairs or replacements and additional costs for fire clean-ups to mitigate environmental harm. Such expenses place an additional strain on the already low fiscal budgets of municipalities (Wiedinmyer et al., 2014; Jakhar et al., 2023). Food waste, a significant contributor to greenhouse gas emissions, represents economic deficits that have not been regulated adequately worldwide. For instance, in Europe, it is estimated that 50% of edible and safe food is unnecessarily discarded every year from households, supermarkets, restaurants, and throughout the food supply chain, despite 79 million citizens living below the poverty line and 16 million depending on food aid from charities, all of which call for change (Seberini, 2020).

There exists a social stigma and a typical decline in housing values in local communities within the proximity of landfills (Du Preez et al., 2016; Jakhar et al., 2022). Studies have extensively applied the Hedonic Pricing Model (HPM) to establish the relationship between housing characteristics and the price that a buyer or tenant is willing to pay (Du Preez et al., 2016; Ofori, 2021). A study conducted in Agogo Asante Akyem, Ghana to assess the extent to which disposal sites influence residential rental values revealed that the majority of the tenants who lived within the distance range of 0–500 metres from disposal sites paid similar and substantially low rents, and the rents gradually increased, the further the distance from the site (Ofari, 2021). A study conducted in South Africa examining the relation between house prices and landfill site proximity in the New Brighton Township of the Nelson Mandela Bay Metropole (NMBM), Eastern Cape province, South Africa, found an average increase of R36,00 for every 100 metres further from the site, proving that property owners' income is impeded by the disposal site. Insurance companies also use a market manipulation strategy where the residents' proximity to sites is considered a high-risk area, which may lead to paying a slightly higher insurance premium, compared to distant areas (Ezell, 2025).

Waste has affected key industries that contribute greatly to the economy of South Africa. It diminishes the urban spaces, deters investment opportunities, and indirectly affects local economic growth and development (Sadan & De Kock, 2021; Adeniran & Shakantu, 2022). These industries include tourism, fisheries, real estate and insurance (Jain et al., 2021; DEFF, 2025). The impacts of marine plastic debris on ecosystems, compounded by the cumulative pressures of climate change, ocean acidification, and

the over-exploitation of marine resources pose significant risks to the sustainability of the fishing and aquaculture industries (Jambeck et al., 2017). Studies conducted in Cape Town and Durban, South Africa, revealed that plastic pollution on the beaches has a major impact on municipalities and the tourism sector, potentially reducing tourism revenue and employment by up to 91% (Jain et al., 2021). Additionally, the city spends about R13 million on regular beach clean-ups per year to curb the loss, which can be projected to about R8,5 billion to the local tourism sector (Sadan & De Kock, 2021). An industrial drawback was documented in the port of Durban, which was forced to close due to the accumulation of waste volumes, especially plastic, which cause damage to the engines of the ships anchored in the area, resulting in high costs of repairs in addition to necessary cleanups. Plastic waste contributes significantly to the clogging of water drainage systems. When these systems become obstructed, water reticulation networks are often damaged, resulting in bursts and subsequent excessive water losses (Sadan & De Kock, 2021). A catastrophic incident happened in Accra, Ghana, where plastic packaging waste accumulated and clogged drains during the rainy season. 150 people lost their lives, and their infrastructure was damaged (Plastic Pollution Coalition, 2017; Adeniran & Shakantu, 2022).

2.6 Sustainable waste impact management strategies

Table 2: Common unsustainable waste management methods and sustainable solutions for high-impact waste streams of concern in South Africa

Waste type	Common unsustainable methods	Sustainable treatment methods	Authors
E-waste	- Dismantling and recovery of precious material – chemical bathing, - Illegal transboundary movement from developed to developing and transitioning countries of second-hand products. - Landfilling - Incineration	- WEEE reduction through prevention of electronic counterfeits and legislative enforcement. - Repairing and refurbishing electrical and electronic goods. - Development and improvement of a formal electronic waste recycling system. - The informal sector (waste pickers) can be transferred or incorporated into the formal sector and usage of certified facilities. - Fair, regulated pricing of e-waste goods. - Development of manufacturer take-back programmes. - E-waste awareness in societies	(Mmereki et al., 2016; Twagirayezu et al., 2021; Kumar et al., 2017; Roy et al., 2022; Siddiqui et al., 2022; Fawole et al., 2023; RebootTech, 2024)

Healthcare risk waste HCRW	- Illegal disposal in a general landfill site. - On-site pit for incineration. - Hazardous waste landfill, where applicable.	- Medium Temperature Microwave Technology, which uses high-energy waves in conjunction with reverse polymerisation for disinfection. It is a low-cost option that can be used conveniently on-site. - Pyrolysis technology, which employs high temperatures (540 °C to 830 °C) for the degradation of organic composites. Reusable bio-oils can be obtained for reuse from this method. - Chemical disinfection uses gases such as methane, chlorine, propylene oxide, ethylene oxide, formaldehyde, and peracetic acid as sterilising agents. Large amounts of waste can be disinfected and reused, depending on the nature, without liquid and gas residuals. - Harnessing energy with appropriate incinerators.	(Mochungong, 2011; Udofia et al., 2017; Su et al., 2021; Kollu et al., 2022; Giakoumakis et al., 2021).
Menstrual hygiene waste	- Dumped in water bodies.	- Health education to pubertal girls and young women about effective and	(Kaur et al., 2018; Elledge et al., 2018; Jahan et al., 2020; Anand et al., 2022).

	- Indiscriminate dumping. - Open waste burning on the landfill site. - Backyard burning. - Sewage system disposal. - Pit latrine disposal.	sustainable menstrual hygiene, which is taboo in other cultures. - Alternative usage of menstrual cups. - The use of biodegradable sanitary pad options. - Use of environmentally friendly chemicals for the manufacturing of sanitary pads. - Effective separation by use of concealing wraps and designated bins at the household level. Provision of these products by the municipalities in impoverished areas. - Effective waste collection. - Municipalities' investment into low-cost smart incinerators or autoclaves to destroy microbial contamination and reduce biowaste volumes in landfills. - Outsourcing of companies that manage hazardous biomedical waste.	
Absorbent waste- diapers	- Pit latrine disposal.	Renewable materials-	(Khoo et al., 2019; Eskander & Saleh, 2017; Tsigkou et al., 2020 & 2021; Plotka-

	- Burying. - Landfilling. - Dumping in open spaces (riverbeds, water sources, bushes, and roadside). - Open burning.	reduction of fossil fuels during production and use of biodegradable materials, e.g. sustainably sourced wood pulp or bamboo. Reusable or modular diapers- A combination of the cloth outer and inner layers of a diaper and the recyclable single-use fluff-pup or SAP absorbent pad. Recycling- plastics, fibres, and cellulose pulp, which can be extracted, sterilised, and used as raw materials to produce other products, e.g. cat litter. Biodegradation and composting- thermal degradation- biochemical reactions of bacteria, fungi, protozoa, or other microorganisms break down the synthetic polymers in diapers, producing environmentally acceptable products (CO₂, H₂O and CH₄). Anaerobic digestion and dark fermentation- conversion of used diapers into renewable biogas.	Wasyłka et al., 2017; The Green Guardian, 2023; UNEP, 2023; Kordecki et al., 2021; Schenck et al., 2023; Chitaka et al., 2024).
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		Composting- Using digestive enzymes, single-use baby diapers can also be recycled into soil fertiliser or garden compost. Diapers are usually combined with other materials in a composting process. - Improved access to water to enable easy use of the reusable diapers. - Health education of caretakers.	
Pharmaceutical waste	- Discarded in sewage sinks. - Flushed down toilets. - Mixed with general waste. - Landfilling.	- Information dissemination and awareness to consumers. - Extended producer responsibility to organise environmentally sound separate collection and treatment. - Marketplaces for the redistribution of unused close-to-expiry date medicines can also improve the matching of supply and demand and prevent wastage. - Implementation of strategies to regulate good practices of health services.	(Constantino et al., 2020; OECD, 2022).

		- Effective waste separation and collection, especially at the household level. - Treatment of pharmaceutical waste from health services, pharmacies, drug stores, and distributors of medicines as hazardous waste.	
Rubber and waste tyres	- Landfilling. - Burning. - Dumped in waterways. - Abandoned on the streets.	Proper storage- minimisation of piles, shading from direct sunlight, and control of ventilation by enclosure to avoid spontaneous ignition. Retreading- replacing the outer tyre layer through vulcanisation to create a second-hand product. An additional advantage of retreading is energy savings, as the process requires only half the energy used for producing a new tyre. Energy recovery technologies, including pyrolysis, thermolysis, and gasification, have been recently incorporated. The cement industry uses whole or shredded tyres as a fuel source in cement kilns	Harrison-Obi, 2019; Czarna-Juszkiewicz, 2023; ETRMA, 2023; Zhang, 2024; Murphy, 2025).

		that operate at temperatures above 1 200 °C. It can also be used for electricity production, steam production, pulping, paper, steel and lime production. Pyrolysis- thermochemical process of breaking down tyres in an oxygen-free environment to produce pyrolysis oil, pyrolytic char (black carbon), and syngas (combustible gas). Product recycling- tyre waste can be incorporated into new automotive components, and can be used for a new purpose, such as making mats, animal stalls, and children's play swings. Material recycling- extraction of rubber, steel, and textile fibre from waste tyres.	
Construction waste	Construction site abandonment. Illegal dumping (roadside or open space). Burying waste. Watercourse disposal. Mixed with municipal waste, burning.	- Construction companies must consider a specialised waste management company.	(ETM Recycling, 2023; Otasowie et al., 2024; Villoria Saez et al., 2019; Brycht, 2020; Sagan & Mach, 2025; Simon et al., 2025)

	Landfilling.	- Optimisation of material usage by proper planning to prevent excessive material ordering and wastage. Reuse of material such as: - The practice of efficient construction methods and training teams to minimise waste while using materials responsibly. - A vast amount of construction waste components can be recycled; these materials can be just as strong as the original 'pure' material. - Reclaimed Asphalt Pavement is used to backfill pavement edges and rework the base and base course.	
Plastic waste	Indiscriminate dumping. Open burning. Landfilling.	- Adoption of circular models by implementing strategies to design products for durability. - Focus on the waste hierarchy by reducing single-use plastic reliance. - The government must increase levies to encourage the avoidance of single-use plastics.	(Zhang et al., 2021; Plastic for Change, 2025; World Wide Fund, 2025; Tesfaye et al., 2025).

		- Promotion of alternative reusables (e.g. reusable shopping bags) by retailers. - Effective separation from source and recycling. - Supporting eco-conscious businesses that use sustainable packaging and materials. - Governmental and municipal support for formal and informal recycling programmes to curb the plastic waste problem.	
Chemical waste	-Indiscriminate dumping. -Sewer drainage. -Landfilling.	- Educational campaigns for members of the community and comprehensive training for employees on proper handling, storage, disposal, personal protection and others' protection. - Identification and segregation of all hazardous chemical waste from (household/workplace). - Effective labelling, collection, and segregation of hazardous reactions.	(Singh, 2025; Purcell, 2024; Safelec. 2024)

		- On-site chemical treatment, which involves physical, chemical, or biological processes that will alter the properties of a substance and reduce toxicity. - Neutralisation by inducing a change in the pH of alkaline and chemical bases. - Recycling to reduce the burden of production. - Partnering with licensed waste disposal providers.	
Organic waste	-Manure fertiliser. -Burying of animal or parts, or blood products, and manure into a trench. -Open burning. -Landfilling.	- Composting of food waste. - Alternative animal feed: waste food can be used as feed and may increase the profit margin for animal producers. - Dried animal waste, such as poultry dung, is broadly equivalent to cereal such as barley in terms of protein and essential amino acids. - Biogas production: used as fuel for cooking and lighting purposes and in diesel engines to substitute diesel oil.	(Swanepoel, 2014; Kooiman et al., 2023).

		- Commercial organic fertiliser: especially poultry manure with high nitrogen content is sought after. - Steam sterilisation: sterilise the blood with steam and dry it into blood meal. - Vermiculture: Animal dropping can be potentially converted into vermin-cast and vermin-meal (protein meal) via a low-cost vermiculture system. - Cleaning and sale of animal hides, horns and hooves.	
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Various techniques are used for solid waste management; however, for a method to be considered sustainable, it must not cause damage to the biophysical environment, ecosystems and the economy (Akinrogunde et al., 2019). Sustainability refers to the integration of environmental health, social equity and economic vitality to foster thriving, resilient and diverse communities for both present and future generations (Purcell, 2024). The principles of Guided by the National Environmental Management: Waste Act 107 of 2008 (RSA, 2008) and the National Waste Management Strategy (NWMS), South Africa's approach to sustainable waste management is anchored in the waste hierarchy, which outlines the options for managing waste in the most environmentally friendly manner (DFFE, 2020). The National Waste Management Strategy (2020) further emphasises core principles that position waste as a valuable resource, promoting sustainable partnership and fostering inclusive socioeconomic growth and development from inception to implementation to allow for a broader scope of solutions to waste management issues to achieve a circular economy (NWMS, 2020; Hector & Lambrechts, 2024). In alignment with this framework, the new Integrated Waste Management Planning Guidelines (IWMP) recognise partnership as a mechanism for providing the services and facilities for integrated waste management (Oelofse & Matinise, 2023). The purpose of the waste disposal restrictions in the National Norms and Standards for Disposal to Landfills is to ensure safety for those working at landfills and protect the environment and public health from long-term effects of hazardous materials, as well as the reflection of the government's intent to promote the waste management hierarchy (RSA, 2013b). Following the order of most preferred methods to the least preferred methods, the waste management hierarchy emphasises waste prevention, reduction, reuse, recycling and recovery before disposal as shown in Figure 2.61.

At the top of the hierarchy is prevention and reduction, which are regarded as the most effective. It involves the avoidance of waste creation in the first place by altering behaviours, consumption patterns, production processes and product use. Reduction focuses on reducing waste generation at the source through responsible consumption, extended product lifespan, reuse of materials or equipment from source, cost saving and minimising hazardous content (ETM Recycling, 2020; Waste Mission, 2024). Waste segregation at source is considered the critical stage for waste management and the successful minimisation of waste (Miamiliotis & Talias, 2024). South Africa

has introduced Extended Producer Responsibility (EPR) schemes across all packaging waste streams to enhance waste reduction efforts to divert waste from landfill (South African Waste Pickers Association [SAWPA], 2023), even though efforts have not made much difference. A study conducted in the Netherlands estimated that approximately 40% of pharmaceutical waste resulting from unused or expired medicines could be prevented. Establishing marketplaces and redistribution systems for unused or near-expiry medicines can enhance the alignment between supply and demand, thereby reducing wastage; however, issues of counterfeits, quality assurance and consequent legal restraints can prohibit this process (OECD, 2022; Ghali et al., 2023).

The next tier, reuse, involves inspecting, cleaning, repairing, or refurbishing discarded items to restore their functionality. The reuse of C&DW is a practical managerial technique that not only reduces landfill longevity but also saves fuel supply used in transportation (EMR recycling, 2023; Otasowie et al., 2024). Maximising reuse is challenged by the lack of sufficient waste collection, transportation and treatment facilities, additional cost of preparing for recycling, and the struggle to balance waste containment with reuse (Waste Mission, 2024). Reuse and refurbishment can be suitable for waste tyres and e-waste. Composting can also have a significant impact at the community level. The replacement of conventional consumer electronics such as television sets, computer monitors, and fluorescent lamps with more energy-efficient technologies like liquid crystal displays (LCDs) and light-emitting diodes (LEDs) could substantially reduce both energy consumption and associated costs, while simultaneously extending the operational lifespan of these electronic products (Awasthi & Li, 2017). For waste tyres, the most sustainable approach involves repairing or retreading used tyres for reuse in their original intended purpose, thereby extending their service life and reducing waste generation (Harrison-Obi, 2019).

Recycling emphasises the reprocessing of waste materials into new products to conserve resources and reduce landfill dependence (Waste Mission, 2024; Silver). In South Africa, approximately 70% of recycled material originates from landfills and other post-consumer sources (Arabi & Nahman, 2017), and waste pickers are key drivers of recycling initiatives. Waste recycling has created income and employment opportunities for waste pickers and recyclers (Oelofse & Matinise, 2022; Silva et al., 2025). South Africa has an estimated 200 000 waste pickers who navigate the urban,

peri-urban and rural areas collecting solid waste (Global Citizen, 2019; Littlewood et al., 2022). However, waste pickers benefit from a small fraction of the R18 billion worth of the recycling industry (SAWPA, 2023). The National Government has formally recognised the role of waste pickers through the National Waste Management Strategy (NWMS) and the Waste Picker Integration Guidelines (WISA) (SAWPA, 2023). The Waste Picker Integration Guideline provides direction on how municipalities and industry stakeholders can collaborate with waste pickers. However, challenges persist in the integration process, primarily due to limited collaboration and the absence of a comprehensive registration system among waste pickers, which complicates coordination efforts. Although some waste pickers have formalised their activities through cooperatives, others prefer to remain informal, opting for self-organisation and independent operations (Oelofse & Matinise, 2022). Formalisation through cooperatives or associations of recyclable material collectors is crucial for improving the livelihoods of these workers, as it often enhances social protection, strengthens collective mobilisation, ensures fair remuneration, and facilitates negotiation processes for their safety (Silver et al., 2025).

Where recycling is not feasible, the level of the hierarchy is energy recovery, which involves converting non-recyclable waste materials into energy through various thermal, biological, or chemical processes (valorisation methods). Waste-to-energy (WTE) conversion facilities generate heat, electricity, or biofuels from residual waste streams, reducing 70–90% volume of waste destined for landfills and counteracting fossil fuel consumption (Reconomy, 2024; Makgato, 2024). The land-to-gas energy approach, which involves the controlled disposal of waste in landfills to capture and convert landfill gas into energy, presents a viable opportunity for African countries, including South Africa (African Union Development Agency [AUDA], 2021). Organic waste can be managed through composting, a biodegradation process in which bacteria decompose organic matter to produce humus, a nutrient-rich material that aids in solid waste disposal and yields valuable manure used as fertiliser for crops (Nor et al., 2019). Sanitary waste, such as nappies and feminine hygiene products, can be treated through composting; however, the right type of hot composting facility is rare, especially in developing countries (UNEP, 2023). Across the United States, numerous programmes, initiatives, non-profit organisations and businesses have

been established to promote and support composting practices (Kooiman et al., n.d.), which could be beneficial for capacity building in low-income communities.

Finally, disposal represents the least preferred option, involving the safe landfilling or incineration of waste that cannot be otherwise reused, recycled, or recovered (ETM Recycling, 2020). The challenge with landfilling is that it is linked to habitat loss, environmental pollution and degradation. Despite being the last option of preference, landfilling remains one of the most widely used waste management practices across the world, regardless of the country's level of development (Siddiqua et al., 2022).

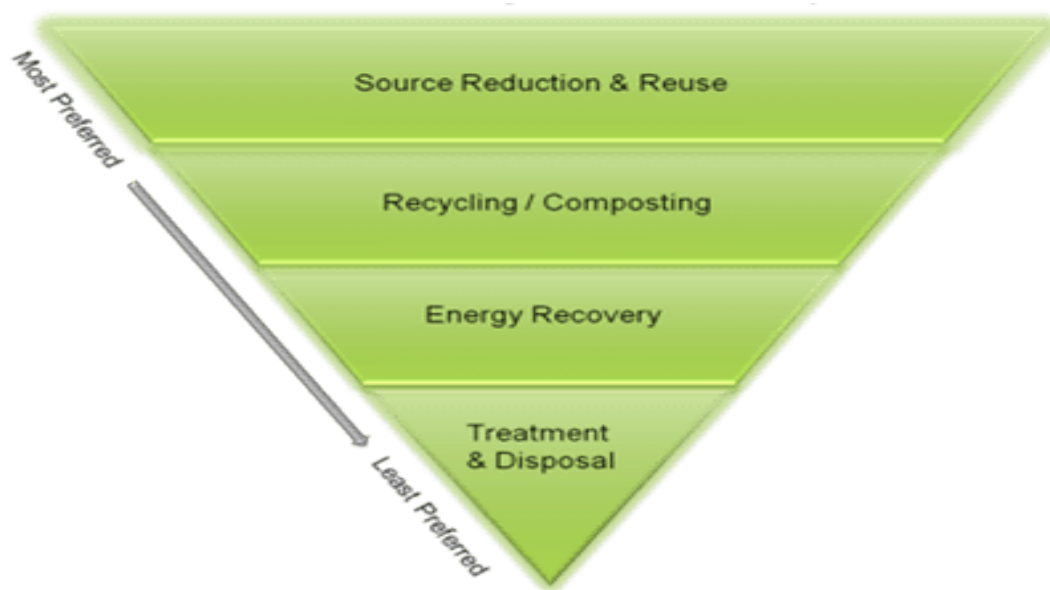


Figure 2.6.1: The waste management hierarchy

Globally, many countries have embraced the Sustainable Development Goals (SDGs), achieving notable progress in certain areas, particularly with respect to highly specific targets (Mumford et al., 2023). South Africa continues to position itself as a custodian of sustainable development, embedding the principles of sustainability at the core of its socioeconomic and environmental policy frameworks. Much of the nation's legislative and strategic planning are aligned with the broader global agenda of achieving the United Nations Sustainable Development Goals (SDGs) (Death, 2011; Mattee & Wright, 2014). The National Waste Management Strategy 2020 was updated to align with lessons learnt, the National Development Plan 2030 and the Sustainable Development Goals 2030 (Local Government Bulletin, 2023).

Waste picking contributes to the attainment of several Sustainable Development Goals (SDGs), including Goal 8 on Decent Work and Economic Growth, Goal 10 on Reduced Inequalities, Goal 11 on Sustainable Cities and Communities, and Goal 12 on Responsible Consumption and Production. Within the South African context, the sector also plays a vital role in addressing critical national development priorities such as poverty alleviation, the reduction of inequality and unemployment, and the advancement of the country's Vision 2030 objectives (NWMS, 2020; Littlewood et al., 2022). Despite widespread global commitment and enthusiasm and acknowledging both the ambitious nature of the SDGs and the setbacks imposed by the COVID-19 pandemic, achieving tangible progress and a meaningful global impact across all the SDGs by 2030 appears unrealistic (Mumford et al., 2023). In South Africa, it is essential to reduce both the volume of waste generated and the number of disposal sites through the implementation of more rigorous and comprehensive recycling initiatives where environmental protection is prioritised, as the conservation of ecosystem services constitutes a fundamental component of sustainable economic development (Tomita & Slotow, 2020).

2.7 Integrated conceptual framework guiding the study

The One Health principle is grounded in the recognition that the health of humans, animals, plants and the environment is interdependent and collectively influences the overall balance of the biosphere (De Oliveira & Gebreyes, 2022). While the One Health approach originates from the control of zoonotic diseases and antimicrobial resistance (AMR) mandates, it has ventured beyond the scope and extended to other meaningful environmental and pollution-related health threats, including waste exposure (Mumford et al., 2023). It has been widely adopted and recognised to handle complex issues by the four collaborative partners, namely World Health Organisation (WHO), Food and Agriculture Association (FAO), World Organization for Animal Health (OIE) and United Nations Environment Program (UNEP), which collaborate in addressing health threats and ensure sustainability across sectors (WHO, 2019; De Oliveira & Gebreyes, 2022; Mumford et al., 2023; Pepin et al., 2024). Landfills are complex environmental systems that pose interlinked risks to human, animal and ecosystem health (Njoku et al., 2019). Within the context of waste landfill impacts, the One Health approach emphasises that waste exposure can affect human, animal and environmental health simultaneously (Gebrekidan et al., 2024). In sub-Saharan Africa,

zoonotic infections account for approximately 26% of the years of healthy life lost to infectious diseases. This burden is projected to increase as growing human populations encroach on wildlife habitats and ecosystem services deteriorate due to the conversion of forests into agricultural and grazing land (Henley et al., 2021). In relation to this study, the health impact, including acquiring zoonotic diseases, worsens with proximity to waste.

Although the One Health approach is often presented as inclusive, in practice it tends to prioritise dominant scientific perspectives related to health, thereby marginalising local communities and overlooking critical disciplines such as the social, psychological and economic sciences. There is growing recognition that the marginalisation of individuals and groups based on race, gender, socioeconomic status, education and occupation profoundly influences their health and wellbeing. Addressing these inequities requires the proactive and sustained inclusion of marginalised communities and their perspectives (Tomita & Slotow, 2020; Mabunda, 2023; Mumford et al., 2023). In addition to the well-established triad of human, animal and environmental health, the One Health conceptual framework should also encompass technical, technological and infrastructural factors, as well as socioeconomic and governance dimensions, to create a more contextually inclusive and responsive structure. Within this framework, One Health-based surveillance and response systems integrate human, animal and environmental health data through near real-time collection, analysis, and feedback to enhance the precision and long-term sustainability of public-health decision-making (Li et al., 2025).

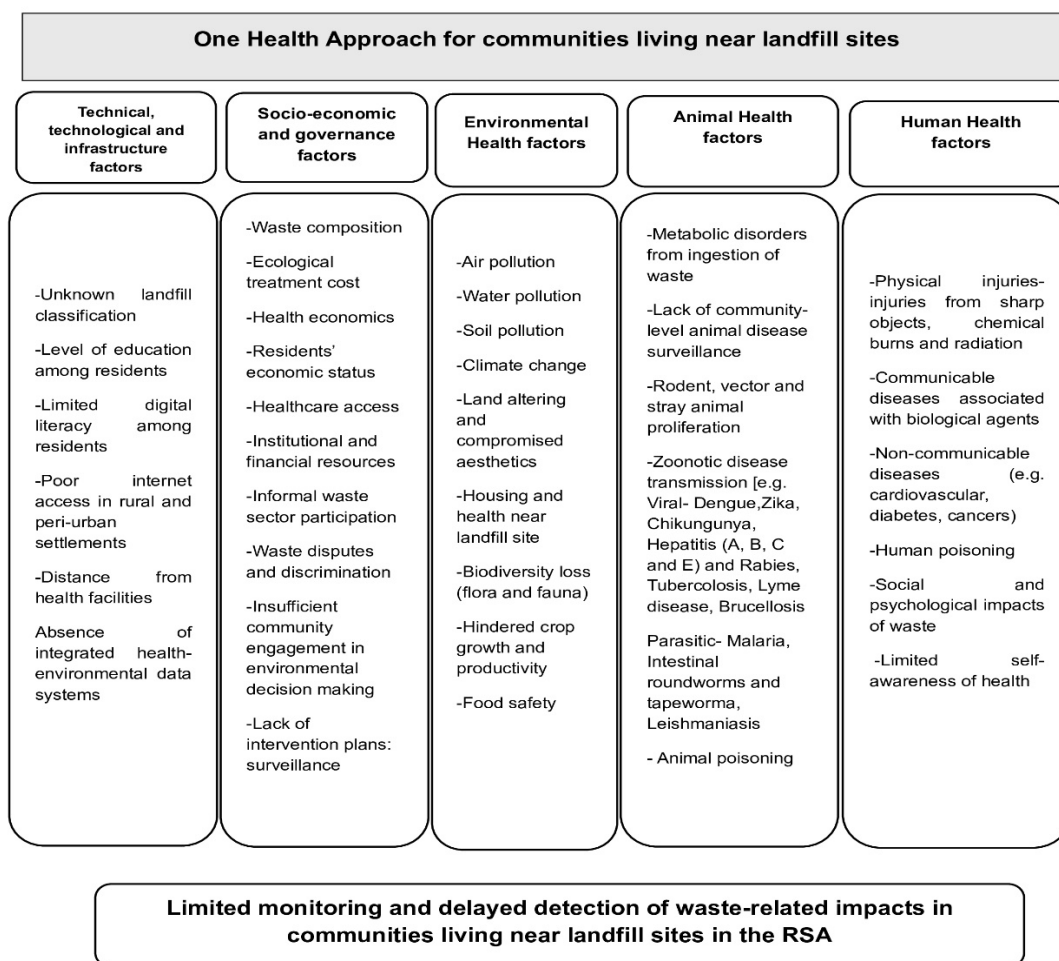


Figure 2.7.1: Conceptual frame for people living near landfill sites using One Health Approach

2.8 Conclusion

Solid waste and its impact in South Africa remain a composite issue shaped by urbanisation, demographic pressures and historic inequalities. Literature shows that the composition and mismanagement of different waste-management streams, both general and hazardous, pose significant environmental and public health risks. Despite legislative frameworks and plans to promote sustainable practices, the persistence of informal settlements, inadequate infrastructure and limited legislative implementations continues to undermine progress. The effective address of waste impacts, therefore, demands a holistic approach that integrates community education, equitable service delivery, circular economy principles and regulation enforcement. Public participation is essential for achieving sustainable waste management and reducing health disparities in South Africa's diverse landscapes.

CHAPTER THREE – METHODOLOGY

3.1 Introduction

This chapter presents the research methodology employed in the study. The methodology outlines the research approach and design, sampling criteria and techniques, data collection procedures, and methods of data analysis. Ethical considerations and data management procedures are highlighted in this chapter. It also discusses the philosophical assumptions underpinning the study, the justification for the chosen methods, and the ethical considerations adhered to during the research process.

3.2 Research approach and design

This quantitative study follows the positivist paradigm, which underpins this study, and is grounded in the philosophical principles of August Comte, who argued that reality can best be understood through systematic observation and logical reasoning. According to this view, true knowledge is derived from empirical evidence obtained through the senses, and thus, can be observed, measured and quantified (Henning et al., 2004; Alele & Malu-Aduli, 2023). The positivist approach construes social reality as something objective and external, enabling the researcher to investigate phenomena without personal bias. The positivist paradigm allowed the collection of quantifiable data such as sociodemographic information, service provision in areas, environmental exposure levels to waste, and prevalence of health-related conditions through structured instruments. This facilitates the identification of patterns and relationships between inadequate waste management and its socioenvironmental consequences, thus enabling objective assessment and generalizable conclusions.

The research study is purely non-experimental, exploratory and descriptive in nature. Non-experimental quantitative design is suitable for describing the phenomena, exploring and explaining the relationships between variables (Taherdoost, 2022). Descriptive approaches identify problems with current practice to justify current practice, make judgements, or to develop theories (Brink et al., 2012; Cassim & Du Plessis, 2021; Nambuli et al., 2021). Cross-sectional design permits an assessment of factors and outcomes of interest simultaneously in a representative sample of the target population (Udofia et al., 2017). They are more manageable, cost-effective and

time efficient, and a common choice for health professionals as large amounts of data can be collected at one point, lowering costs as there is no need for follow-up of participants and making the results more readily available (Matthers et al., 2007; Brink et al., 2012; Zangirolami-Raimundo et al., 2018). Hussainzad and Gou (2025) also established that the cross-sectional method enables assessment of existing conditions and the identification of opportunities to enhance the quality of life (QoL), which is relevant to what this study aims to achieve. Due to the frequent changes that happen at landfill sites influenced by municipal implementation, politics and sometimes disasters, several other authors who conducted their studies at landfill sites with residents and/or waste pickers, also opted for the cross-sectional method in their studies (Kistan et al., 2020; Nambuli, 2021; Oghuehi et al., 2022).

3.3 Description of the study areas and selection criteria

The Free State is South Africa's third-largest province by land area, covering approximately 129 480 km², with a population of about 2.8 million distributed across four district municipalities, namely, Xhariep, Lejweleputswa, Fezile Dabi, Thabo Mofutsanyana, and the Mangaung Metropolitan Municipality (CSIR, 2024), as shown in Figure 1. The province faces numerous developmental challenges, including widespread poverty, high HIV/AIDS prevalence, skills shortages, brain drain, and environmental degradation (Lejweleputswa District Municipality, 2017; COGTA, 2020; CSIR, 2024). Economically, the Free State ranks eighth in GDP contribution nationally, with its share declining from 0% in 2015 to -0.2% in 2019. Although agriculture occupies over 90% of the land, its economic contribution has declined, with an average of minus 5.5% annually between 2015 and 2020. Nonetheless, the sector remains important, contributing 12.1% to South Africa's gross agricultural income (DESTEA-FS, 2022). The study is located in three district municipalities, as shown below.

3.3.1 Thabo Mofutsanyana District Municipality

This district is in the eastern Free State. Thabo Mofutsanyana comprises the Mantsopa, Setsoto, Dihlabeng and Maluti-a-Phofung municipalities. Over 52% of the population lived below the lower poverty line in 2019, exceeding both national and provincial rates (COGTA, 2020). The district features mountainous terrain and fertile valleys, supporting tourism and fruit farming. The service delivery amongst populations remains uneven. Only 62% of households have piped water in their yards, and 59.6%

access to flush or chemical toilets. About 50.3% of households receive refuse collection services, and 81% have prepaid electricity meters (COGTA, 2020; Thabo Mofutsanyana, 2022).

3.3.2 Fezile Dabi District Municipality

This district is situated in the northern Free State. Fezile Dabi contributes 18.3% to the provincial population. The district economy is diversified, driven by manufacturing, trade, agriculture and services, with Metsimaholo being the primary economic contributor. However, poverty and unemployment remain high, with 61.9% living below the upper poverty line and 36.7% unemployed. Rapid urbanisation and growth in informal settlements strain service delivery. Many municipalities lack Integrated Waste Management Plans, relying on disposal-focused approaches (Fezile Dabi District Municipality, 2022; COGTA, 2023).

3.3.3 Lejweleputswa District Municipality

This district is in the western part of the province. It includes historically mining-dependent towns such as Welkom and Virginia. The decline in mining has led to job losses and an unemployment rate of 36.5%, the highest in the province (Lejweleputswa District Municipality, 2017). The provision of infrastructure in this area has improved over time, with electricity access increasing from 61.6% in 1996 to 91.4% in 2011 and refuse removal rose to 81.8%. However, 13.3% of residents still lack piped water, and 3.3% have no sanitation access (Lejweleputswa District Municipality, 2017; CSIR, 2024).



Figure 3.3.1: The administrative districts and municipalities in the Free State Province

3.4 Selection criteria of the study areas

Eighteen hotspot landfills in sixteen towns were observed and documented during fieldwork conducted for two waste studies in the Free State, supported by existing literature on landfill sites in the Region. Every Free State town has at least one landfill, but some have two or more, such as Virginia and Phuthaditjhaba towns. The selection of the landfill sites for this study was based on proximity to human settlements and environmental resources and operational status, and activity level. Landfills and residential areas in the vicinity, namely Parys, Vredefort and Heilbron in the Ngwathe Local Municipality, Sasolburg in the Metsimaholo Local Municipality, Viljoenskroon in the Moqhaka Local Municipality, Virginia and Odendaalsrus in the Matjhabeng Local Municipality, Wesselsbron and Bothaville in the Nala local municipality, Theunissen and Winburg in the Masilonyana Local Municipality, Phuthaditjhaba and Harrismith in the Maluti-a-phofung Local Municipality, Paul Roux in the Dihlabeng Local Municipality, and Frankfort in the Mafube Local Municipality were included in the study. The 15 towns were situated in three district municipalities, namely Lejweleputswa, Fezile Dabi, Thabo Mofutsanyana, and the nine local municipalities included in the

study form a 60% and 45% representation of the parts of the Free State that were included in the study respectively.

3.5 Study population

The study population consisted of residents living near selected landfill sites in the Free State province, South Africa. This group was chosen based on their direct exposure to potential environmental and health hazards associated with waste management practices. The number of residents who were willing to participate per landfill cannot be estimated. The inclusion criteria encompassed adults 18 years and above who work or reside within a 2 km radius of the landfill sites at the time of data collection, which places them at a heightened risk of waste exposure. This age category did not require assent from parents to respond and was used because it was believed that individuals are mature enough to provide information on the impact of landfills on their immediate environment and health, and could make informed decisions (Suleman et al., 2015; De & Debnath, 2016; Ampofo, 2020). The immediate groups that were potential participants for the study in these areas varied from residents living in both formal and informal settlements, waste pickers, recyclers, and municipal site employees.

3.6 Sampling techniques and size

In instances where the inclusion of the entire population was impractical or where not all members of the target population could be identified, sampling techniques were utilised to collect data that are considered to reflect the characteristics of the broader population accurately (Wang & Cheng, 2020; Stratton, 2021). Given the exploratory and descriptive nature of the study, a non-probability convenience sampling method was utilised to select participants from the identified population (Udofia et al., 2017). A convenience sample was selected based on availability and willingness to participate. Residents living on and/or in the vicinity of the landfill were selected. The frequent visits to the landfill sites during fieldwork, which form the experience of the researcher, revealed that this method will be viable due to the daily fluidity of the research population.

For this study, the convenience sampling method, which is a form of non-probability sampling, was employed. This method does not allow for equal opportunity for all

members of the target population to be included in a study but depends on the willingness of the participants to participate, regardless of whether they were handpicked by the researcher and the fieldworker, referred by others, or voluntarily opted to take part in the study (Stratton, 2021). Despite being a non-probability sampling technique, it remains the most applied method in clinical research, due to the ease of access and availability to the participants (Elfil & Negida, 2017). Convenience sampling is widely applied in environmental health studies due to practical limitations such as community access, budget constraints, and informal settlement dynamics (Parikh et al., 2020; Stratton, 2021). Like other sampling methods, there are biases that could occur with this sampling method. Notably, motivation to participate may depend upon the interest one has in the research topic, a wish to express a dissatisfied point of view, or a desire to support one's specific opinions (Stratton, 2021). Therefore, a structured questionnaire guided the required answers to counteract this.

The number of participants approached and asked to participate in the study was 185, while the actual number of residents who were willing to participate in the study was 121. The uneven distribution of study respondents in towns was as follows: 4.13% in Parys, 5.79% in Vredefort, 3.31% in Heilbron, 10.74% in Sasolburg, 6.61% in Viljoenskroon, 6.61% in Virginia, 7.43% in Odendaalsrus, 1.65% in Wesselsbron, 3.31% in Bothaville 4.96% in Theunissen, 9.92% in Winburg, 14.88% in Phuthaditjhaba, 6.61% in Harrismith, 3.31% in Paul Roux, 10.74% in Bethlehem and 0% Frankfort

3.7 Data collection tools and techniques

In this section, the data collection tools and techniques, which include mapping, questionnaire distribution, and site observation by use of a checklist that were used for this study are discussed in detail.

3.7.1 Mapping using a Global Positioning System (GPS) device

This technique involves taking fieldtrips to the selected landfill sites. Landfill site locations were mapped with the help of a Garmin Global Positioning System (GPS) (mobile Etrex 10 model). The device was calibrated for 10 minutes, and a waypoint

was created for 90 minutes as recommended for good results in the guideline pamphlet. Next, the GPS coordinates indicating locations were saved on the device with the town names or distinctive locations where there was more than one landfill in the area. This medium-power device uses alkaline batteries; therefore, it is convenient to use for outdoor activities, especially in remote areas without the need to recharge. The distance of landfill sites from human settlements was measured and noted. After recording coordinates, a landfill boundary was marked in each site and the researcher created a waypoint, navigating towards the edge of the landfill to the closest point of the housing structures (distance within 2km) in the vicinity. The closest housing structure was also marked and labelled (e.g. Virginia 1). A study mapped diaper waste sites, also highlighting that future research should consider incorporating verifiable measurements such as GPS waypoints from one location of interest to another when conducting research of this nature (Kordecki et al., 2023).

3.7.2 Questionnaires

Structured questionnaires were used to assess the knowledge and perceptions of residents. Due to the diversity of ethnic groups at the dumpsite, the questionnaires were distributed to the participants in their preferred language, which was either Sesotho, English, or Afrikaans. These languages are also common in the Free State. For the Afrikaans language, a translator was hired to translate the documents (questionnaire, information sheet, and consent form). Translations from English to Sesotho were prepared by the researcher, whose home language is Sesotho and who understands the vernacular of the area language. The questionnaire was designed based on reviewed literature and past related studies (Oghuehi et al., 2022). Parameters of the questionnaire were sectioned A, B and C. Section A included demographic data and socioeconomic data (age, gender, nationality, education, family size, household income, employment opportunities, involvement in waste-picking). Section B inquired about their environment and livelihood (access to water and ablution amenities, energy sources, sanitation conditions, rental value, and crime in the areas). Section C gathered information on the health aspects of the participants (injuries sustained, health history and symptoms, healthcare visitation frequency, hospitalisation, smoking lifestyle, and response to disasters in their areas). The questionnaire was a combination of closed-ended and open-ended questions with

nominal, ordinal and Likert-scale options (*strongly agree, agree, disagree, strongly disagree*) (Ampofo, 2020).

A fieldworker who was knowledgeable in the three vernaculars and fluent in two (English and Sesotho) was recruited to assist in collecting residents' data in the Free State. The fieldworker was a Central University of Technology staff member who also originates from the Free State and was familiar with the identified areas. To provide them with a comprehensive knowledge of the study, including ethical processes and the objectives of the research project, a Google Meet meeting was scheduled where the information sheet, consent form and questionnaires were discussed before collection (Eshete et al., 2024). To simplify data collection, ways to approach participants and carry out data collection were discussed. The researcher, who also collected data, guided onsite, attended to enquiries and ensured that the right data collection procedure was followed. For safety purposes, reliable adults from each area under study who were willing to help navigate the area with us when collecting data were selected through recommendations, as needed, at disposal sites (e.g. the chair of a waste-pickers' association). Familiar faces assisted in putting other residents and waste pickers at ease. Their duty was to watch out for any danger and to advise on security measures to follow in their areas. They could also help in interpreting different dialects of their areas. They were informed of their right to withdraw from their duties whenever they felt they could no longer continue with their service provision. The safety personnel were required to indicate on a receipt the hours of service rendered so they could be compensated.

At the landfill site, the management or security personnel were informed of the reason for the visitation, where available. Ethical and permission letters were handed out to verify our claim before meeting with recyclers, waste pickers and residents who live at some sites. Data from waste pickers were collected both during offloading periods and most of the time when no offloading occurred. Offloading refers to the moment when a waste-filled truck arrives at the landfill site and unloads its contents. This period is typically characterised by waste pickers hurrying to the truck to retrieve recyclable or reusable materials (Nambuli et al., 2021). For nearby households, a door-to-door approach was used to collect data. After salutations and introductions, information sheets were handed out. In this document, the purpose of the research was explained for the residents to understand the value of their participation. If they were willing to

participate, they would be asked to sign consent forms. Because the questionnaire tool is reputable for a low response rate, they were therefore collected immediately after completion (Ezeah & Roberts, 2012; Cassim & Du Plessis, 2021). The residents completed questionnaires in the language they understand best and, where needed, they were assisted with writing because some may have had a limited educational background or no formal education. Only one person per household was allowed to participate to avoid repetition of information. Questionnaire administration lasted approximately 15 to 30 minutes, depending on the concentration and activities of each respondent (Udofia et al., 2017). A study conducted in Ethiopia preferred to blind-study participants to the objectives and hypothesis during the data collection process to minimise bias in the study (Aydano et al., 2023); however, in this study, no information was withheld in order to remove any coercive control in their willingness to participate.

3.7.3 Checklist

A structured checklist was used to evaluate the environmental conditions in the vicinity of disposal sites through observations. Observations were used to gain insights into a certain setting and actual behaviour without trying to influence the setting with their presence, as opposed to reported behaviour or opinions (Busetto et al., 2020). Characteristics of the landfill and the conditions of its proximate environment (human settlements and natural resources) were evaluated using a structured checklist. The checklist was adapted from the one developed by AfriForum and the Minimum Requirements for Waste Disposal by Landfill guidelines and modified to suit the objective (Department of Water Affairs and Forestry, 1998; De Klerk, 2021). Checklists were used during or after the observations, depending on feasibility and acceptability, as people tend to change behaviour and practices when they know that they are observed (Hawthorne effect) (Busetto et al., 2020; Cassim & Du Plessis, 2021). Observations were conducted irrespective of whether the situation portrayed negative or positive outcomes, to avoid bias in the study. When permitted to do so, pictures of the environmental conditions were taken, excluding human subjects.

3.8 Validity and reliability of the study instruments

3.8.1. Validity

A research instrument is considered valid when it accurately measures the specific

concept or construct it is intended to assess (Ampofo, 2020). Face validity is in relation to the misunderstanding and misinterpretation of the question, and this is where the researcher or a content domain expert simply looks at the contents of the instrument and decides whether it looks like it will measure what it is supposed to measure (Robertson, 2017). For this study, the researcher gave five potential participants a pretest and asked them to rate out of 10 if the instrument (questionnaire) looked like it measured what it was supposed to measure, and the responses were between 8 and 10, which was a high score. Another form of validity test is the content validity, which is the extent to which the instrument adequately captures or represents all relevant aspects of the topic or construct being studied (Ampofo, 2020). To ensure the content validity of the data to be collected, the questionnaires were peer reviewed by the study promoters and qualified field experts, and adjustments were made based on the responses to improve clarity and suitability. Additionally, questionnaires that were translated into other languages (Sesotho and Afrikaans) were backtranslated into the developmental language (English) to ensure that they gave the same meaning.

3.8.2 Reliability

Reliability refers to the consistency of a research instrument, indicating its ability to produce the same results under consistent conditions each time it is used (Udofia et al., 2017; Ampofo, 2020). The questionnaires were tested on residents in five towns of the Free State to validate the contents and check for ambiguity, and then adjustments were made where required. After incorporating feedback from pre-testing and making changes, the researcher wrote to the ethical committee to seek approval before directly administering it to study participants. This pilot was conducted to ensure the research instrument meets a suitable level of quality in terms of credibility and dependability (Fashina et al., 2020, 2021). Only questionnaires with 95% or more completion were included for analysis.

3.9 Data analysis

The GPS coordinates of the landfill sites recorded by the mobile GPS device were captured in Microsoft Excel and converted into a CVX file. The CVX file and shapefiles downloaded from SANBI Biodiversity GIS (public domain data sets) were sent to a data engineer who ran an analysis on Quantum Geographic Information System (QGIS) 3.44 model to create the visualizations (Open Street map) showing where each

landfill is located, and to determine the distance from the nearest buildings, waterbodies, waterways and land use areas.

Numerical and nominal data collected by the questionnaire and checklist were coded and captured by the researcher in a Mentimeter application. A biostatistician conducted any further analysis. Descriptive statistics, namely frequencies and percentages, were calculated for categorical data, and means, standard deviations, medians, and percentiles were calculated for numerical data. Inferential analysis was carried out using IBM SPSS Version 29.

3.9.1 Group differences

This section examines group differences to assess whether a particular variable varies across different categories of another grouping variable. Identifying such differences can help highlight potential patterns or disparities within the data. The Kruskal-Wallis Test was applied in this section to determine statistical differences in the median values of healthcare visits and the perceived diseases/conditions/ symptoms, and also residents' housing type and rodent and vector proliferation. This is a non-parametric test used to compare more than two independent groups when the data do not meet the assumptions required for parametric tests (Pallant, 2010). It helps to determine whether there are statistically significant differences in the distribution of a variable across the groups. The Fishers exact test was also conducted to determine if there is a significant association between municipal water and usage of wood for heating purposes. This non-parametric tests are used to determine two categorical binary values when sample sizes are small, and cell frequencies are low (Pallant, 2010). 3.9.2 Relationship/association of environmental and health determinants.

Cross-tabulations were applied to investigate the interactions and patterns between the variables. This analytical technique is widely used in research to explore relationships between two categorical variables. By presenting the frequency distribution of one variable relative to another, crosstabulations provide valuable insights into potential associations, patterns and relationships within the data.

Three tables were generated from the output. The cross-tabulation table presents the frequency of responses across the categories of two variables, illustrating how responses in one variable are distributed across the groups of the other. The Chi-

Square Test table then assesses whether the observed differences in these distributions are statistically significant. A significance value (p-value) of 0.05 or below indicates a statistically significant relationship between the variables, whereas a value greater than 0.05 suggests that any observed differences may be attributable to chance (Kwak, 2023; McLeod, 2025). The third output, the Symmetric Measures table, includes the phi coefficient, which reflects the strength of any association between the two variables. Phi values range from 0 (no association) to 1 (strong association). Cohen (1988) proposed guidelines for interpreting the magnitude of correlations and estimating statistical power. According to these conventions, correlation coefficients of $r = 0.10$, $r = 0.30$, and $r = 0.50$ represent small, medium and large effect sizes, respectively.

3.10 Ethical considerations

Ethical clearance was sought through an application to the Health Sciences Research Ethics Committee at the University of the Free State (UFS-HSREC), and approval was subsequently granted. The ethical clearance reference number is UFS-HSD2023/1726/0110. Permission to conduct the study in the selected areas in the Free State was also obtained via the National Health Databases application system of the Free State Department of Health, with the approval reference number FS2023/12/006. A signed, written consent to participate in the study was requested, and participation in the study was solely voluntary before commencing. The researcher assured participants that data were not used for any other reasons except for academic or scientific purposes and explained their full rights to refuse and to withdraw from participation at any time during the interview and distribution of the questionnaire. Photographs were taken only with the participants' consent; however, no video recordings were made for this study. The contact details of the study promoter and UFS-HSREC were included in the information sheet for participants to report any misconduct during data collection.

3.11 Data management

The completed questionnaires and consent forms were handled by the Protection of Personal Information (POPIA) Act 4 of 2013 principles. According to the Protection of Personal Information Act (POPIA) for researchers, any research involving human participants requires ethical approval from a recognised or constituted research ethics

committee, and that information is to be protected in accordance with Sections 14, 15, and 17 of the National Health Act 61 of 2003 about confidentiality (RSA, 2013b, 2003). The questionnaires were identified by numeric values and not names, towns, or any other descriptions that could be identified easily (e.g. Town 1 or T1). The questionnaires were stored in a biometric fingerprint-lock briefcase or custom-lock safe with a code and locked in the vehicle boot when travelling. Relevant studies have also highlighted the use of digitised survey tools such as Survey 123 to create standardised, structured questionnaires, which could be saved automatically after administration, for fieldworkers to use on a handheld device (Kistan et al., 2020; Schenck et al., 2023). The use of this tool is much safer than the printed paper questionnaire; however, it would require the availability of adequate tablet devices.

At the end of each data collection day, data were captured into a Mentimeter application, and the study supervisors checked both the data entered and the forms for quality control. Pictures were uploaded to a POPIA-compliant data storage platform for research data storage called SharePoint. After approval of data capturing, the forms were shredded and discarded at the institution (Central University of Technology) to avoid traceability. The only people who have access to the collected data, other than the study's main supervisor, are the Library Information System personnel who manage the institution's SharePoint software for guidance and the biostatistician for analysis purposes. The biostatistician and the data engineer were required to sign a non-disclosure agreement. No one outside of the research group had access to data, and all data were anonymised and encoded before sharing.

3.12 Conclusion

This chapter outlined a quantitative methodology grounded in the positivist paradigm to investigate environmental and health impacts associated with landfill proximity in the Free State. A cross-sectional, descriptive design, supported by convenience sampling, enabled the collection of empirical data from exposed communities. Multiple data collection tools (GPS mapping, questionnaires, and checklists) enhanced methodological triangulation. Validity, reliability, ethical compliance, and robust data analysis procedures ensured the credibility of the findings to address the study objectives and support generalisable, evidence-based conclusions.

CHAPTER FOUR – INTERPRETATION OF RESULTS

4.1 Introduction

The purpose of this study was to assess the state of the area where 121 respondents live (near disposal sites) and to determine the environmental and health impacts of waste they experience in their area. The analysis includes the following outputs: descriptive statistics, normality assessment, measures of central tendency, reliability analysis, cross-tabulations, group differences, and correlations.

4.2 Sociodemographic and economic information of residents

This section covers presents the biographical characteristics of the respondents.

4.2.1 Gender distribution of respondents

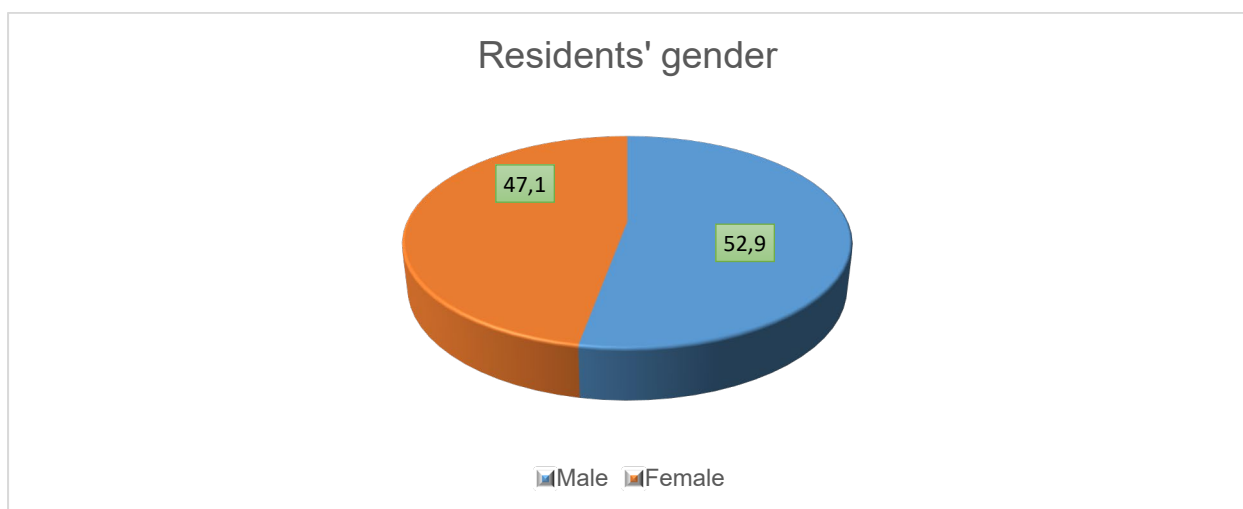


Figure 4.2.1: Gender distribution of participants

The results in Graph 1 show that the majority of respondents living near or around landfill sites are male (52.9%), while 47.1% are female.

4.2.2 Age category of respondents

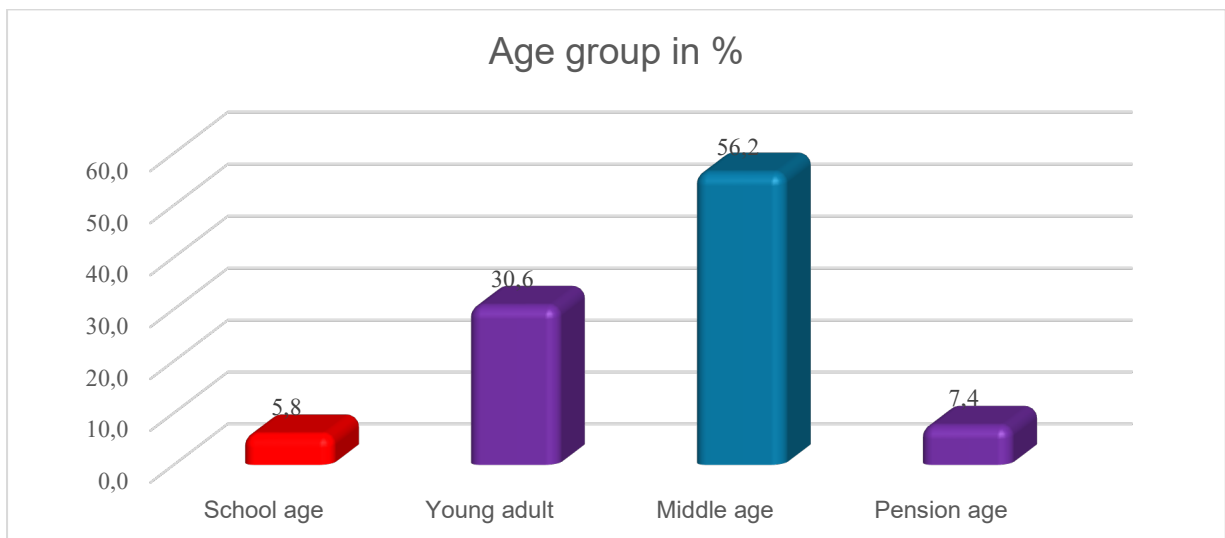


Figure 4.2.2: Age category of participants

Figure 4.2.2 reports that the results show that over half of the respondents (56.2%) were middle aged (between 36 and 59 years), followed by young adults (30.6%) aged 22–35 years and pensioners (7.4%) aged 60 years and above. Only 5.8% of respondents were aged 18–21 years.

4.2.3 Respondents' nationality distribution

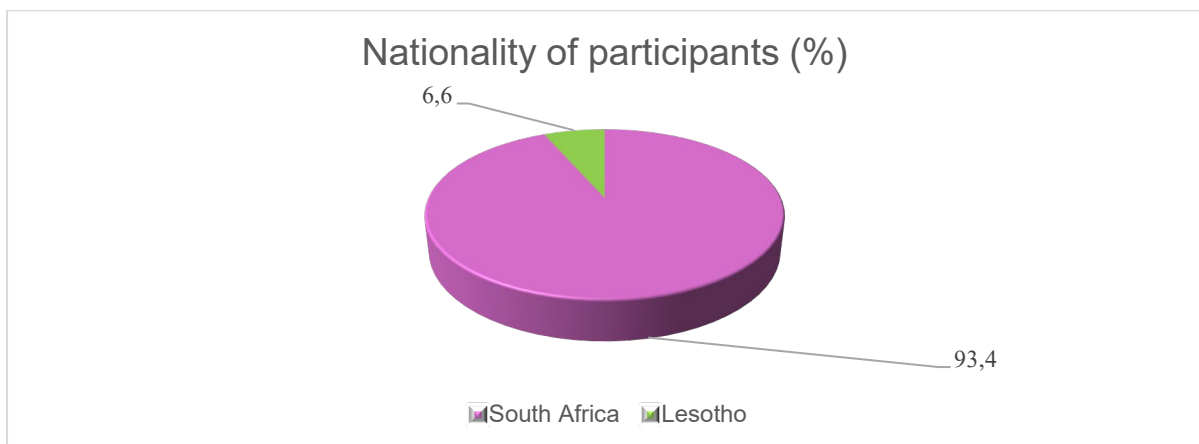


Figure 4.2.3: Respondents' nationality distribution

The results presented in Figure 4.2.3 indicate that the majority of respondents (93.4%) were South African citizens, while a smaller proportion of 6.6% were Lesotho nationals.

4.2.4 Place of birth distribution across South African provinces

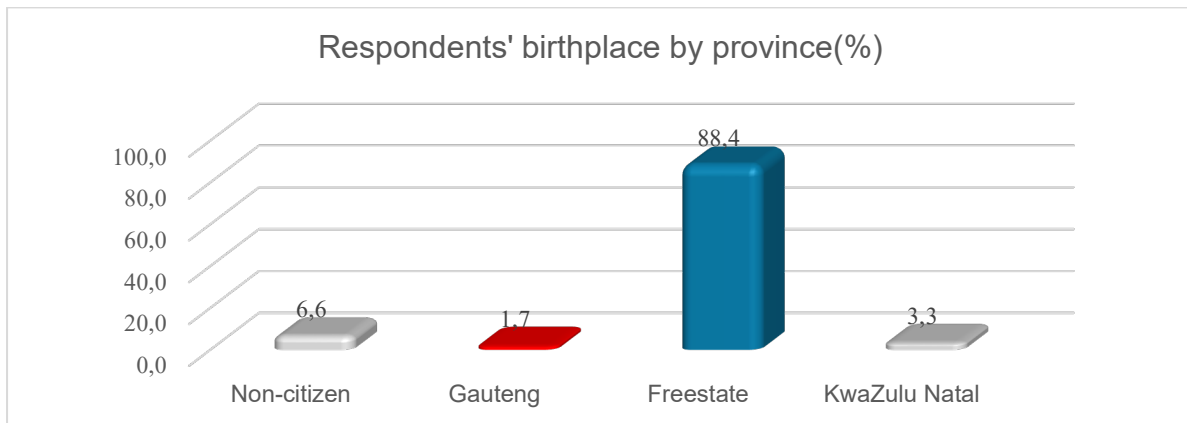


Figure 4.2.4: Place of birth distribution across South African provinces

Figure 4.2.4 indicates that most respondents (88.4%) were born in the Free State province, followed by 3.3% in KwaZulu-Natal, while the smallest proportion (1.7%) originated from Gauteng.

4.2.5 District-level distribution of participants

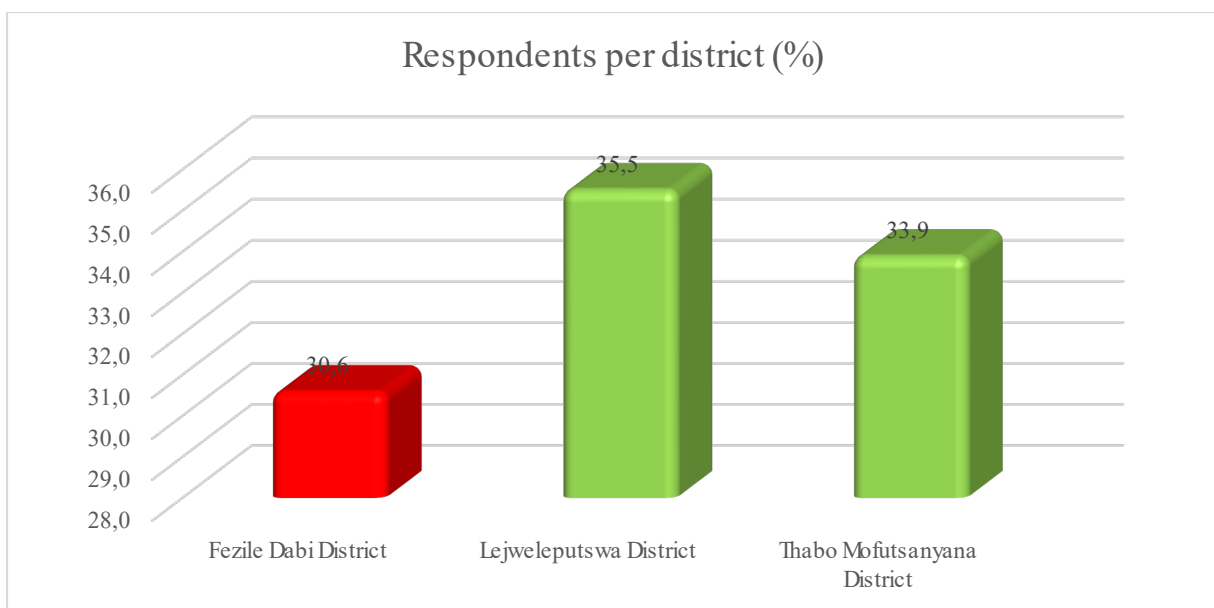


Figure 4.2.5: District-level distribution of respondents

The results in Figure 4.2.5 illustrate that 35.5% of respondents reside in the Lejweleputswa district, followed closely by 33.9% in the Thabo Mofutsanyane district, and 30.6% in the Fezile Dabi district.

4.2.6 Municipal-level distribution of respondents

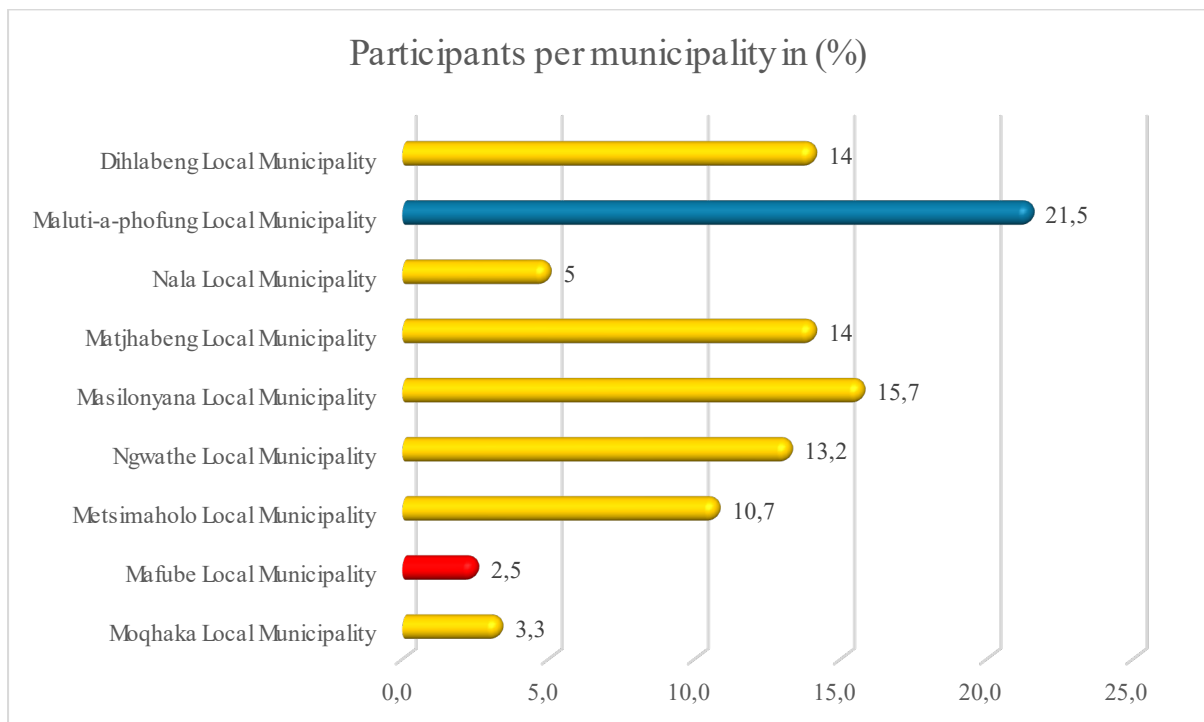


Figure 4.2.6: Municipal-level distribution of respondents

Figure 4.2.6 reveals that 21.5% of respondents resided in the Maluti-a-Phofung Local Municipality, followed by 15.7% in Masilonyana, while the lowest proportion (2.5%) was recorded in the Mafube Local Municipality. The uneven distribution reflects the demographic and special characteristics of the selected municipalities, where population size, urbanisation level, and proximity to landfill sites vary considerably.

4.2.7 Educational profile of the respondents

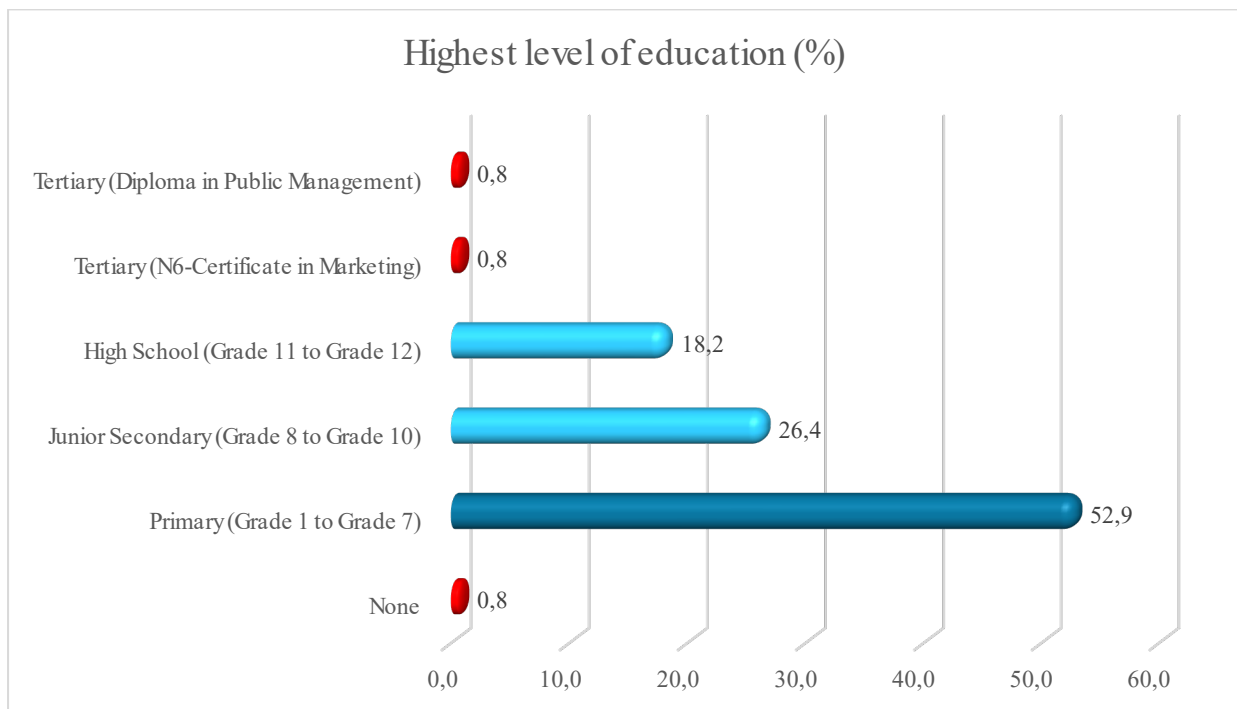


Figure 4.2.7: Educational profile of the respondents

As shown in Figure 4.2.7, the majority of respondents (52.9%) had a primary level of education (Grades 1–7), followed by 26.4% who had completed junior secondary education (Grades 8–10) and 18.2% who had completed high school (Grades 11–12).

4.2.8 Employment status of respondents

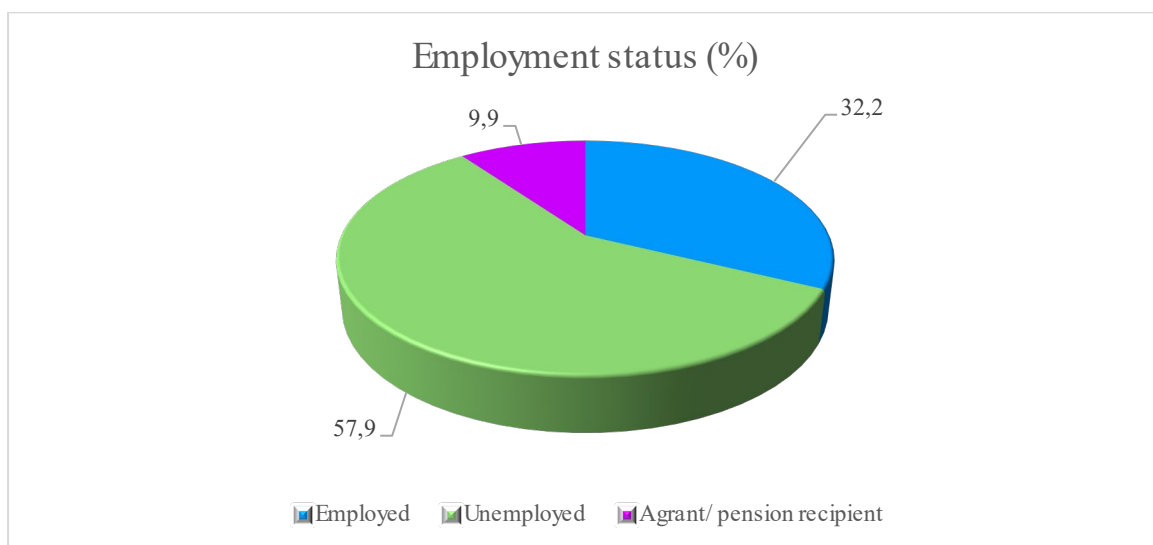


Figure 4.2.8: Employment status of respondents

According to Figure 4.2.8, most respondents (57.9%) were unemployed, 32.2% were employed, and only 9.9% are grant or pension recipients.

4.2.9 Occupational categories of respondents

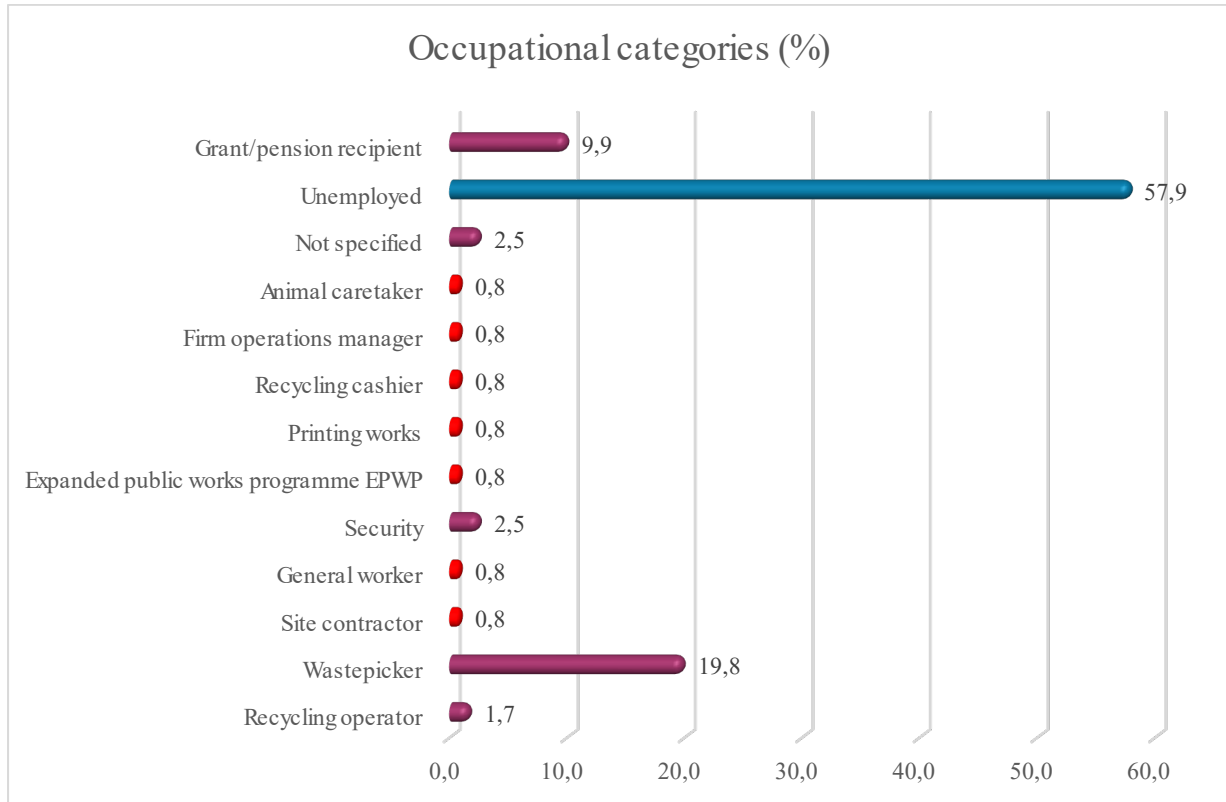


Figure 4.2.9: Occupational categories of respondents

The results in Figure 4.2.9 illustrate that over half of the respondents (57.9%) are unemployed, followed by 19.8% who worked as waste pickers and 9.9% who relied on grants or pensions. Smaller proportions were engaged in informal businesses such as animal caretakers, recycling cashiers, and printing work.

4.2.10 Waste picking status of respondents

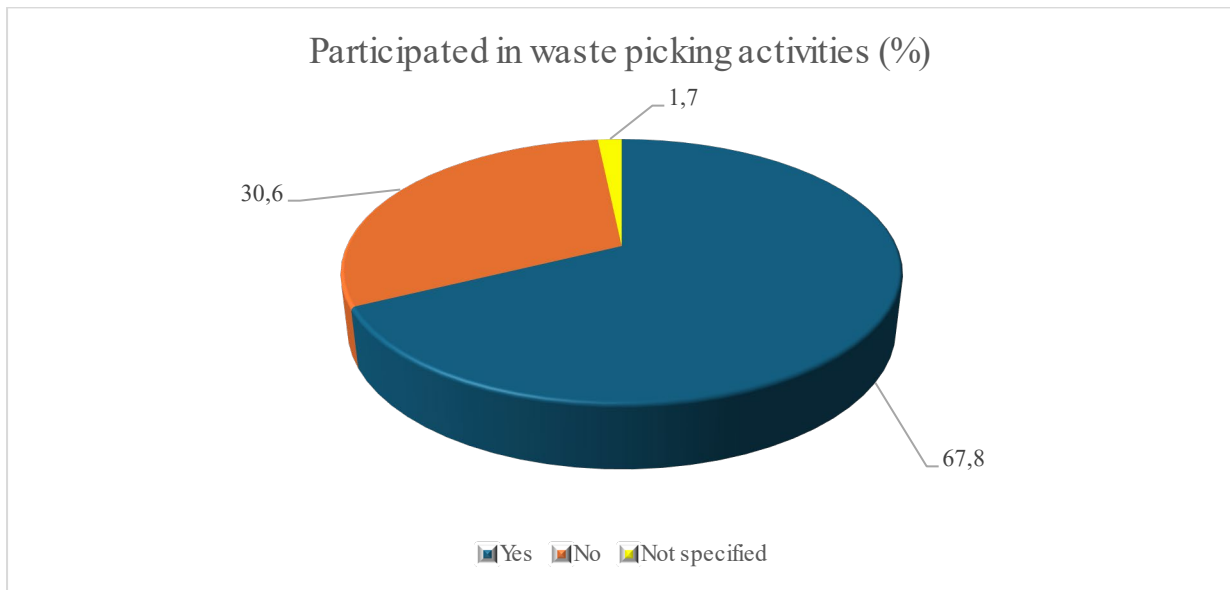


Figure 4.2.10: Waste picking status of respondents

Figure 4.2.10 shows that most respondents (67.8%) confirmed that they had participated in waste picking activities in the past or still actively involved, while 30.6% said they had never participated in waste picking. Only 1.7% of respondents did not specify or recall the state of their involvement.

4.2.11 Type of housing occupied by respondents

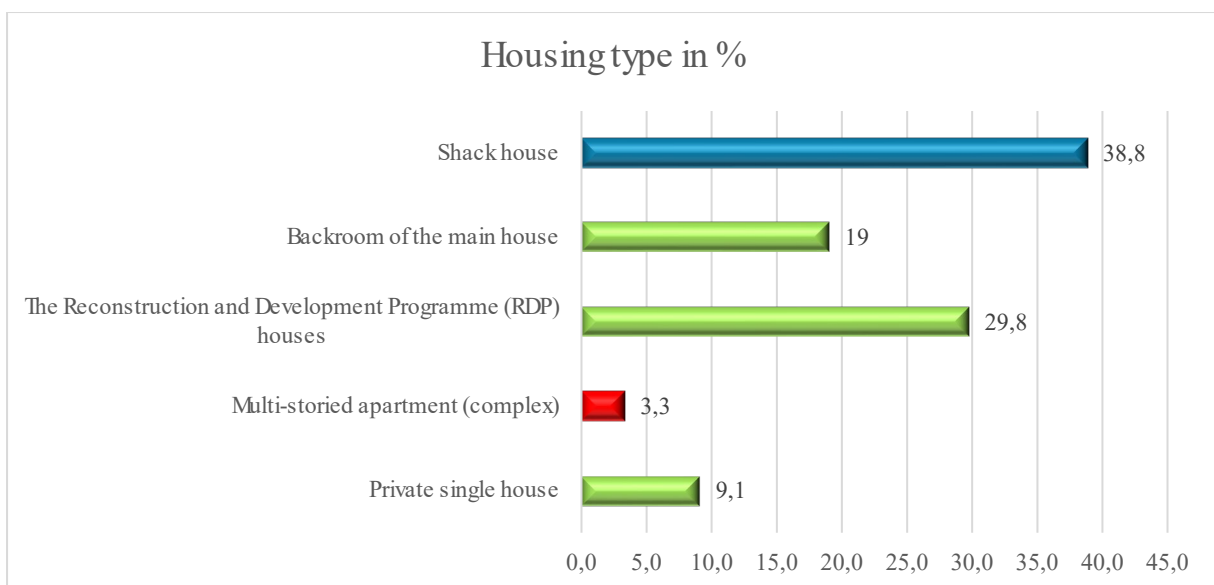


Figure 4.2.11: Type of housing occupied by respondents

Figure 4.2.11 reports that the largest proportion of respondents (38.8%) lived in shack houses, followed by 29.8% in Reconstruction and Development Program (RDP) houses. Additionally, those living in backrooms of main dwellings and private properties were 9.1%, and only 3.3% lived in multi-storied apartments (complexes).

Table 3: Average number of bedrooms in a household

N	Mean	Std. Deviation
121	1,64	0,904

Table 3 shows that respondents have an average of two bedrooms in their households.

4.2.12 Household composition of minors below 18 years

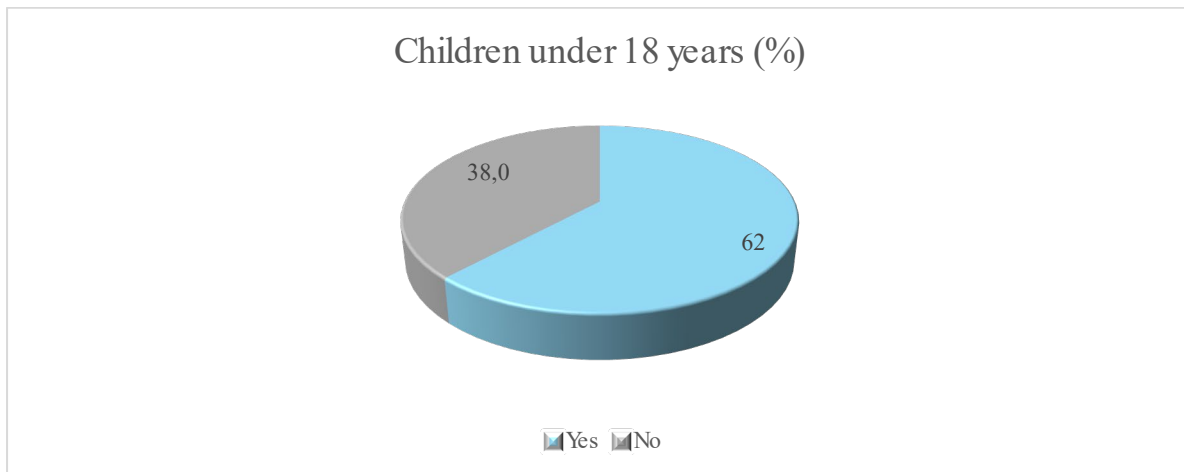


Figure 4.2.12: Household composition of minors below 18 years

Figure 4.2.12 shows that most households (62%) included children under the age of 18, the typical school-going age, while 38% consisted solely of adults.

Table 4: Number of children per household unit

N	Mean	Std. Deviation
121	1,56	1,760

The results in Table 4 show that respondents have an average of two children living in their households.

The respondents reported an average of approximately two children per household.

4.2.13 Household composition by size

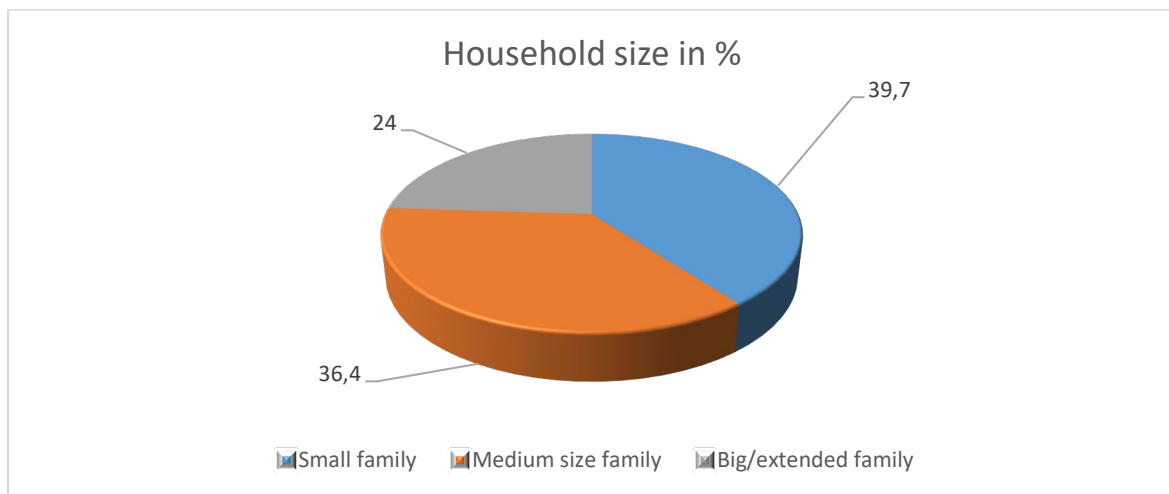


Figure 4.2.13: Household composition by size

Figure 4.2.13 shows that 39.7% of respondents belong to small families comprising 1 to 3 members, 36.4% to medium-sized families with 4 to 6 members, and 24% to large or extended families consisting of 7 or more members. The determination of a household size and number of members is subjective to a region. One to three household members is the standard definition of an average or small family and is common in European countries. A medium family is a frequently consisting of four to five members who may include one additional extended family member particularly in African countries increasing the range to six. Lastly a big family or nuclear family consists of about seven and more family members and is common in African, Asian and Middle East family settings (United Nations [UN], 2017a; World Population Review, 2026)

4.2.14 Duration of residence near the landfill area

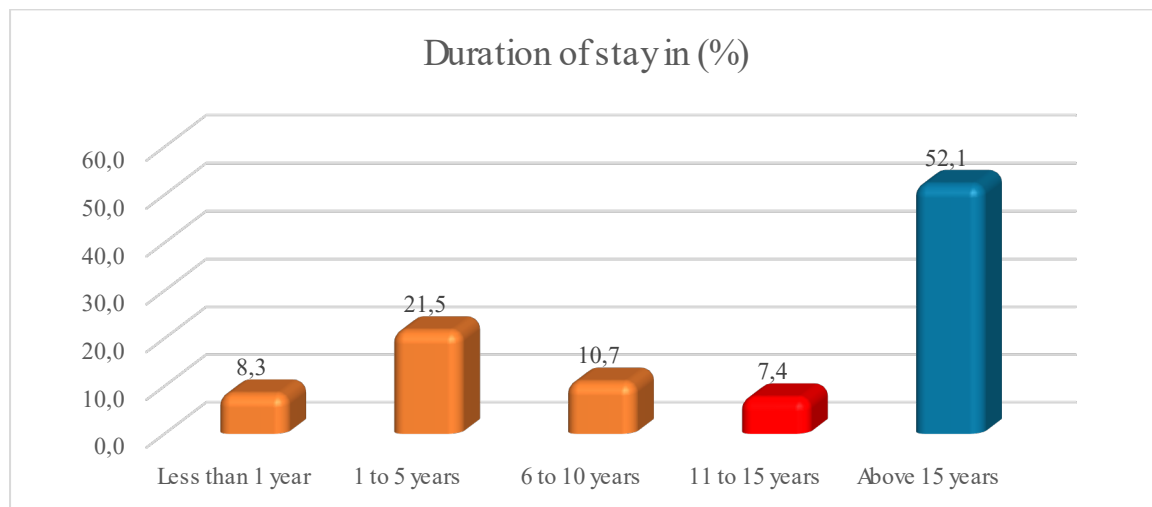


Figure 4.2.14: Duration of residence near the landfill area

Figure 4.2.14 indicates that the majority of respondents (52.1%) have resided in their area for more than 15 years. This is followed by 21.5% who have lived there for 1 to 5 years, and 10.7% who have been residents for 6 to 10 years. The smallest proportion of respondents (7.4%) reported living near the landfill for 11 to 15 years.

Table 5: Cumulative monthly income

N	Mean	Std. Deviation
121	1877,85	1688,961

According to the results in Table 5, respondents have an average combined monthly income of R1 877,85.

Table 6: Relationship between housing type and combined monthly income

Ranks			
Housing type		N	Mean Rank
Combined monthly income (R)	Private single house	11	76,86
	Multi-storied apartment (complex)	4	51,38
	The Reconstruction and Development Programme (RDP) houses	36	54,49
	Backroom of the main house	23	63,52
	Shack house	47	61,86
	Total	121	

Table 7: Kruskal-Wallis H for monthly income

Test Statistics^{a,b}	
	Combined monthly income (R)
Kruskal-Wallis H	3,946
Df	4
Asymp. Sig.	0,413
a. Kruskal Wallis Test	
b. Grouping Variable: Housing type	

According to the results presented in Tables 6 and 7, respondents residing in private single houses recorded the highest mean rank (76.86), suggesting that this group generally reported higher combined monthly incomes. This was followed by those living in backrooms (63.52), shack houses (61.86), RDP houses (54.49), and multi-storied apartments, which had the lowest mean rank (51.38). However, the difference was not statistically significant ($p = 0.413 > 0.05$), indicating that the observed variation in combined monthly income across the five housing types is likely attributable to random variation rather than a true effect.

4.3 Description of landfill site conditions under study

The section below shows the landfill locations and distance from geographic features, describe observed environmental conditions and activities.

4.3.1 Landfill location and the distance from geographic features

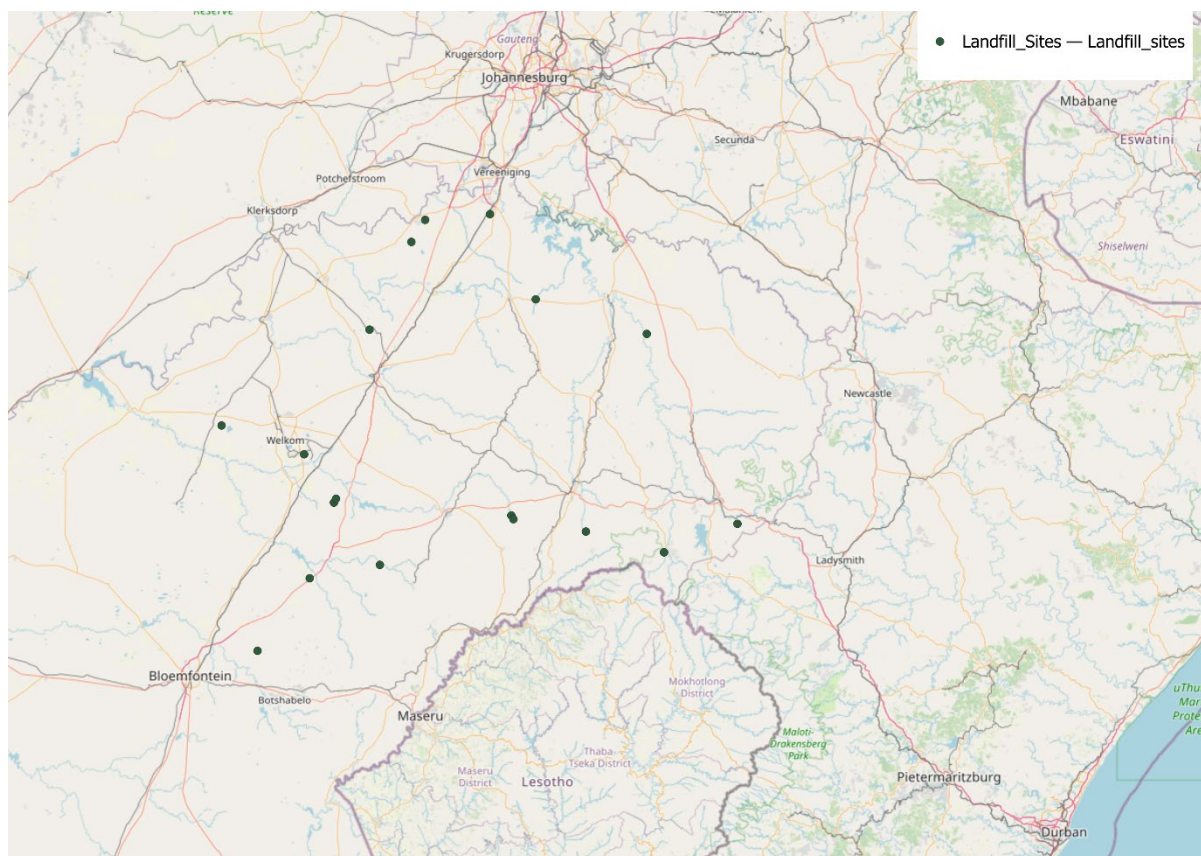


Figure 4.3.1: Open Street map showing landfill site locations and under study in the Free State.

Table 8: Location of the disposal sites and the distance from land use (agricultural or commercial), water sources, and waterways

Locations	Latitude S	Longitude E	Land use (km)	Water bodies (km)	Water ways (km)
1. Virginia 1	-28.2841667	27.00444444	8.71	5.82	1.83
2.Odendaalsrus	-28.2658333	27.01611111	6.38	7.23	2.10
3. Bothaville	-28.9975	26.58555556	6.73	6.28	13.34
4.Wesselsbron	-27.9113889	26.38805556	1.60	4.61	17.26
5. Paul Roux	-28.3463889	27.97805556	5.09	2.24	4.67
6. Bethlehem	-28.3644444	27.98944444	7.29	3.35	10.16
7.Viljoenskroon	-27.4461111	27.2	2.94	3.01	30.97
8. Maqhekung- Phuthaditjhaba	-28.4241667	28.38722222	0.75	0.14	10.35

9.Pereng-Phuthaditjhaba	-28.5242306	28.81581944	14.70	1.99	1.68
10. Vredefort	-27.0183333	27.42944444	4.95	2.79	2.38
11.Heilbron	-27.2983333	28.11194444	8.75	3.09	1.14
12.Sasolburg	-26.8825	27.86083333	1.42	1.20	20.84
13. Frankfort	-27.4666667	28.72138889	2.68	9.42	4.42
14. Harrismith	-28.3869444	29.21861111	10.42	4.13	8.57
15. Virginia 2	-28.0508333	26.84138889	3.05	2.09	16.71
16. Theunissen	-28.6488889	26.87166667	11.09	11.75	2.91
17. Winburg	-28.5847222	27.25694444	12.21	11.69	11.18
18. Parys	-26.910866	27.505161	2.10	2.04	20.59

Table 8 above presents that half the number of landfill sites were within a distance of 5 km from land use, four (22%), which were within 2 km and one below 1 km, situated only 750 m away from the landfill. Land use is defined as the manner in which land may be used lawfully in terms of a land-use scheme or in terms of any other authorisation, which includes residential, agricultural, commercial, industrial and conservation areas (RSA, 2013c; TownPlanner, 2025) and does not explicitly include informal settlements, which are considered to be outside formal land-use control. About 11 (61.1%) of the landfills were within 5 km of waterbodies, six (33.3%) were within 2 km, and one was below 1 km, situated only 140 m from the waterbodies. The waterbodies in this context are inland water sources that include groundwater systems, wetlands, lakes, pans, dams and reservoirs (South African National Biodiversity Institute [SANBI], 2019). Lastly, the table shows that the distance of sites from 7 (38.9%) of the landfills were within 5 km of waterbodies, four (22%) were situated within 2 km, and one was within 1 km away from the waterbodies. The inland waterways in the Free State comprise specific types of water bodies or channels acting as transportation routes, i.e. major river systems such as the Orange River, Vaal River, Klip River and Caledon River, including the artificial lakes and dams that are largely used for crop irrigation (Free State Provincial Spatial Development Framework [FSPSDF], 2024).

Table 9: Distance of landfills from residential areas (km)

N	Mean	Std. Deviation
121	1,11	0,776

The results in Table 9 show that respondents live an average of 1.11 km from the site. The distances represent the closest proximity of human habitation, irrespective of whether the settlements are classified as formal or informal. Annexures 1.1 to 1.4 below show settlements and institutions very adjacent to the sites and on the landfill site.

Table 10: Description of landfill sites' conditions and management in alignment with the DWAF minimum requirements of a landfill site

Minimum Requirements	Frequency and percentage of cases		
	Yes	Partially	No
1. Signs erected in the appropriate official languages indicating distance and route leading to the landfill site	6 (33.3%)		12 (66.7)
2. The route leading to the site allows two-way traffic	7 (38.9%)		11 (61.1%)
3. Information boards at the gate indicating what type of waste can be disposed of and site operating hours	6 (33.3%)		12 (66.7%)
4. There is 24-hour security personnel for control	2 (11.1%)		
The landfill site has a fence	4 (22.2%)	5 (27.8%)	9 (50%)
5. (a) Fence is 1.8 m high (where fencing is available, n=9)	4 (22.2%)	5 (27.8%)	
6. (b) Type of fence used (where fencing is available, n=9)	1 (5.6%)		
(i) Barbed wire fence			
(ii) Precast concrete panel		4 (22.2%)	
(iii) Galvanised steel (clear view) fence	2 (11.1%)		
(iv) Diamond link wire mesh with razor wire topping	1 (11.1%)	1 (11.1%)	
7. Vehicles are inspected upon arrival to confirm the type of waste entering the site		5 (27.8%)	13 (72.2%)
8. There are offices and ablution facilities	3 (16.7%)	2 (11.1%)	13 (72.2%)
9. There is clean water access on site	5 (27.8%)		13 (72.2%)
10. There is electricity	4 (22.2%)		
11. There is a weighbridge on site		2 (11.1%)	
12. Landfill gas monitoring equipment is installed			18 (100%)
13. There is a retention dam for leachate control	1 (5.6%)		17 (94.4%)
14. There is an emergency assembly and emergency control equipment on site (e.g. fire hydrants)			

15. Staff members wear personal protective equipment (gloves, masks, overalls, eye shields)		6 (33.3%)	12 (66.7%)
16. There is a clear waste operating management plan	2 (11.1%)		16 (88.9%)
17. The emergency evacuation plans are available onsite	2 (11.1%)	1 (5.6%)	15 (83.3%)
18. Waste burning does not occur onsite			18 (100%)
19. Litter is contained inside the landfill			18 (100%)
20. Leachate is not trickling/flooding	9 (50%)		9 (50%)
21. The active landfill area has minimal birds, insects, and rodents			18 (100%)
22. Noise is controlled		5 (27.8%)	13 (72.2%)
23. Dust is controlled	1 (5.6%)		17 (94.4%)
24. Odours are controlled			18 (100%)
25. Medical waste is prohibited on-site	4 (22.2)		14 (77.8%)
26. Animal waste (carcass, stomach contents, bones, and blood) is prohibited on-site	2 (11.1%)		16 (88.9%)
27. Waste tyres are prohibited on-site			18 (100%)
28. E-waste is prohibited on-site			18 (100%)
29. There are waste pickers at the landfill	18 (100%)		
30. Recycling facilities are available on-site	3 (16.7%)		15 (83.3%)
31. Children are not present on-site	8 (44.4%)		10 (55.6%)
32. Domestic animals do not scavenge onsite			18 (100%)
33. No people are living on-site	7 (38.9%)		11 (61.1%)

Table 10 above presents the characteristic features of the landfill sites under study. The assessment revealed that half of the landfill sites lacked fencing and, where available at five sites (27.8%), they were dilapidated fences resulting from vandalism and forced entry, or unsuitable for containing waste litter, as shown in the Annexure 1.9. Only four sites (22.2%) were fully fenced and properly maintained. Where fencing existed, it was typically 1.8 metres high, with cement palettes being the most preferred material, followed by galvanised steel and diamond wire mesh with razor-wire topping. Annexures 1.7, 1.8 and 1.10 show vandalised landfill fences.

Basic staff facilities such as shelters, ablution blocks, and clean water were present at five sites, of which three (16.7%) were in good condition and two (11.1%) were vandalised and left unusable, as shown in Annexures 1.11 and 1.13. Vehicle registration and minor inspection at entry were recorded at five (27.8%) landfills, capturing information such as vehicle origin, time of entry, and registration details, though the contents of waste loads were not inspected.

Organised waste-picker associations are present and active at a few landfill sites, providing a degree of regulation and conflict resolution, including adherence to safety rules such as avoiding waste off-loader vehicles, minimising noise, and refraining from waste burning practices. At sites with active staff supervision, vehicle speeds were limited to 20 km/h, reducing dust and noise, but at the majority of sites this requirement was not complied with. However, only two sites (11.1%) had operational plans and emergency evacuation procedures available onsite, while 15 sites (83.3%) lacked such documentation, as shown in Annexure 1.15.

Only three sites (16.7%) had formal recycling facilities with designated buildings, compactors and dedicated staff. These facilities either acted as intermediaries between waste pickers and buyers or directly purchased recyclable materials. Children and infants were observed at eight (44.4%) landfills, as shown in Annexures 1.16 to 1.17, either participating in waste picking or accompanying parents, particularly where no security personnel were present to prohibit entry. These sites were overseen by contracted personnel or Extended Community Worker Programme (ECWP) employees appointed by local municipalities. While staff were equipped with personal protective equipment (PPE), compliance with safety practices was inconsistent. Waste pickers who formed part of the recognised association, such as the Waste Picker Association, had partial personal protective equipment, including overalls and reflectors, while waste pickers operating individually did not have any form of PPE, as shown in Annexures 1.18 and 1.19, respectively.

Infrastructure was generally poor: most sites had no weighbridges, and the two sites (11.1%) that did, had non-functional equipment, as shown in Annexures 1.20 and 1.21. Only three landfills had working machinery such as bulldozers or excavators typically to push waste to the sides to make way for incoming waste vehicles, as shown in Annexures 1.22, 1.23 and 1.25. One site operated a water tanker to suppress dust

and odours by wetting the soil in Annexure 1.24. No sites applied lime or had landfill gas collection or monitoring systems in place.

Medical waste, including discarded medicines, syringes, sanitary products, diapers, bandages and swabs was observed in the majority of sites, mixed with general waste, as shown in Annexures 1.26 to 1.31. Workers and guards also recorded incidents involving deceased fetuses and fatalities among waste pickers, which were typically reported as natural deaths by authorities. Chemical waste such as aerosols, vehicle oils and paint containers from household and workshops, as well as various industrial waste, were seen disposed of in several landfill sites as shown in Annexures 1.32 to 1.33.

Due to inadequate fencing, ineffective management of disposed waste, and limited monitoring at the entrances of most landfill sites, domestic animals, including cattle, pigs, goats and dogs, as well as wildlife, particularly birds and burrowing small mammals, were frequently observed scavenging for food and edible organic waste, and even inhabiting the landfill sites, as illustrated in Annexures 1.34 to 1.38.

Severe vector and vermin infestations were common, with flies, mosquitoes, rats, and occasionally snakes observed by waste pickers. Animal waste, including bones, hides, carcasses, and blood, was prevalent in 16 sites (88.9%), primarily from abattoirs and households as shown in Annexures 1.38 to 1.41, which also attract rodents and vector proliferation as shown in Annexures 1.42 to 1.43.

Tyres were observed at all landfills, and some were submerged in leachate, while others were burned as shown in Annexures 1.44 and 1.45. Although some efforts towards REDISA tyre collection were underway in other landfill sites, implementation remained limited. Leachate pools and leachate-filled trenches were present on approximately half of the sites, likely exacerbated by seasonal rainfall as shown in Annexures 1.46 to 1.47. Electronic waste (e-waste) was also received at all sites, often stripped for valuable metals by waste pickers on arrival before final disposal.

Open burning of waste was observed at all landfills, with visible signs of ongoing combustion. As a measure to reduce waste volumes, or 'clean' e-waste, which is a term used to describe the burning of plastic or fibre components to extract valuable metals like copper, waste was burned and had residues at all sites during site

visitations. There are also unclear speculations about whether the burning may persist in relation to unmonitored landfill gas, as all sites were non-engineered and lacked gas monitoring equipment or simply due to human intervention. Annexures 1.48 to 1.53 below shows some of the landfill sites that were burnt.

4.4 Access to resources and amenities in households in the vicinity of landfill sites

In this section, participants mentioned their drinking water sources, energy sources, the availability and type of sanitary facilities.

4.4.1 Sources of household drinking water

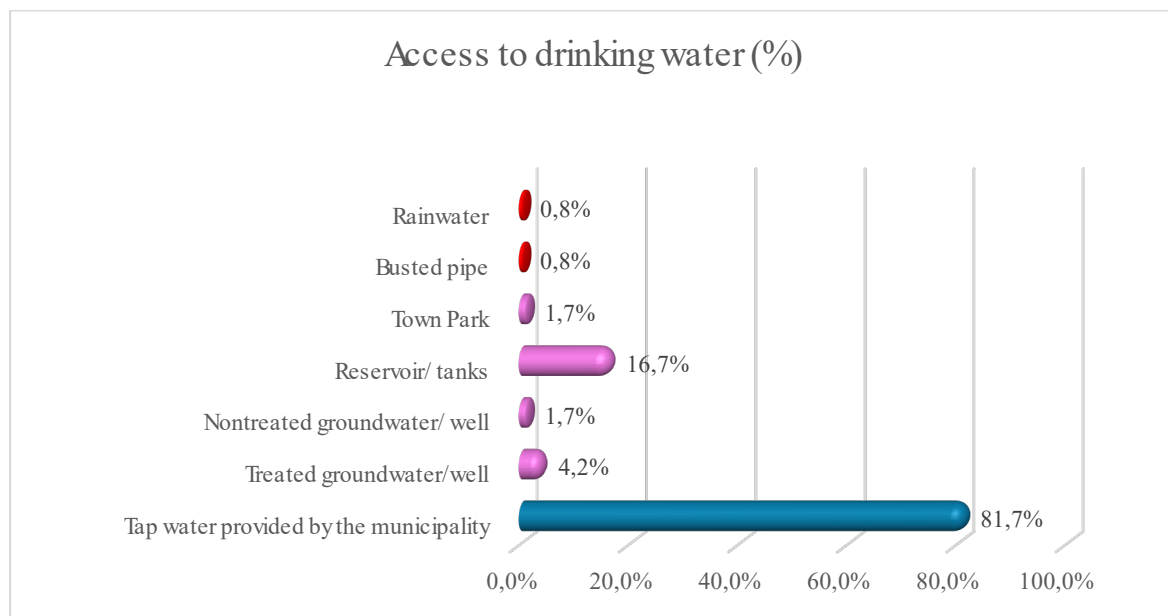


Figure 4.4.1: Sources of household drinking water

Figure 4.4.1 indicates that the majority of respondents (81.7%) obtain their drinking water from municipal taps. This is followed by 16.7% persons who access water from reservoirs or tanks, and 4.2% from treated groundwater or wells. A smaller proportion of respondents rely on public parks in town centres (1.7%), damaged municipal water pipes awaiting repair (0.8%), or collected rainwater in buckets or tanks (0.8%).

4.4.2 Household energy sources for heating

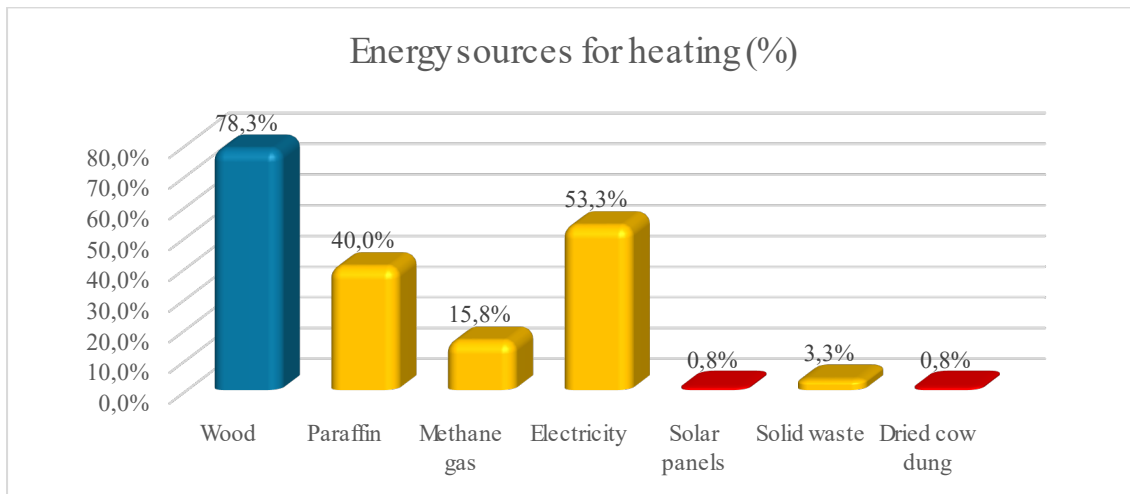


Figure 4.4.2: Household energy sources for heating

The results presented in Figure 4.4.2 indicate that the majority of respondents (78.3%) use wood as their primary household energy source for heating. More than half of the respondents (53.3%) reported using electricity, 40% rely on paraffin, and 15.8% use methane gas. Only 0.8% of respondents had solar panels installed, while 3.3% reported burning solid waste, and 0.8% used dried cow dung as additional sources of heat. More than one option was selected when responding to this inquiry, therefore n=more than 100%.

4.4.3 Types of sanitary facilities in respondents' households

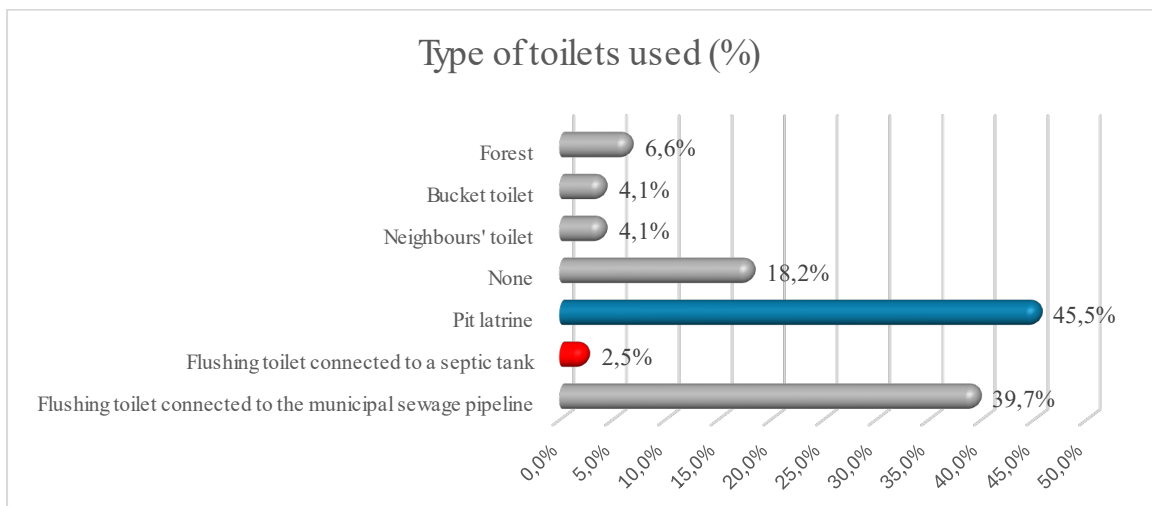


Figure 4.4.3: Types of sanitary facilities in respondents' households

Figure 4.4.3 reveals that 45.5% of respondents use pit latrines as toilets in their households, followed by 39.7% that use flushing toilets connected to the municipal

sewage pipeline. About 18.2% of respondents admitted to having no ablution facilities in their household. An additional number of respondents who lacked proper toilet facilities defecated in forests (6.6%), bucket toilets (4.1%), and asked for permission to use neighbours' toilets (4.1%).

4.5 Environmental and social impacts on residents living proximate to landfills

This section represents the environmental, health and social impacts associated with the landfill sites on respondents under study

4.5.1 Rodent and vector proliferation in respondents' households

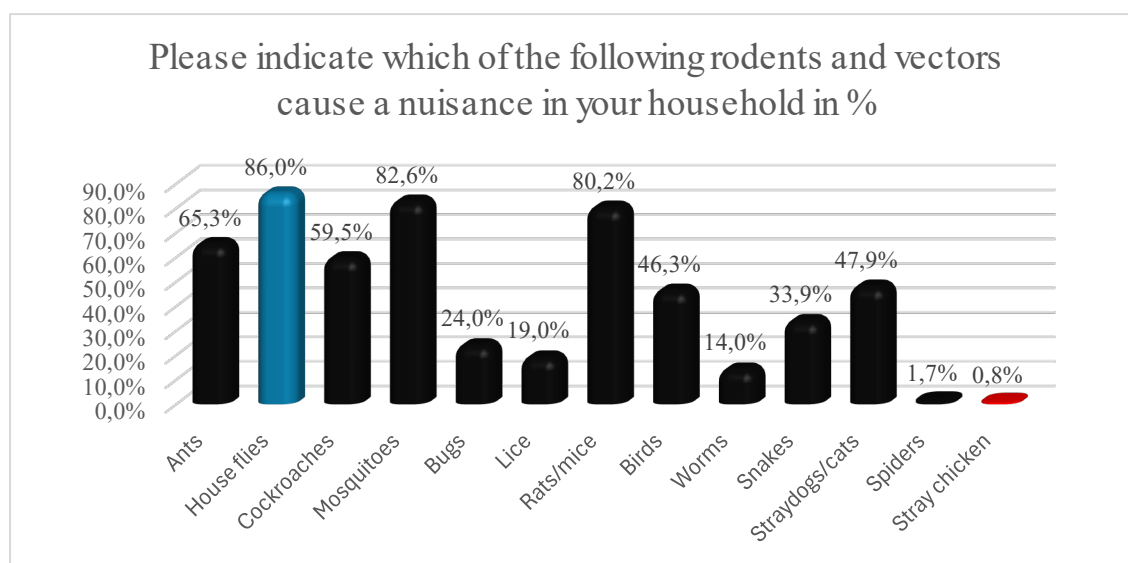


Figure 4.5.1: Rodent and vector proliferation in respondents' households

Figure 4.5.1 indicates that the majority of respondents (86%) reported that house flies constitute a common nuisance in their households. This was followed by 82.6% of respondents who identified a proliferation of mosquitoes, especially during warm seasons similar to the one when data were collected, and 80.2% who reported similar concerns regarding rats or mice. A few respondents (0.8%) mentioned that stray chickens were a nuisance and should be considered as rodents. The selection of more than one option was allowed for this inquiry, therefore n=more than 100%.

Table 11: Impacts of landfills on the immediate environment, health, and livelihood

Level of agreement	Frequency	Valid Percentage (%)
Odours from the site are unbearable		
Strongly disagree	5	4,1

Disagree	1	0,8
Neutral	15	12,4
Agree	6	5
Strongly agree	94	77,7
Total	121	100
Smoke fog from waste burning affects our daily chores		
Strongly disagree	15	12,4
Disagree	12	9,9
Neutral	8	6,6
Agree	13	10,7
Strongly agree	73	60,3
Total	121	100
Local water sources are contaminated		
Strongly disagree	35	28,9
Disagree	14	11,6
Neutral	27	22,3
Agree	9	7,4
Strongly agree	36	29,8
Total	121	100
Compromised environmental aesthetics (e.g. eyesore waste heaps, leachate, and smoke)		
Strongly disagree	23	19
Disagree	4	3,3
Neutral	7	5,8
Agree	11	9,1
Strongly agree	76	62,8
Total	121	100
There is an increase in road accidents due to the smoke fog		
Strongly disagree	68	56,2
Disagree	18	14,9
Neutral	9	7,4
Agree	8	6,6
Strongly agree	18	14,9
Total	121	100
Loss of property or goods (e.g. housing, car) from uncontrolled fires		
Strongly disagree	58	47,9

Disagree	10	8,3
Neutral	7	5,8
Agree	7	5,8
Strongly agree	39	32,2
Total	121	100
Residents opt to sell their properties or move to other areas because of the unbearable living conditions		
Strongly disagree	86	71,1
Disagree	17	14
Neutral	9	7,4
Agree	2	1,7
Strongly agree	7	5,8
Total	121	100
Rented tenants are not staying longer in their rental and the renting business is compromised		
Strongly disagree	87	71,9
Disagree	19	15,7
Neutral	8	6,6
Agree	2	1,7
Strongly agree	5	4,1
Total	121	100
Lack/ loss of business (our businesses are not busy and flourishing)		
Strongly disagree	92	76
Disagree	15	12,4
Neutral	6	5
Agree	2	1,7
Strongly agree	6	5
Total	121	100
Flooding during storms (drains blocked with waste)		
Strongly disagree	49	40,5
Disagree	6	5
Neutral	14	11,6
Agree	12	9,9
Strongly agree	40	33,1
Total	121	100

Poor crop production		
Strongly disagree	67	55,4
Disagree	18	14,9
Neutral	12	9,9
Agree	8	6,6
Strongly agree	16	13,2
Total	121	100
High cases of chemical poisoning in children		
Strongly disagree	25	20,7
Disagree	6	5
Neutral	6	5
Agree	13	10,7
Strongly agree	71	58,7
Total	121	100
High (sudden) mortality rate in animals		
Strongly disagree	15	12,4
Disagree	1	0,8
Neutral	7	5,8
Agree	7	5,8
Strongly agree	91	75,2
Total	121	100
High vector infestation (e.g. mosquitoes, flies, cockroaches)		
Strongly disagree	8	6,6
Disagree	1	0,8
Neutral	1	0,8
Agree	3	2,5
Strongly agree	108	89,3
Total	121	100
High rodent infestation (e.g. rats, snakes)		
Strongly disagree	9	7,4
Disagree	1	0,8
Neutral	1	0,8
Agree	5	4,1
Strongly agree	105	86,8
Total	121	100

High cases of gender-based violence (e.g. rape, beatings)		
Strongly disagree	31	25,6
Disagree	7	5,8
Neutral	10	8,3
Agree	8	6,6
Strongly agree	65	53,7
Total	121	100
The area is noisy		
Strongly disagree	28	23,1
Disagree	20	16,5
Neutral	11	9,1
Agree	10	8,3
Strongly agree	52	43
Total	121	100
High crime rate (burglary, street robbery)		
Strongly disagree	22	18,2
Disagree	4	3,3
Neutral	6	5
Agree	11	9,1
Strongly agree	78	64,5
Total	121	100

The results in Table 11 indicate that most respondents strongly agreed that odours from the sites are unbearable (77.7%) and that smoke or fog from waste burning affected their daily activities (60.3%). Additionally, 62.8% strongly agreed that environmental aesthetics have been compromised (e.g. unsightly waste heaps, leachate, and smoke), while 29.8% strongly agree that local water sources are contaminated.

Conversely, 56.2% of respondents strongly disagreed that smoke or fog has led to an increase in road accidents, and 47.9% strongly disagreed that uncontrolled fires have caused a loss of property or goods (e.g. housing, vehicles). The majority (71.1%) strongly disagreed that residents sell their properties or relocate due to unbearable living conditions. Similarly, they disagreed that there was a lack or loss of business. Regarding environmental hazards, only 40.5% and 55.4% of respondents strongly

disagreed that they experienced flooding during storms and poor crop production, respectively.

In terms of health and safety, 58.7% of respondents strongly agreed that children experience high rates of chemical poisoning. Likewise, 75.2% strongly agreed that there had been sudden deaths among animals, as shown in Figures 4.5.2, and 89.3% strongly agreed that vector infestations (mosquitoes, flies and cockroaches) were common. A further 86.8% strongly agreed that rodent infestations (e.g. rats and snakes) were prevalent.



Figure 4.5.2: A sheep from a local community herd was found dead on the Paul Roux landfill site

Lastly, the results indicate that 53.7% of respondents strongly agreed that there were high cases of gender-based violence (e.g. rape and beatings); 43% strongly agreed that the area was noisy, and 64.5% strongly agreed that the community experienced a high crime rate.

The Kruskal-Wallis test was conducted to evaluate the link between the type of housing and the attraction of rodents and vectors in Tables 12 and 13 below.

Table 12: Relationship between the residents' housing type and rodent and vector proliferation

Ranks			
Housing type		N	Mean Rank
Rodent/Vector	Private single house	11	50.05
	Multi-storied apartment (complex)	4	37.13
	The Reconstruction and Development Programme (RDP) houses	36	60.75
	Backroom of the main house	22	68.23
	Shack house	47	61.13
	Total	120	

Table 13: Kruskal-Wallis H test of housing type and rodent and vector proliferation variables

Test Statistics ^{a,b}	
	Rodent/Vector
Kruskal-Wallis H	3,959
Df	4
Asymp. Sig.	0,412
a. Kruskal Wallis Test	
b. Grouping Variable: Housing type	

The results presented in Tables 12 and 13 indicate the highest mean rank (68.23) in respondents residing in backrooms, suggesting that this group reported more nuisance by rodents and vectors in their households. This was followed by those living in corrugated iron sheet houses (shack structures) with a mean rank of 61.13, RDP houses (60.75), private single houses (50.05), and multi-storied apartments, which recorded the lowest mean rank (37.13). However, as shown in Table 51, the observed differences in rodent and vector nuisance across the five housing types were not statistically significant ($p = 0.412 > p = 0.05$), suggesting that the variation may be attributed by chance rather than a true difference between housing categories.

Table 14: Relationship between respondents' access to municipal water and usage of wood for heating purposes

Crosstab					
			Wood		Total
			Yes	No	
Tap water provided by the municipality	Yes	Count	72	26	98
		% in tap water provided by the municipality	73,5%	26,5%	100,0%
		% in wood	77,4%	96,3%	81,7%
		% of total	60,0%	21,7%	81,7%
	No	Count	21	1	22
		% in tap water provided by the municipality	95,5%	4,5%	100,0%
		% in wood	22,6%	3,7%	18,3%
		% of total	17,5%	0,8%	18,3%
Total		Count	93	27	120
		% in tap water provided by the municipality	77,5%	22,5%	100,0%
		% in wood	100,0%	100,0%	100,0%
		% of total	77,5%	22,5%	100,0%

Table 15: Chi-Square results

Chi-Square Tests					
	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4,980 ^a	1	0,026		
Continuity Correction ^b	3,799	1	0,051		
Likelihood Ratio	6,431	1	0,011		
Fisher's Exact Test				0,025	0,018
Linear-by-Linear Association	4,939	1	0,026		
N of Valid Cases	120				
a. 1 cells (25,0%) have expected count less than 5. The minimum expected count is 4,95.					
b. Computed only for a 2x2 table					

Table 16: Cramer's V results

Symmetric Measures			
		Value	Approximate Significance
Nominal by Nominal	Phi	-0,204	0,026
	Cramer's V	0,204	0,026
N of Valid Cases		120	

The results presented in Table 14 indicate that the majority of respondents (73.5%) who obtain their drinking water from municipal tap water use wood as an energy source for household heating, while only 26.5% of them do not rely on wood. Among those who do not access their drinking water from municipal tap water, an even larger proportion (95.5%) reported using wood for heating, compared to 4.5% not who did not. These results suggest that wood remains a predominant energy source for heating across both groups, particularly among households that lack access municipal tap water. As shown in Table 15, there is a statistically significant association between access to municipal tap water and the use of wood as a heating source ($p = 0.026 < 0.05$). Furthermore, Table 16 demonstrates that this relationship, while significant, exhibits a weak effect size ($\phi = -0.204$). This implies that although access to drinking water from municipal sources is significantly related to the use of wood for heating, the strength of the association is relatively modest.

4.6 Injuries, diseases, and conditions of respondents

The section below presents the perceived injuries, diseases and conditions of participants. Their health care visitation frequency and lifestyle practices such as smoking are also included.

4.6.1 Injury incidences

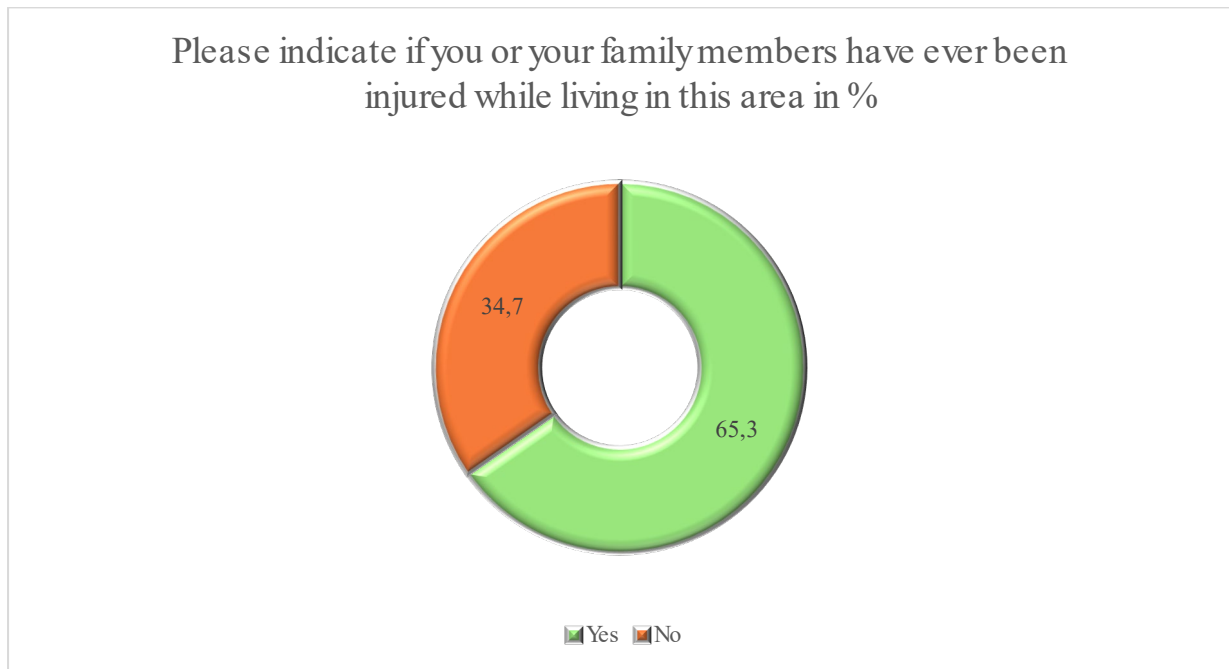


Figure 4.6.1: Injury incidences

Figure 4.6.1 indicates that the majority of respondents (65.3%) reported that either they or a family member had sustained an injury while residing in the area, whereas 34.7% indicated no history of injury.

4.6.2 Percentage of respondents who sustained injuries and incidents near the landfill site

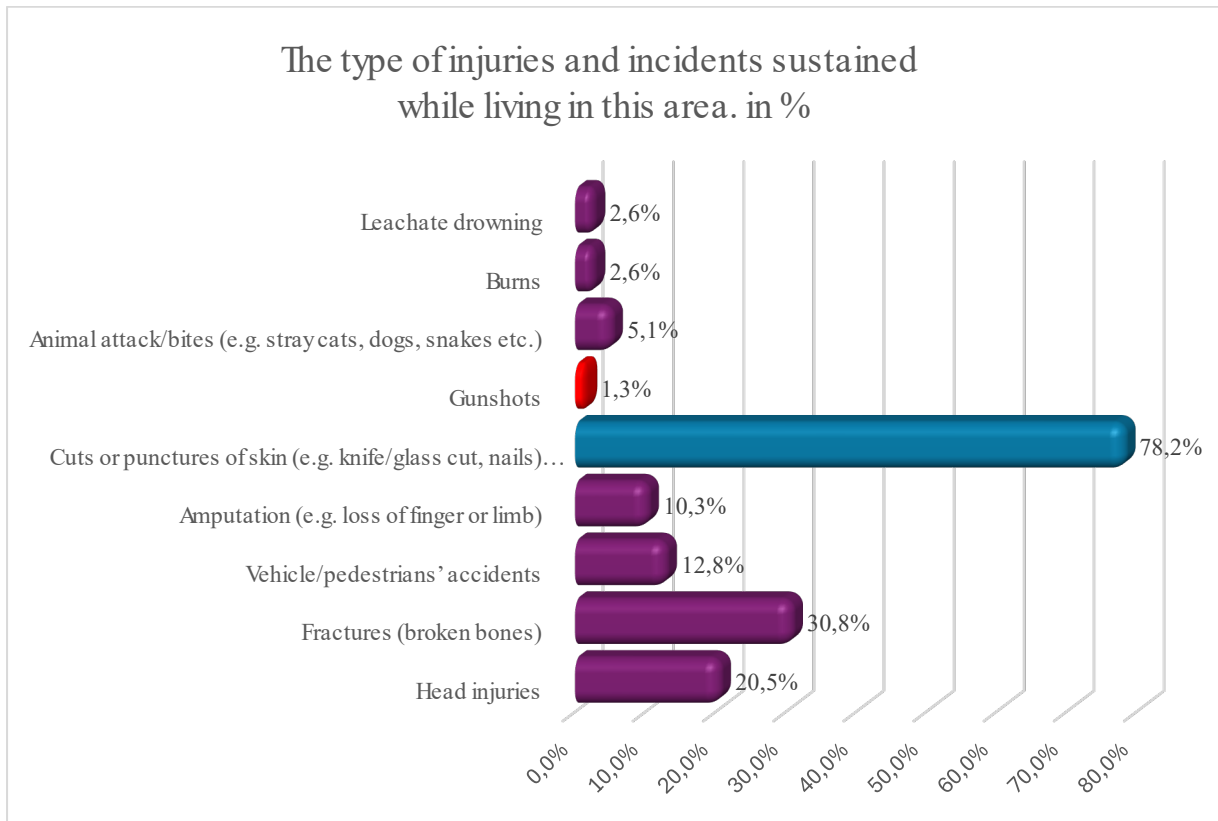


Figure 4.6.2: Percentage of respondents who sustained injuries and incidents near the landfill site

The results presented in Figure 4.6.2 indicate that the majority of respondents (78.2%) experienced cuts or puncture wounds (e.g. from scrap metals, knives, glass, or nails) while handling waste as shown in Figure 4.6.4. This was followed by 30.8% who reported sustaining fractures, vehicle-related accidents (12.8%), amputations (10.3%) as shown in Figures 4.6.5 and 4.6.6, head injuries (20.5%) and animal attacks (5.1%), leachate drowning and burns (2.6%), respectively, as shown in Figure 4.6.3, and only 1.3% indicated injuries resulting from gun violence. More than one options was selected for the graph depicted in Figure 4.6.2, therefore n=more than 100%.



Figure 4.6.3: A resident's limb burn scar from a landfill burning incident in Paul Roux



Figure 4.6.4: A waste picker's limb scar from a healed cellulitis infection wound in Viljoenskroon



Figure 4.6.5: A waste picker's amputated index finger in Bethlehem



Figure 4.6.6: A waste picker's amputated thumb finger in Bethlehem

4.6.7 Overall health scaling

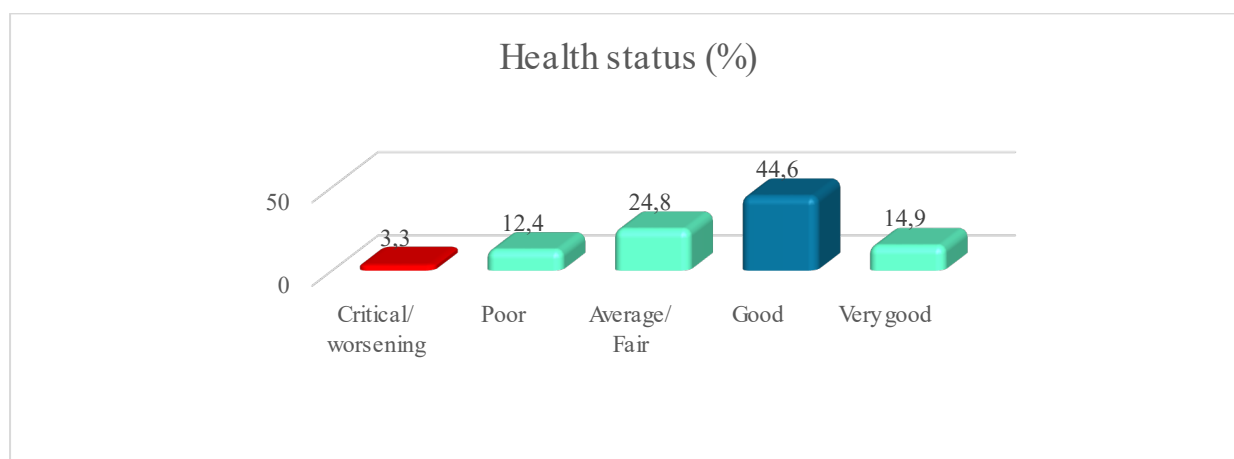


Figure 4.6.5: Overall health scaling

Figure 4.6.7 illustrates that 44.6% of respondents reported being in good health, 24.8% described their health as average, and 14.9% indicated very good health. In contrast, 12.4% reported poor health, while only 0.4% admitted that their health status was critical or worsening.

Table 17: Prevalence of disease or condition symptoms

	Frequency	Valid Percent
Respiratory problems – difficulty breathing, chest pain, nasal irritation, continuous coughing, and sputum		
Never	32	26.4
Once every 2 years	5	4.1
Yearly	7	5.8
Monthly	20	16.5
Weekly	11	9.1
Daily	46	38
Total	121	100
Reproductive problems – miscarriages, difficulty in falling pregnant, fibroids in women, children born with physical deformities or disability		
Never	102	84.3
Once every 2 years	12	9.9
Yearly	1	0.8
Monthly	1	0.8
Weekly	2	1.7
Daily	3	2.5
Total	121	100
Gastrointestinal symptoms – nausea, vomiting, watery or bloody faeces, stomach pain		
Never	26	21.5
Once every 2 years	6	5
Yearly	13	10.7

Monthly	18	14.9
Weekly	26	21.5
Daily	32	26.4
Total	121	100
Skin problems – allergies, bites, rashes, sores, blisters		
Never	50	41.3
Once every 2 years	16	13.2
Yearly	7	5.8
Monthly	10	8.3
Weekly	9	7.4
Daily	29	24
Total	121	100
Musculoskeletal problems – muscle aches, painful joints and back, arthritis		
Never	45	37.2
Once every 2 years	4	3.3
Yearly	4	3.3
Monthly	14	11.6
Weekly	10	8.3
Daily	44	36.4
Total	121	100
Vision problems – poor sight, partial blindness, cataracts, allergies (itchiness and redness)		
Never	51	42.1
Once every 2 years	2	1.7
Yearly	1	0.8
Monthly	7	5.8
Weekly	7	5.8
Daily	53	43.8
Total	121	100
Hearing problems – partially/impaired hearing – not hearing clearly)		
Never	93	76.9
Once every 2 years	1	0.8
Yearly	2	1.7
Monthly	3	2.5
Weekly	4	3.3
Daily	18	14.9
Total	121	100
Dental problems – tooth decay, bleeding gums, change of teeth colour)		
Never	63	52.1
Once every 2 years	14	11.6
Yearly	4	3.3
Monthly	8	6.6
Weekly	6	5
Daily	26	21.5
Total	121	100
Depression – prolonged stress and tiredness, anxiety (feeling unsettled)		
Never	53	43.8

Once every 2 years	8	6.6
Yearly	5	4.1
Monthly	12	9.9
Weekly	7	5.8
Daily	36	29.8
Total	121	100
Other mental health disorders or symptoms in adults – schizophrenia (having false images or scenarios), forgetfulness, being easily angered, acting out of character		
Never	96	79.3
Once every 2 years	3	2.5
Yearly	3	2.5
Monthly	2	1.7
Weekly	2	1.7
Daily	15	12.4
Total	121	100
Mental health disorder or symptoms in children (e.g. extreme hyperactivity/hypoactivity, slow development, speech problems, and cognitive abilities)		
Never	115	95
Once every 2 years	1	0.8
Weekly	1	0.8
Daily	4	3.3
Total	121	100
Sudden falling and/or seizures – falling followed by jerking movements of arms and legs, loss of consciousness		
Never	110	90.9
Once every 2 years	2	1.7
Yearly	2	1.7
Monthly	1	0.8
Daily	6	5
Total	121	100
Cardiovascular symptoms – heart attack, low/high blood pressure)		
Never	94	77.1
Once every 2 years	1	0.8
Daily	26	21.5
Total		
Blood sugar level disorder – dryness in the mouth, increased thirst, frequent urination, changes in appetite)		
Never	107	88.4
Once every 2 years	2	1.7
Daily	12	9.9
Total	121	100
Cancer-related symptoms – lumps in body parts, degeneration of tissue (parts of the body looking older than their age/losing shape); change of skin colour and texture		
Never	118	95.9
Once every 2 years	1	0.8
Monthly	1	0.8
Daily	1	0.8
Total	121	100

Stroke – numbness in the face, arm, and legs; loss of balance or coordination		
Never	116	95.9
Once every 2 years	1	0.8
Yearly	1	0.8
Monthly	1	0.8
Daily	2	1.7
Total	121	100
Weight loss in a short period		
Never	59	48.8
Once every 2 years	5	4.1
Yearly	9	7.4
Monthly	15	12.4
Weekly	5	4.1
Daily	28	23.1
Total	121	100
Fatigue (extreme tiredness/weakness)		
Never	54	44.6
Once every 2 years	3	2.5
Yearly	3	2.5
Monthly	9	7.4
Weekly	12	9.9
Daily	40	33.1
Total	121	100
Jaundice – (yellowing of eyes, skin, and mucous membrane; dark urine and pale stools)		
Never	112	92.6
Once every 2 years	2	1.7
Yearly	3	2.5
Monthly	2	1.7
Weekly	1	0.8
Daily	1	0.8
Total	121	100
Fever – (high body temperatures and heavy sweats, chills and shivering, breathing faster)		
Never	52	43
Once every 2 years	3	2.5
Yearly	5	4.1
Monthly	9	7.4
Weekly	8	6.6
Daily	44	36.4
Total	121	100
Headache or migraines		
Never	61	50.4
Once every 2 years	5	4.1
Yearly	7	5.8
Monthly	7	5.8
Weekly	12	9.9
Daily	29	24

Total	121	100
Acute sickness and death without being sick for a long time		
Never	116	95.9
Once every 2 years	2	1.7
Yearly	1	0.8
Daily	2	1.7
Total	121	100

Table 17 reports that 38% of respondents reported that they or their household members experienced respiratory problems, such as difficulty breathing, chest pain, nasal irritation, persistent coughing and sputum daily. Similarly, 26.4% indicated daily gastrointestinal symptoms, including nausea, vomiting, watery or bloody stools, and stomach pain.

In contrast, the majority (84.3%) reported never experiencing reproductive health issues, such as miscarriages, infertility, fibroids in women, or children born with physical deformities or disabilities. Likewise, 41.3% stated that neither they nor their households had ever suffered from skin conditions (e.g. allergies, bites, rashes, sores, or blisters), while 37.2% reported never having experienced musculoskeletal problems, such as muscle aches, joint pain, back pain, or arthritis.

With respect to vision-related problems, 43.8% of respondents indicated daily experiences of poor sight, partial blindness, cataracts, or allergies. In contrast, 76.9% reported never having encountering hearing problems, including partial or impaired hearing.

Findings also revealed that 52.1% of respondents had never experienced dental issues, such as tooth decay, bleeding gums, or discolouration, while 43.8% reported no history of depression within their households. Furthermore, 79.3% stated they had never experienced other adult mental disorders or symptoms, including schizophrenia, memory loss, irritability, or unusual behaviour, and 95% reported no signs of childhood mental health problems, such as hyperactivity, delayed development, speech difficulties, or cognitive impairments.

A large proportion of respondents also reported the absence of more severe conditions: 90.9% had never experienced sudden falls or seizures; 77.7% had never encountered cardiovascular symptoms such as heart attacks or abnormal blood

pressure; 88.4% had never reported blood sugar-related symptoms (e.g. excessive thirst, frequent urination, or appetite changes); 97.5% had never experienced cancer-related symptoms (e.g. bodily lumps, tissue degeneration, or changes in skin appearance); and 95.9% had never suffered a stroke.

Additionally, 48.8% of respondents stated that they or their households had never experienced rapid weight loss, and 44.6% reported never experiencing fatigue. The majority further indicated no history of jaundice (92.6%), fever (43%), or headaches and migraines (50.4%). Finally, 95.9% of respondents reported that neither they nor their household members had ever experienced sudden acute illness or unexpected death without prolonged sickness.

4.6.8 Healthcare facility visits by respondents

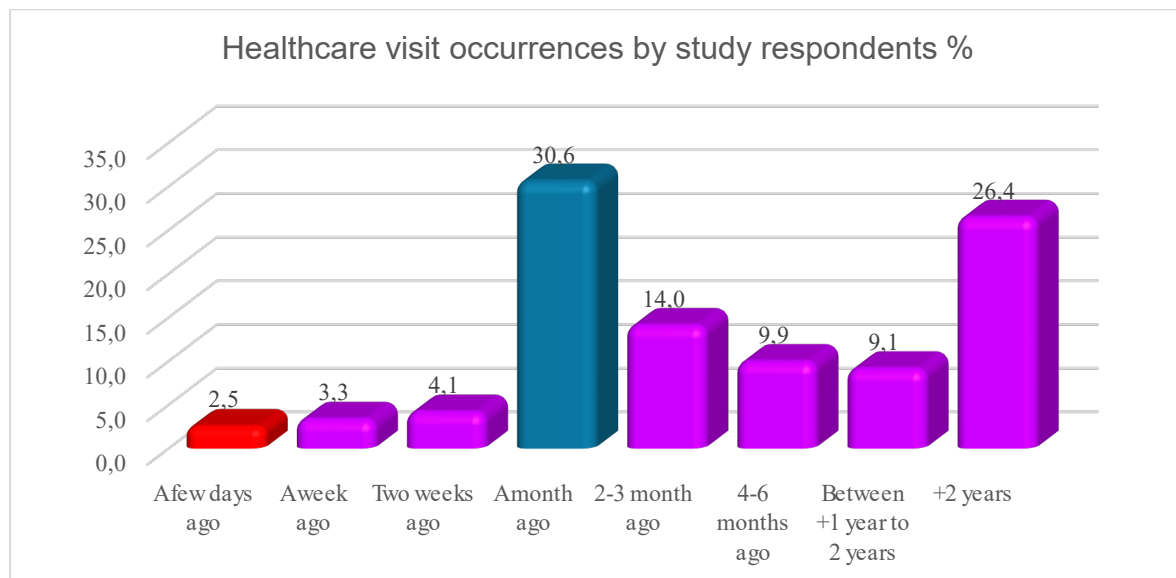


Figure 4.6.6: Healthcare facility visits by respondents

The results presented in Figure 4.6.8 indicate that 30.6% of respondents had last visited a healthcare facility one month prior, followed by 14% whose most recent visit had occurred 2–3 months earlier. Only 2.5% reported visiting a healthcare facility within the previous few days. About 26.4% of the respondents recalled visiting the health facility years back.

4.6.9 Hospitalisation record of respondents

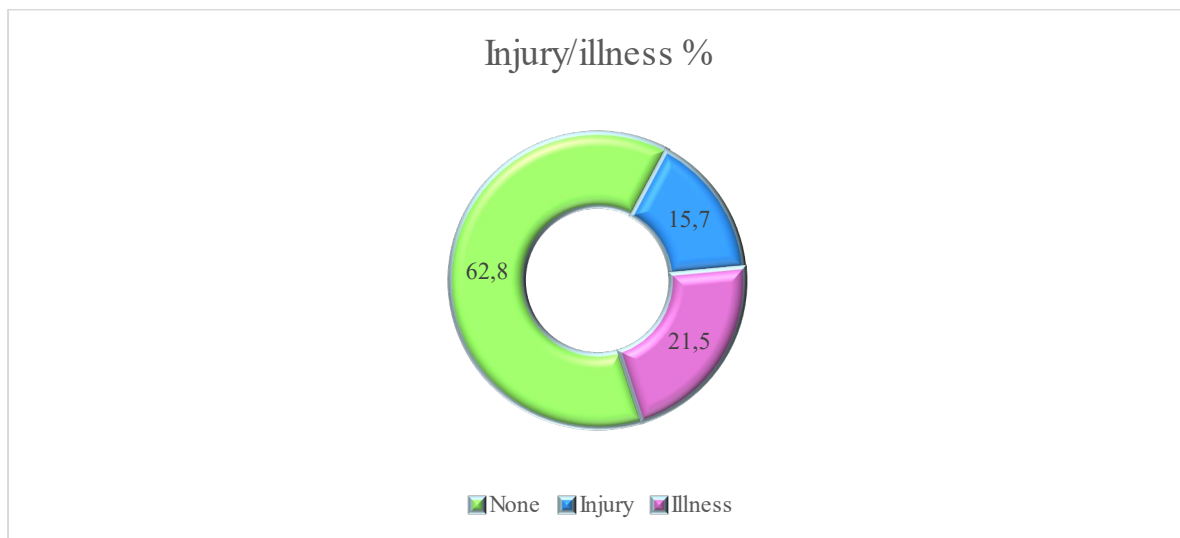


Figure 4.6.7: Hospitalisation record of respondents

Figure 4.6.9 reveals that the majority of respondents (62.8%) reported never having been hospitalised, whereas 21.5% indicated hospitalisation due to illness and 15.7% due to injury.

4.6.10 Type of injury or illness leading to hospitalisation

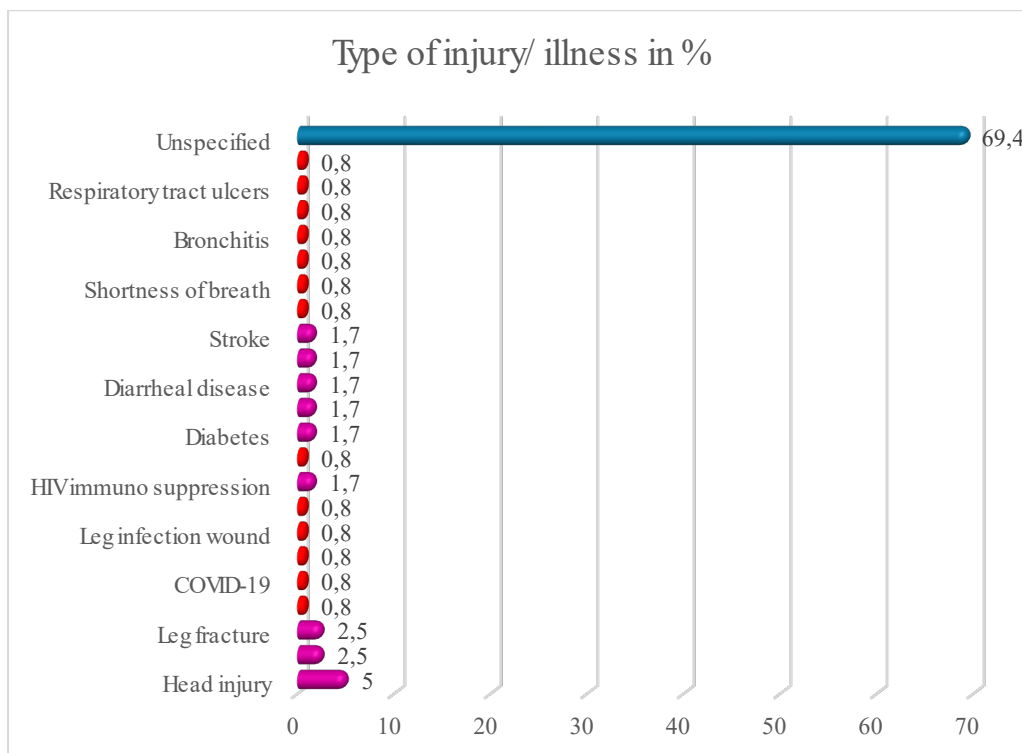


Figure 4.6.8: Type of injury or illness leading to hospitalisation

The majority of respondents (69.4%) in Figure 4.6.10 did not specify the type of injury or illness, which was within their right to consent to the disclosure of information about their medical conditions or not. This is followed by 5% who reported having experienced head injuries, 2.5% who stated that they have had tuberculosis, and another 2.5% who indicated having experienced leg fractures. A significant number of mentioned illnesses were related to respiratory ailments (respiratory tract ulcers, bronchitis, shortness of breath). A proportion of the reported injuries were limb-related.

The Kruskal-Wallis test was conducted to evaluate the link between the respondents' last visit to the healthcare visits and the diseases/conditions reported in Tables 18 and 19 below.

Table 18: The relationship between healthcare visits and the reported diseases/conditions/symptoms

Ranks			
Please indicate when last you or your family visit healthcare facilities.		N	Mean Rank
Disease/ Conditions Symptoms	A few days before	3	53,67
	A week before	4	85,00
	Two weeks before	5	62,40
	A month before	37	75,32
	2–3 months before	17	65,88
	4–6 months before	12	64,96
	Between +1 year to 2 years	11	56,95
	+2 years	32	39,22
	Total	121	

Table 19: Kruskal-Wallis H test

Test Statistics ^{a,b}	
	Disease/ Conditions Symptoms
Kruskal-Wallis H	21,187
Df	7
Asymp. Sig.	0,004
a. Kruskal Wallis Test	
b. Grouping Variable: Please indicate when last you or your family visit healthcare facilities.	

The findings presented in Tables 17 and 18 reveal that respondents who reported visiting healthcare facilities a week before had the highest mean rank (85.00), indicating a greater occurrence of self-reported disease or condition symptoms within

this group. This was followed by respondents who visited a month before (75.32), 2–3 months before (65.88), 4–6 months before (64.96), two weeks before (62.40), between one to two years before (56.95), and a few days before (53.67). The lowest mean rank (39.22) was observed among those whose last healthcare visit had occurred more than two years ago.

The observed differences in mean ranks suggest variation in the occurrence of disease or condition symptoms based on the recency of healthcare facility visits. These differences were found to be statistically significant ($p = 0.004 < 0.05$), indicating a meaningful association between the time since last healthcare visit and the frequency of reported disease or condition symptoms.

4.6.11 Participants' smoking practices

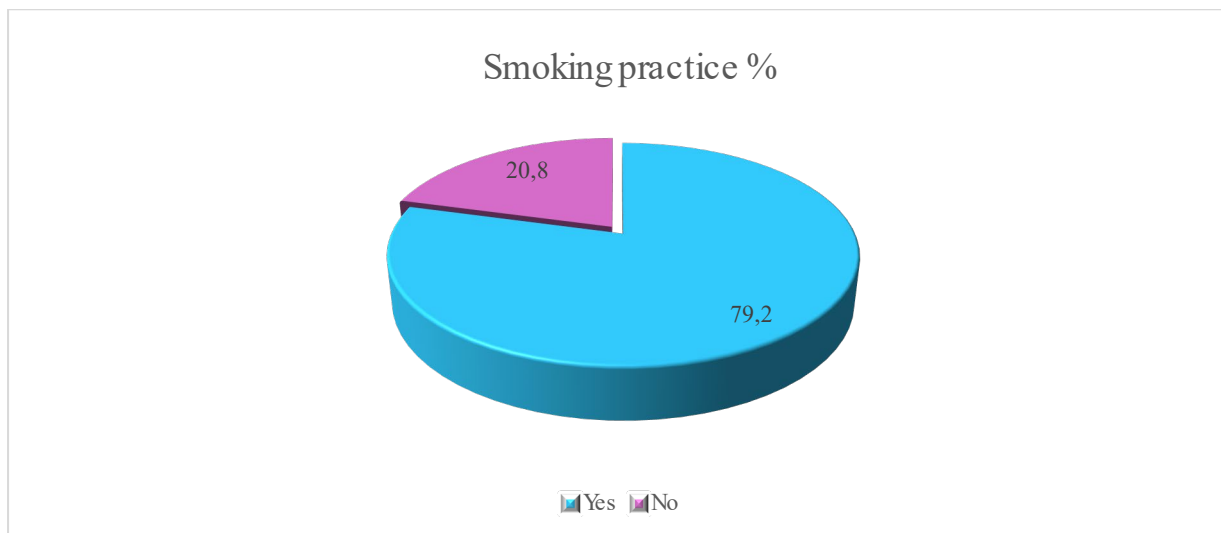


Figure 4.6.9: Participants' smoking practices

The results in Figure 4.6.11 show that the majority of respondents (79.2%) either smoked or had family members who smoked, while 20.8% reported that neither they nor their family members smoked.

4.6.12 Disaster reporting

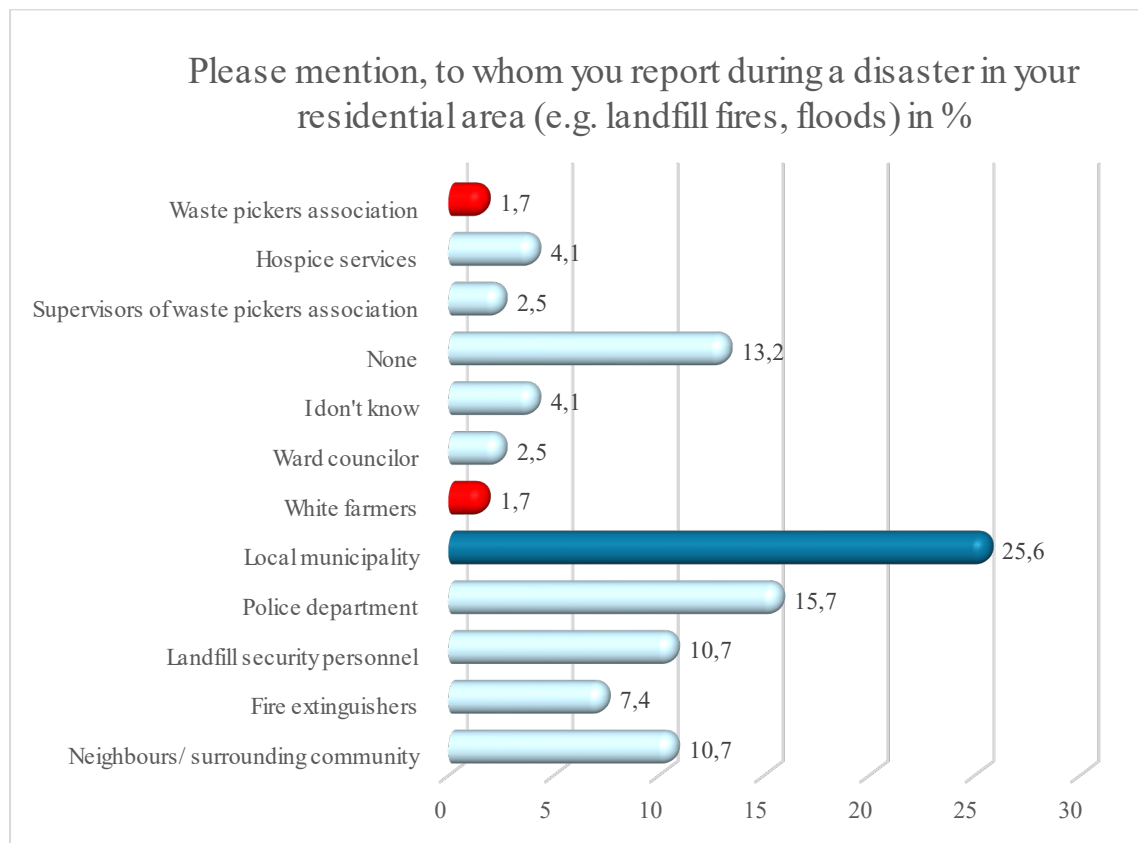


Figure 4.6.10: Disaster reporting

Figure 4.6.12 shows that 25.6% of respondents indicated that they reported disasters in their residential areas to the local municipality, followed by 15.7% who reported to the police department, and 13.2% who did not report to anyone. A smaller proportion of respondents reported to the Waste Pickers Association (1.7%) and to white farmers (1.7%).

4.7 Validity and reliability test results

This section presents the validity and reliability test outcomes and inferences to the study.

4.7.1 Normality Test

A normality test was performed on the two constructs under investigation to determine the suitability of statistical techniques for analysing central tendency and group differences. The null hypothesis (H_0) assumes that the variable follows a normal

distribution, whereas the alternative hypothesis (H_1) assumes that the variable deviates from normality. Specifically:

- When $p \leq 0.05$, the null hypothesis is rejected, indicating that the variable does not follow a normal distribution.
- When $p > 0.05$, the null hypothesis is retained, suggesting that the variable can be considered normally distributed.

The findings (Table 19) show that both *Impacts of Landfills* and *Disease/Condition Symptoms* are not normally distributed, as their Shapiro–Wilk test results were statistically significant ($p < 0.05$). Consequently, the median was deemed the most appropriate measure of central tendency for these variables.

Table 20: Normality test

	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	df	Sig.
DISEASE/ CONDITIONS SYMPTOMS	0,104	121	0,003	0,954	121	0.000
IMPACTS OF LANDFILLS	0,099	121	0,006	0,961	121	0.001
a. Lilliefors Significance Correction						

4.7.2 Central tendency measures

Central tendency measures were applied to examine how centred the distributions of the study constructs are. For the construct measuring Impacts of Landfills, a five-point Likert scale was used, where 1 = *strongly disagree* and 5 = *strongly agree*. Since the scale midpoint is 3, a median of 3 suggests that at least half of the respondents neither *agreed* nor *disagreed* with the statements. A median closer to 2 indicates a tendency to *disagree*, while a median closer to 1 reflects *strong disagreement*. Conversely, a median closer to 4 suggests *agreement*, and a median of 5 indicates *strong agreement* among at least 50% of the respondents.

For the construct measuring the Occurrence of Disease and Condition Symptoms, a six-point Likert scale was employed, where 5 = *daily*, 4 = *weekly*, 3 = *monthly*, 2 = *yearly*, 1 = *once every two years*, and 0 = *never*. A median closer to 5 suggests daily occurrence for at least half of the respondents, while a score near 4 indicates weekly occurrence. A median of 3 shows that symptoms are most likely experienced monthly

by at least 50% of respondents. Similarly, a median closer to 2 suggests yearly occurrence; a score near 1 reflects occurrence once every two years; and a median closer to 0 indicates that at least half of the respondents had never experienced such symptoms.

Table 21: Central Measure of Tendency (Median)

Construct	Items	Mean	Median	Std. Deviation	Interpretation
IMPACTS OF LANDFILLS	Odours from the site are unbearable.	4,51	5	1.026	The results indicated that at least 50% of the respondents find the statements regarding the Impacts of landfills neutral (neither agree nor disagree), as reflected by an overall median of 3.33; that is, closer to 3 than it is to 4.
	Smoke fog from waste burning affects our daily chores.	3,97	5	1.483	
	Local water sources are contaminated.	2,98	3	1.599	
	Compromised environmental aesthetics (e.g. eyesore waste heaps, leachate, and smoke).	3,93	5	1.595	
	There is an increase in road accidents due to the smoke fog	2,09	1	1.500	
	Loss of property or goods (e.g. housing, cars) from uncontrolled fires.	2,66	2	1.805	
	Residents opt to sell their properties or move to other areas because of the unbearable living conditions.	1,57	1	1.094	
	Rented tenants are not staying longer in this area,	1,50	1	0.993	

	and the renting business is compromised.				
	Lack/loss of business (our businesses are not busy and flourishing).	1,47	1	1.025	
	Flooding during storms (drains blocked with waste).	2,90	3	1.763	
	Poor crop production.	2,07	1	1.456	
	High cases of chemical poisoning in children.	3,82	5	1.638	
	Sudden death in animals.	4,31	5	1.371	
	High vector infestation (e.g. mosquitoes, flies, cockroaches).	4,67	5	1.044	
	High rodent infestation (e.g. rats, snakes).	4,62	5	1.097	
	High cases of gender-based violence (e.g. rape, beatings).	3,57	5	1.731	
	The area is noisy.	3,31	4	1.678	
	High crime rate.	3,98	5	1.576	
	OVERALL AVERAGE:	3,22	3,33	0.761	
DISEASE/ CONDITION SYMPTOMS	Respiratory problems – difficulty breathing, chest pain, nasal irritation, continuous coughing, and sputum.	2,92	3	2.060	The results indicated that at least 50% of the respondents experience symptoms once every two years, as reflected by an overall
	Reproductive problems – miscarriages, difficulty in falling pregnant, fibroids in women, children born with	0,33	0	0.995	

physical deformities or disability.				median of 1.45, which is closer to 1 than it is to 2.
Gastrointestinal symptoms – nausea, vomiting, watery or bloody faeces, stomach pain.	2,89	3	1.879	
Skin problems – allergies, bites, rashes, sores, blisters.	1,99	1	2.088	
Musculoskeletal problems – muscle aches, painful joints and back, arthritis.	2,60	3	2.220	
Vision problems – poor sight, partial blindness, cataracts, allergies (itchiness and redness).	2,63	3	2.363	
Hearing problems – partially/impaired hearing-not hearing clearly.	0,99	0	1.895	
Dental problems – tooth decay, bleeding gums, change of teeth colour.	1,65	0	2.076	
Depression – prolonged stress and tiredness, anxiety (feeling unsettled).	2,17	1	2.200	
Other mental health disorders or symptoms in adults – schizophrenia (having false images or scenarios), forgetfulness, being easily angered, and acting out of character.	0,81	0	1.734	
Mental health disorder or symptoms in children (e.g.	0,21	0	0.965	

extreme hyperactivity/hypoactivity, slow development, speech problems and cognitive abilities).				
Sudden falling and/or seizures – falling followed by jerking movements of arms and legs, loss of consciousness.	0,32	0	1.142	
Cardiovascular symptoms – heart attack, low/high blood pressure.	1,08	0	2.060	
Blood sugar level disorder – dryness in the mouth, increased thirst, frequent urination, changes in appetite.	0,51	0	1.501	
Cancer-related symptoms – lumps in body parts, degeneration of tissue (parts of the body looking older than their age/losing shape); change of skin colour and texture.	0,07	0	0.535	
Stroke – numbness in the face, arm, and legs; loss of balance or coordination.	0,13	0	0.718	
Weight loss in a short period.	1,88	1	2.094	
Fatigue (extreme tiredness/weakness).	2,35	3	2.276	
Jaundice – yellowing of eyes, skin, and mucous	0,19	0	0.756	

	membrane; dark urine and pale stools.				
	Fever – (high temperatures and heavy sweats).	2,41	3	2.286	
	Headache or migraines.	1,93	0	2.169	
	Acute sickness and death without being sick for a long time.	0,12	0	0.673	
	OVERALL AVERAGE:	1,37	1,45	0.849	

Reliability refers to the consistency or extent to which the measurement of a phenomenon yields stable and consistent results. The results on Table 22 below demonstrate that all the constructs are internally consistent in their measurement because the Cronbach Alpha values are above the required thresholds (0.7). It justifies that the questions work together to measure the same idea or concept (Taherdoost, 2016; Anderson et al., 2024). A reliability analysis was conducted for the constructs Impacts of Landfills and Disease/Condition Symptoms, including their respective items, to assess internal consistency. A Cronbach's alpha value of 0.7 is considered the acceptable limit (Izah et al., 2024), although some studies reported that values of 0.6 is moderate and may sometimes be deemed sufficient, but may indicate that a larger sample is required (Buhang et al., 2018; Duad et al., 2018).

Table 22: Reliability of constructs

CONSTRUCTS	ITEMS	ITEM TOTAL CORRELATION	CRONBACH ALPHA	FINAL NUMBER OF ITEMS (INITIAL)
Impacts of landfills	Smoke fog from waste burning affects our daily chores.	0,521	0,859	16(18)
	Compromised environmental aesthetics (e.g. eyesore waste heaps, leachate, and smoke).	0,481		
	There is an increase in road accidents due to the smoke fog.	0,439		
	Loss of property or goods (e.g. housing, cars) from uncontrolled fires.	0,483		

	Residents opt to sell their properties or move to other areas because of the unbearable living conditions.	0,412		
	Rented tenants are not staying longer in this area, and the renting business is compromised.	0,486		
	Lack/ loss of business (our businesses are not busy and flourishing).	0,376		
	Flooding during storms (drains blocked with waste).	0,375		
	Poor crop production.	0,339		
	High cases of chemical poisoning in children.	0,541		
	Sudden death in animals	0,523		
	High vector infestation (e.g. mosquitoes, flies, cockroaches).	0,480		
	High rodent infestation (e.g. rats, snakes).	0,535		
	High cases of gender-based violence (e.g. rape, beatings).	0,642		
	The area is noisy.	0,512		
	High crime rate.	0,588		
Disease/ Condition symptoms	Respiratory problems – difficulty breathing, chest pain, nasal irritation, continuous coughing, and sputum.	0,564	0,865	13(22)
	Gastrointestinal symptoms – nausea, vomiting, watery or bloody faeces, stomach pain.	0,668		
	Skin problems – allergies, bites, rashes, sores, blisters.	0,474		
	Musculoskeletal problems – muscle aches, painful joints and back, arthritis.	0,595		
	Vision problems – poor sight, partial blindness, cataracts, allergies (itchiness and redness).	0,467		
	Hearing problems – partially/impaired hearing, not hearing clearly.	0,329		

Dental problems – tooth decay, bleeding gums, change of teeth colour.	0,407		
Depression – prolonged stress and tiredness, anxiety (feeling unsettled).	0,722		
Cardiovascular symptoms – heart attack, low/high blood pressure.	0,302		
Weight loss in a short period.	0,616		
Fatigue (extreme tiredness/ weakness).	0,598		
Fever – (high temperatures and heavy sweats).	0,642		
Headaches or migraines.	0,556		

4.8 Limitations of the study

The study was conducted between peak summer and early autumn seasons (December to March), meaning the findings from this cross-sectional study cannot be conclusive for other seasons. Another limitation of the research method is that the cross-sectional design limits the ability to draw causal inferences. The reliance on self-reported data from questionnaires may be subject to bias recall bias and response bias where respondents may not accurately remember the frequency or intensity of past behaviours or to answer towards the middle of the scale. Respondents may also pretend to be healthier or exaggerate their illness to appear more distressed hoping for benefits (Altruistic, 2016; Caolli, 2021).

Data collection can be challenging for individuals who do not speak Sesotho as their first language, particularly due to the respondents' varying levels of education and the need to interact throughout the questionnaire to explain complex texts. Additionally, some residents from the eastern part of the Free State (Phuthaditjhaba and Harrismith), closer to KwaZulu-Natal, preferred communication in the isiZulu language, even though they were fluent in the Sotho language.

The collection was sometimes conducted on weekends to accommodate the availability of the research team, but several residents, especially in Theunissen, felt inconvenienced by having to participate on a Sunday, which they considered time for

their loved ones, and asked to be excused for participation. The research team was treated with hostility and received an unwelcoming demeanour at the Frankfort landfill, where only mapping coordinates were taken, and observations were carried out. Still, residents refused to participate in the study. One woman confused the researchers' vehicle with that of a municipal authority, which promised to remove their shacks, leading to their forcible eviction from the site. The other residents claimed that a university from Johannesburg gave them a false promise that they would provide them with PPE, food, and equipment to keep them warm and comfortable in their shack on their intended second visit if they cooperated with them, and this exploitation created mistrust from any researchers who visited the site.

4.9 Conclusion

The results show that communities living near landfill sites are socio-economically vulnerable and exposed to poorly managed landfills located. Exposure to odours, rodent and vectors, and hazardous waste is reported by residents. Reported injuries and multiple health problems indicate significant environmental and occupational health burdens. Limited healthcare utilisation further reflects existing health inequalities.

CHAPTER FIVE – DISCUSSION

5.1 Introduction

In this chapter, the study findings and limitations of the study are highlighted and discussed in comparison with existing literature to answer the objectives of the study. The chapter consists of five sections, namely the sociodemographic information of residents, the association between waste landfill proximity and environmental exposure, waste-related environmental and public health risks through a One Health lens, perceived and lived health outcomes among residents living proximate to landfill sites, and lastly the proposition for a digitised community awareness and self-monitoring model.

5.2 Sociodemographic information of residents

The population of respondents was 52.9% male and 47.1% female, indicating a relatively balanced gender distribution, with a slight predominance of males. The findings are consistent with the provincial demographic trends of the Community Survey conducted in 2016, which reported that 58,3% of the population in the Free State province are male and 41,7% are female (Statistics South Africa, 2016). While the recent 2022 Census results provided an updated population total of 2.9 million in the Free State, specific gender percentages have not been highlighted in the initial report release (Statistics South Africa, 2023a). The national population trends for 2025, however, indicate that females account for 51% of the population, which is approximately 32 million out of the 63 million current population, and men only account for 49% (Statistics South Africa, 2025a). The higher female participation may also suggest that most households near the landfill site were female headed. Over half of the respondents (56.2%) were middle-aged (between 36 and 59 years), followed by young adults (30.6%) aged 22–35 years and pensioners (7.4%). The findings are slightly similar to the national trends that indicate that children under the age of 15 make up about 26,2% of South Africa's population, an estimated 16,5 million people. Adults between the ages of 35 to 59 are 19.2 million (30.4%). Meanwhile, around 10,5% of the population, or 6,6 million people, are aged 60 and older (Statistics South Africa, 2025a). Most of the respondents have stayed in these areas for over fifteen years, which can mean that they know the dynamics of the places better and have been exposed to environmental waste for a longer period of their lives.

A smaller proportion of the migrants (6.6%) in the study were from Lesotho. To the east, it has an international boundary with Lesotho; therefore, cross-border movement is common due to geographical proximity (Free State Online, n.d.). International migration trends, however, show that Gauteng is the number-one preferred destination, followed by the Western Cape province. These provinces have a higher economic affluence, which can be a pull factor (Statistics South Africa, 2025b). The demographic data of a study conducted on female waste pickers in Masheyeng, Free State, revealed that they originally came from Lesotho and their ages ranged from 35 to 45 years (Ramolelle & Xweso, 2022). This shows that waste picking is one of the informal jobs that can attract international migration or sustain migrants who have moved into South Africa for greener pastures but found waste picking as the most viable source of income. Most respondents in this study are 35 to 45 years old, i.e. are within the middle adulthood group of 35–59 years. The middle-aged adult group generally demonstrate high labour force participation in the formal sector, often occupying mid-to-late-career positions. However, those with lower educational attainment and limited access to formal employment may resort to waste picking as an informal means of livelihood, especially after COVID-19 layoffs and failure in business ventures (Yu et al., 2020; Schenck et al., 2016). Even in most European countries, poverty rates among older people remain higher for women than for men. In more than half of the countries with available data, this gender gap widens among one-person households compared to all households, reflecting women's heightened economic vulnerability when living alone (UN, 2017b).

Most respondents (88.4%) were born in the Free State, followed by 3.3% in KwaZulu-Natal, while the smallest proportion (1.7%) originated from Gauteng. This high proportion of respondents born in the Free State is unsurprising, as the province, located on the vast, flat plains in the centre of South Africa, shares borders with most of the country's provinces, except Limpopo and the Western Cape (Free State Online, n.d.). A total of 35.5% of respondents resided in the Lejweleputswa District, followed closely by 33.9% in the Thabo Mofutsanyane District and 30.6% in the Fezile Dabi District. This relatively even distribution across the three districts suggests that the study achieved balanced geographical coverage within the Free State province. The slightly higher representation from Lejweleputswa may be attributed to the greater number of landfill sites included in this district (seven in total) or the closer proximity

of residential areas to participating landfill sites, given that respondents were selected through convenience sampling. The majority of respondents (52.9%) had attained only a primary level of education (Grades 1–7), followed by 26.4% who had completed junior secondary education (Grades 8–10) and 18.2% who had completed high school (Grades 11–12). Approximately 34% of respondents reported secondary schooling as their highest level of education, indicating relatively high dropout rates and limited progression to tertiary education (Statistics South Africa, 2023b). Nationally, the proportion of individuals attending educational institutions between the prime ages of 5 and 24 years increased by nearly 4%, from 73.1% in 2011 to 76.8% in 2016, reflecting gradual improvements in educational access (Statistics South Africa, 2023b). However, the concentration of respondents with only primary and incomplete secondary education in this study suggests that national achievements may not be evenly distributed across provinces, particularly in communities situated near landfill sites where socioeconomic constraints remain distinct.

Most respondents (57.9%) were unemployed, 32.2% were employed, and only 9.9% were grant or pension recipients. The high unemployment rate reflects a broader national challenge, as unemployment in South Africa, including in the Free State province, has remained persistently high and was further exacerbated by the socioeconomic disruptions of the COVID-19 pandemic (DESTEA, 2022). The province's dependency ratio, which measures the burden placed on the working-age population to support dependents, declined from 66 in 2011 to 60 persons per 100 in Census 2022, indicating a modest demographic improvement (Lejweleputswa District Municipality, 2022). However, given the high proportion of unemployed respondents, economic dependency remains a significant concern in many communities within the province. Approximately 19.8% of respondents reported working as waste pickers, while 9.9% relied on social grants or pensions. Smaller proportions were engaged in informal economic activities such as animal caretaking, recycling, cashier work and small-scale printing. In total, 67.8% indicated that they had participated in waste picking activities at some point during their stay near the landfill sites. Waste pickers are often highly mobile, and the nature of their work tends to fluctuate seasonally. Their limited engagement with researchers may also stem from concerns that information provided could be relayed to authorities, potentially affecting their livelihoods. Globally, waste picking represents a small, but critical segment of informal

labour; for example, in India, waste pickers account for only about 1% of the total of 2.2 million workers employed (WIEGO, n.d.).

Most respondents live in informal housing. About 38.8% live in shacks, reflecting the continued growth of informal settlements around landfill sites, often attributed to delays in the delivery of Reconstruction and Development Programme (RDP) housing, which accounts for only 29.8% and backyard dwelling (19% of the respondents) (Aydano et al., 2020; Ojo-Aromokudu et al., 2020; Parikh et al., 2020). Respondents residing in private, single houses recorded the highest income mean rank (76.86), suggesting that this group generally reported higher combined monthly household incomes. They were followed by those living in backrooms (63.52), shack houses (61.86), and RDP houses (54.49). However, the difference in combined monthly income across the five housing types was not statistically significant ($p = 0.413 > 0.05$), implying that the observed variation is likely due to random variation rather than a true association between housing type and household income. According to Statistics South Africa, the proportion of households living in backyard dwellings, either in formal or informal settlements, increased from 7.3% in 2011 to 12.5% in 2016, with such dwellings being particularly common in urban areas (Statistics South Africa, 2023c). These types of dwellings typically provide affordable accommodation for families who cannot afford regular rent, are awaiting RDP allocation, or do not qualify for government housing. Nationally, the share of formal dwellings rose to 83.5%, followed by 12.2% informal and 3.9% traditional dwellings (Statistics South Africa, 2023). The finding that 9.1% of respondents resided in private or traditional dwellings was therefore noticeably higher than the national average, suggesting distinct local housing dynamics in communities near landfill sites. Around the world, one's home is a key asset for stored wealth (UN, 2017b).

Respondents reported an average combined monthly income of R1 877,85, which is approximately nine times lower than the national average combined monthly income of about R17 000, and four times lower than the median monthly household income of around R8 000, as reported in the 2022/2023 Income and Expenditure Survey (Statistics South Africa, 2025b). The majority of households (62%) had children under the age of 18, the typical school-going age, while 38% consisted solely of adults, and the respondents had an average of 1,56 (approximately two) children living in their households. There are similarities in the findings nationally, with an average of 2.21

(approximately two) children. The relatively young population structure in communities around landfill sites also shows that there is additional pressure on household resources, especially where unemployment and people are living in poverty. Literature has also shown that children living near landfill sites are at a greater risk of environmental hazards (Gumede, 2015; Alabi et al., 2023).

The majority of respondents (78.3%) reported using wood as their primary household energy source for heating. Slightly more than half (53.3%) used electricity, 40% relied on paraffin, and 15.8% used methane gas. Only 0.8% of respondents had solar panels installed, while 3.3% reported burning solid waste, and 0.8% used dried cow dung as additional sources of heat. Despite the notable national progress of expanding electricity access, from just over 36% of households in 1994 to more than 94% by 2024, representing over 8.4 million new household connections, many South Africans continue to experience energy poverty. Approximately 1.6 million households remain unelectrified, particularly in informal settlements, peri-urban areas, deep rural regions, and newly developed housing projects (ESI Africa, 2025). Residents of informal and low-income formal settlements often have a high energy demand, which sometimes leads to illegal electricity connections (Monyai et al., 2023), often following repeated delays and unfulfilled service delivery promises by local authorities. However, due to the unreliability of electricity caused by frequent load shedding, especially in these areas, cheaper and more accessible energy sources such as wood are often preferred (Mocwagae et al., 2024). Previous studies have shown that dependence on wood fuel contributes to indoor air pollution, which is associated with severe health impacts, particularly among women and children (Alabi et al., 2023; World Bank/WHO, 2024; WHO, 2024b). These risks are further exacerbated in households where cow dung and solid waste are used as substitute biofuels. The chi-square test indicates that the association of limited access to municipal water connections and the reliance on wood as their primary energy source were statistically significant ($p = 0.026 < 0.05$). This relationship is largely driven by intersecting factors such as poverty, time poverty, and inadequate infrastructure. Households without municipal water access are typically low-income and face significant economic constraints. Consequently, wood becomes a preferred energy source, because it is freely available or low-cost, unlike municipal services such as water and electricity, which require regular payment (Netshipise & Semanya, 2022; Choudhuria & Desai, 2021). Globally, access to clean fuels and

technologies for cooking increased from 50% in 2000 to 57% in 2014. Nevertheless, over 3 billion people, primarily in Asia and sub-Saharan Africa, remain without access to clean cooking fuels and technologies, exposing them to high levels of household air pollution (UN, 2017b).

Almost half of the respondents reported using pit latrine toilets, a pattern similar to that observed in Limpopo province, where the predominant sanitation facility is the ventilated improved pit (VIP) latrine (NEWS24WIRE, 2023). The proportion of respondents with access to flush toilets connected to sewerage systems was 39.7%, considerably lower than the provincial average of 76.0% recorded for the Free State (Statistics South Africa, 2023). Additionally, the proportion of households relying on bucket toilets and practising open defecation was slightly higher than the national figures of 3.5% and 4%, respectively (Statistics South Africa, 2016; NEWS24WIRE, 2023). The continued lack of adequate sanitation facilities and the need for residents to share toilets even after 1994 reflect not only a shortfall in post-apartheid reparation efforts to restore dignity to previously marginalised citizens, as envisioned in the Bill of Rights, but also contribute to ongoing public health challenges, environmental contamination, and social and psychological distress. These conditions particularly affect women and children, who may be more vulnerable to health risks and sexual exploitation (Salem et al., 2019; NEWS24WIRE, 2023). In some informal areas where no sanitation facilities exist, the use of pit latrines has been recommended as a temporary measure (Netshipise & Semanya, 2022).

5.3 Association between waste landfill proximity and environmental exposure

More than half of the landfill sites were located within a distance of 5 km from areas of land use, with four sites (22%) situated within 2 km and one site located less than 1 km away, approximately 750 m from residential, agricultural, commercial, industrial, or conservation areas. The geospatial findings of this study corroborate previous South African research showing a continuous reduction in the average distance between landfill sites and human settlements over time, from 68.5 km in 2008 to 8.5 km in 2015 (Tomita & Slotow, 2020). In the present study, nine landfill sites were found to be situated less than 5 km from land use zones, with an average distance of 1.11 km from human settlements in 2025. These results align with earlier observations that disposal sites, once located at acceptable distances from residential areas, now lie adjacent to

predominantly low-income suburban housing (Du Preez et al., 2016). The situation is further exacerbated in informal settlements and slum areas, where increased population influx, rapid urbanisation, and expanding developments intensify land demand and lead to the encroachment of residential areas towards landfill zones (Akinrogunde et al., 2019). Studies have shown the possibility of contamination and significant health impacts on residents' living and water contamination where the buffer zone is 5 km or less from landfill sites (Gumede, 2015; Mokhadi et al., 2020; Phan et al., 2021; Maluleka et al., 2025).

Over the past decades, and continuing to the present, research on the effective management of landfill buffer zones in South Africa has remained limited, accompanied by inconclusive legislation and fragmented implementation. This has resulted in a lack of practical experience and the absence of well-established tools or conceptual models to guide best practices and promote the sustainable long-term management of these areas (Moodley et al., 2012; Macfarlane et al., 2014). The establishment and maintenance of buffer zones are enforceable under the Health Act, 2003 (Act 61 of 2003), which provides for measures necessary to prevent nuisances, unhygienic or offensive conditions, and any circumstance deemed harmful to public health, as outlined in the *Minimum Requirements for Waste Disposal by Landfill* (DWAF, 1998). The landfill buffer distance from airports is explicitly prescribed as 3 km; however, the required distances from water bodies and land-use areas remain subject to the landfill's operational plans, as well as administrative and physical acceptance criteria determined at departmental discretion (DWAF, 1998; DFFE, 2021). In 2017, the *Gauteng Pollution Buffer Zones Guideline* was introduced, recommending a best-case buffer of 400 m (or, in the worst case, 200 m) for general landfills, and a best-case buffer of 2 km (or, in the worst case, 1 km) for hazardous landfills. Despite these provisions, South Africa, particularly the Free State province, continues to experience challenges in distinguishing landfill classifications due to operational inconsistencies and the acceptance of mixed-waste streams containing both general and hazardous materials (Roberts, 2013; Machete & Shale, 2017). The findings of this study revealed that residential dwellings were present on seven landfill sites (38.9%). Three sites (16.7%) were located less than 2 km from water bodies, with the closest situated approximately 140 m away.

5.4 Waste-related environmental and public health risks through a One Health lens

5.4.1 Environmental factors

Field observations revealed that the type of waste loads was not inspected upon arrival at landfill sites, leading to the indiscriminate disposal of various hazardous and non-hazardous waste streams. Medical waste, including discarded medicines, syringes, inhalers, sanitary products, diapers, bandages and swabs, was observed at most sites, often mixed with general waste. Similarly, chemical waste such as aerosols, vehicle oils and paint containers from households, workshops and small-scale industries were commonly disposed of together with domestic refuse. These findings highlight a lack of waste segregation at source and weak enforcement of regulatory controls.

In the Free State, the majority of landfill sites are neither engineered nor designed to accommodate hazardous waste. Even at the few sites equipped with synthetic liners, prolonged exposure to toxic substances can cause structural degradation, compromise containment integrity and increasing risks of soil and groundwater contamination (Aladi et al., 2023). Leachate pools and trenches were visible on approximately half of the observed sites, exacerbated by seasonal rainfall. Prior studies confirm that uncontrolled leachate discharge contributes significantly to water source contamination (Danthurebandara et al., 2013; Deffnika et al., 2021). At some sites, tyres and plastics were partially submerged in stagnant leachate pools, which could provide breeding habitats for disease vectors.

The unsafe co-disposal of healthcare and household hazardous waste reflects systemic governance and infrastructural weaknesses. Health-care risk waste (HCRW) is particularly concerning, as it is ranked second only to radioactive waste in terms of toxicity (WHO, 2008). Studies show that there is no accurate national estimate of the HCRW generated in South African households, largely due to ambiguous classification within the National Environmental Management: Waste Act 59 of 2008 (NEM:WA) and the absence of a clear national strategy for its management (RSA, 2008; Zithathile & Atangana, 2018a). This regulatory gap has resulted in unsafe disposal practices. For example, Magagula et al. (2022) found that unused medicines are often mixed with general household waste, while Berrian et al. (2016) report that 80% of caregivers

in Mpumalanga disposed of used diapers by burning, burying, or dumping them in open spaces and rivers. Similarly, Made et al. (2021) observe that poor planning and mismanagement of hazardous waste such as batteries, medical waste and chemicals increase disease risks among waste pickers.

As a measure to reduce waste volumes or “clean” e-waste, open burning was observed at all sites. This practice, commonly used to extract valuable metals such as copper, involves burning plastic or fibre components, producing toxic residues and air pollutants. Similar trends were reported in Ghana, where 34% of waste pickers reported burning e-waste, 25% burning wires, and 10% removing wire coatings as part of their routine activities, typically four days per week (Takyi et al., 2021). The burning of waste contributes to poor air quality, odour nuisance and greenhouse gas emissions. In the present study, 77.7% of respondents strongly agreed that odours from landfill sites were unbearable, and 60.3% indicated that smoke or fog from waste burning disrupted their daily activities. The unpleasant odours are primarily associated with hydrogen sulphide (H_2S), volatile organic compounds, and other sulphur-containing gases produced during waste decomposition (Danthurebandara et al., 2013; Njoku et al., 2019). The problem is compounded by the disposal of abattoir waste, as the Free State is South Africa’s leading cattle-producing province, accounting for 11% of the national herd (Stats SA, 2020). These processes collectively contribute to greenhouse gas emissions and climate change. According to the Intergovernmental Panel on Climate Change (IPCC), the waste sector contributed approximately 5% of global greenhouse gas emissions in 2014, primarily from solid-waste disposal and wastewater treatment. South Africa ranked among the top 20 global carbon-dioxide emitters in 2019 (EU, 2024).

The physical security and management of landfill sites were also found to be inadequate. Only five sites (27.8%) had fencing, most of which was vandalised or unsuitable for containing litter. Damaged or missing fences allow unauthorised access, including by criminals, and have reportedly facilitated illicit activities such as the disposal of human remains and aborted fetuses. These findings underscore the broader social risks associated with unmanaged landfill sites. Indeed, 64.5% of respondents strongly agreed that the surrounding community experiences high crime rates, echoing findings from Nigeria, where proximity to landfill sites was associated with increased crime and community dissatisfaction (Akinrogundeg et al., 2019).

Interestingly, despite these challenges, a majority of respondents (71.1%) strongly disagreed that residents sell their properties or relocate due to poor environmental conditions, while 76% disagreed that living near landfill sites leads to loss of business or rental income. These perceptions contrast with studies from the Eastern Cape, Lesotho and Ghana, where property values and rental demand declined near landfill sites (Du Preez et al., 2016; Ofori, 2021; Mokoka, 2022). This divergence may reflect a form of risk normalisation among low-income residents, who may prioritise affordability and proximity to income-generating opportunities, such as recycling, reported by 62% of participants, over environmental or health risks. The environmental health burden associated with these sites extends beyond visible pollution. A study by Bouwman et al. (2020) detected traces of pharmaceuticals and microplastics, including antiretroviral residues, in South African water resources. Although the concentrations were below harmful limits, prolonged exposure could contribute to the growing problem of antimicrobial resistance. Together, these findings reveal that inadequate waste governance, unsafe disposal practices, and environmental degradation interact to reinforce a cycle of health vulnerability and social inequity among communities living near landfill sites.

5.4.2 Animal factors

Domestic animals and wildlife, particularly birds and small burrowing species, were frequently observed scavenging for food and edible organic waste on landfill sites, including waste contaminated with human excreta from disposable nappies. Cattle herds were also seen grazing on litter-contaminated pastures in the vicinity of landfill sites in several towns. Approximately 75.2% of respondents strongly agreed that sudden deaths have occurred among animals grazing on or near these sites. Similarly, a study conducted in the Eastern Cape reported that 53.8% of residents had witnessed animals consuming litter, while 69% associated various animal health problems, such as pain, poor body condition, abdominal distension, abnormal respiration, and signs of dehydration or anorexia, and, in worst cases, sudden death with waste ingestion (Nongcula et al., 2020). Further investigations revealed that plastics, wire, nails, rope, bones, stones, cloth, hair and polybezoars were among the most common foreign materials recovered from slaughtered animals exposed to waste (Nongcula et al., 2020). The ingestion of such materials is highly detrimental, as animals can develop a range of environmental and infectious diseases, including clostridial infections such

as blackleg, botulism, malignant oedema, red-water disease, enterotoxemia (types C and D), and tetanus conditions often associated with exposure to contaminated waste (TB Hub, 2020; Dejene, 2023; MSD Animal Health, 2022). Moreover, human faeces are well-recognised carriers of infectious and zoonotic pathogens. Faecal contamination not only poses immediate health risks to both animals and humans, but also contributes to long-term environmental threats, notably the emergence and spread of antimicrobial resistance (AMR) (Deffnika et al., 2021; Kordecki et al., 2023).

Abattoir waste, including bones, hides, carcasses and blood, was detected at 16 landfill sites (88.9%), originating primarily from local abattoirs and households. The presence of such waste provides food sources for rodents and other vectors, thereby facilitating their proliferation and increasing the risk of disease transmission. In several instances, whole animal carcasses, including those of sheep and chickens, were observed being openly disposed of at landfill sites. When animals die before reaching slaughterhouses, their carcasses are frequently discarded alongside general municipal waste, a practice that poses considerable environmental, biosecurity and public-health concerns (Clark, 2022).

According to the Meat Safety Act (RSA, 2000), condemned materials must be disposed of through approved methods such as safe incineration, denaturing, or burial. These processes should include disinfection and the immediate covering of material at a depth of at least 60 cm below the ground surface and must occur at secure sites situated at least 100 m from water sources or public areas, with disposal authorised by the provincial executive officer and local government. In addition, such waste may be processed at sterilisation facilities. Under the National Environmental Management: Waste Act 59 of 2008 (NEM:WA) (RSA, 2008) and Schedule 3 of the Act, non-infectious animal carcasses, including those euthanised by veterinarians to prevent further suffering, are categorised as general or healthcare waste. Conversely, carcasses that are infectious or treated with veterinary pharmaceuticals are classified as hazardous waste and must be managed at authorised hazardous-waste facilities, as they are prohibited from disposal at ordinary landfill sites (RSA, 2008; EarthPet, 2021). Furthermore, the National Norms and Standards for the Disposal of Waste to Landfill designate non-infectious animal waste as moderate-risk waste (Type 2), which requires disposal at a Class B landfill facility and all infectious wastes to be treated at

a hazardous-landfill site; yet there are no records of whether the animal waste was infectious or non-infectious due to the minor or little monitoring at sites.

Improper handling and disposal of abattoir and animal waste represent a significant environmental health hazard. These practices contribute to soil and water contamination, attract disease vectors, and increase the risk of zoonotic transmission between animals and humans. When combined with the widespread presence of decomposing organic matter and faecal contamination on landfill sites, such conditions create an ideal environment for the proliferation of pathogens and the development of antimicrobial resistance, thereby intensifying the public health burden in nearby communities. Consistent with these risks, 86.8% of respondents strongly agreed that rodent infestations, particularly rats and snakes, are prevalent near landfill sites, while 89.3% strongly agreed that disease vectors are common in these areas. The majority of respondents (86%) identified house flies as a persistent household nuisance, followed by 82.6% who reported a proliferation of mosquitoes, especially during the warmer months, and 80.2% who expressed similar concerns about rats and mice. Other nuisance and vector species frequently mentioned included ants, cockroaches, snakes, stray dogs and cats, bugs, and lice. It should be noted that the data were collected during a relatively short period spanning the warm peak season from December to March (summer to early autumn). As such, the findings may not fully capture seasonal variations in vector and rodent activity. Environmental factors such as temperature, humidity and wind direction fluctuate across seasons and may influence the breeding and nesting behaviour of these species. Spring and summer are typically recognised as peak breeding periods for rodents and vectors due to the abundance of vegetation, natural food sources (such as seeds and insects), and rainwater that provide suitable nesting and breeding conditions. These observations highlight the importance of conducting longitudinal studies to assess seasonal differences in the ecological and health impacts of landfill sites throughout the year (Wu et al., 2016; Krystosik et al., 2020).

5.4.3 Human factors

School-age children and infants were observed in 44.4% (8) of landfills, either participating in waste picking or accompanying parents, particularly where no security personnel were present to prohibit entry. Similar findings were identified in the northern

region of Ghana, where 80% of the total sum of waste pickers were children, with only 20% attending school (Global Plastic Action Partnership, 2025). These effects lessened as the distance from the landfill increased. This shows that child access to landfill sites may not only have implications for school attendance. In the case of South Africa this undermines the South African School Act of 1996 (SASA) that states that school attendance is compulsory for children from the first day of the year in which they turn seven, until the last school day of the year in which they turn fifteen, or until they complete Grade 9, whichever occurs first (Department of Education – Free State, 2025). According to the Children's Act of 38 of 2005 Regulations, all waste must be properly covered, kept out of reach of children, and handled using safe disposal methods (RSA, 2008).

Approximately 58.7% (71/121) of respondents strongly agreed that children experience high rates of chemical poisoning associated with proximity to landfill sites. This finding, while notable, is slightly lower than the 65.9% (254/385) reported in an explanatory mixed-method study conducted in Kampala, Uganda, which assessed caregivers' knowledge, attitudes, and chemical safety practices. The observed variation may be influenced by differences in sample size, study design, and contextual factors. Whereas the Ugandan study targeted a larger cohort and focused specifically on household chemical exposures, the present study examined environmental exposures emanating from landfill sites, which may account for the comparatively lower level of agreement among respondents (Akello et al., 2025). According to Siddiqua et al. (2022) children living close to landfills showed reduced immune function, with lower levels of lysozyme and immunoglobulin A (SIgA) due to exposure to gases such as CH_4 , H_2S and NH_3 . 53.7% of respondents strongly agreed that there are high cases of gender-based violence, such as rape and beatings, which puts the safety of children in more jeopardy. In the year 2019/2020 there were 42 289 rape cases, which translates to 115 rapes per day, as well as 7 749 sexual assaults reported (The Conversation, 2022).

Only waste pickers affiliated with recognised organisations, such as the Waste Picker Association, were found to possess partial personal protective equipment (PPE), which typically included basic items such as overalls and reflectors. This finding underscores the crucial role that structured and well-established waste picker associations play in promoting occupational safety and facilitating access to essential

protective resources. In contrast, unorganised or independent waste pickers often operate without adequate safety gear, exposing themselves to significant occupational hazards. A study conducted in South Africa revealed that many waste pickers resort to collecting and reusing discarded, worn-out clothing from landfill sites as makeshift PPE, which provides minimal protection against cuts, puncture wounds, and exposure to infectious materials (Made et al., 2020). According to the Occupational Health and Safety Act (Act No. 85 of 1993), landfill operators bear the legal responsibility to ensure the safety and welfare of all individuals working within landfill environments, including waste reclaimers. The Act stipulates that operators must supply and enforce the use of appropriate protective clothing, such as industrial gloves, boots with reinforced soles, and high-visibility tunics, which also function as identification and registration markers. Similarly, the Department of Water Affairs and Forestry (DWAF, 1998) prescribes that all site personnel should be equipped with suitable protective gear, including gloves, boots and overalls, as well as smoke masks and goggles when working under hazardous or dusty conditions. Despite these regulatory provisions, evidence suggests that the enforcement of occupational health and safety measures at landfill sites remains weak and inconsistent across the country. The inadequate provision of PPE and the lack of structured safety oversight not only compromise the health and dignity of waste pickers but also reflect broader institutional neglect within the informal waste sector. Strengthening waste picker associations, integrating them into formal waste management frameworks, and ensuring compliance with occupational safety regulations are therefore essential to advancing both human rights and environmental justice in South Africa's waste economy.

The majority of respondents (79.2%) reported that they either smoked or had family members who smoked, while 20.8% indicated that neither they nor their family members engaged in smoking. This high prevalence of smoking is particularly concerning in landfill environments, where individuals are already exposed to multiple biological and chemical hazards. Biological hazards in particular are derived from microorganisms that enter the host and proliferate within the body, leading to disease. These pathogens can easily be transmitted through contaminated hands, ingestion, and smoking practices (European Union [EU], 2020). Given that most waste pickers handle waste manually, often without adequate protective equipment, smoking during

or after work may further increase the risk of infection and exposure to harmful microorganisms.

5.5 Perceived morbidity among residents living proximate to landfill sites

The majority of respondents (65.3%) reported that they or a family member had sustained an injury while residing near a landfill site, whereas 34.7% indicated no history of injury. Among those who had been injured, the most commonly reported incidents were cuts or puncture wounds (78.2%), followed by fractures (30.8%), head injuries (20.5%), vehicle-related accidents (12.8%), and amputations (10.3%). A smaller proportion reported animal attacks (5.1%), leachate-related drowning or burns (2.6%), and injuries resulting from gun violence (1.3%). The largest proportion of respondents sustained injuries such as puncture wounds, cuts and fractures, which are usually associated with handling waste manually without appropriate personal protective equipment (Made et al., 2020; Tshivhase et al., 2022). Amputations and accidents can be associated with encounters with operational machinery and jumping on and off incoming traffic at landfill sites (Uhunamure et al., 2021). The incidences of animal attacks and children drowning in leachate further reflect the poor site management, inadequate fencing and free access of sites (Njoku et al., 2019; Tabloid Newspapers, 2023). Gun-related violence may suggest escalated conflicts at the landfill site amongst waste pickers, or broader socioeconomic problems in relation to waste picking in adjacent communities. One male respondent, aged 29, was reportedly shot and killed at the scene, while 17 other individuals sustained gunshot wounds and were transported to nearby hospitals for medical treatment after an altercation at Buffelsdraai landfill site in Durban (Tabloid Newspapers, 2023).

About 38% of respondents reported respiratory problems, 26.4% indicated daily gastrointestinal symptoms, musculoskeletal problems (36.6%) and 43.8% of respondents indicated daily experiences of eye problems. Several community health surveys have identified a range of health problems among residents, including respiratory symptoms, skin, nose and eye irritation, gastrointestinal issues, psychological disorders and allergies (Nor et al., 2019). Previous studies reported a higher risk of adverse reproductive problems due to exposure to landfill sites, due to exposure to heavy metals, volatile organic compounds and endocrine disrupters (Njoku et al., 2019; Singh et al., 2018). In contrast, the majority (84.3%) reported never

experiencing reproductive health issues such as miscarriages, infertility, fibroids in women, or children born with physical deformities or disabilities. The prevalence percentage is slightly lower, but it is noteworthy that a larger sample size was used, compared to this study.

High percentages of respondents had never experienced the following diseases or symptoms: cancer-related symptoms (97.5%), stroke (95.9%), childhood mental health problems (95%), jaundice 92.6%, sudden falls or epilepsy (90.9%), blood sugar-related symptoms (88.4%), and cardiovascular diseases (77.7%). Similarly, a study conducted in Johannesburg, South Africa, also revealed that 36.57% of waste pickers were at risk of mental health problems; chronic diseases were reported in 25.56% of the participants; while the majority (83.93%) reported having suffered from infectious diseases (Made et al., 2020). Chronic diseases or noncommunicable diseases (NCDs) typically develop in middle age after prolonged exposure to unhealthy lifestyles such as tobacco use, physical inactivity, and environmental pollution. Since the 1980s, an exponential increase in childhood diseases such as autism, asthma, attention-deficit hyperactivity disorder (ADHD), obesity, diabetes and various congenital disabilities has been observed worldwide, including Africa (AUDA, 2021). Despite their growing prevalence, these conditions are often underestimated in Sub-Saharan Africa, where the disease burden is largely associated with infectious diseases (Steyn & Damasceno, 2006; Stacherl & Sauzet, 2023).

The findings reveal that a considerable proportion of respondents had limited engagement with formal healthcare services, with only 30.6% reporting a visit to a healthcare facility within the previous month and 14% within two to three months prior. The fact that over a quarter (26.4%) last sought medical attention several years ago suggests that access to healthcare among landfill-adjacent communities remains sporadic and often reactive rather than preventive. This irregular utilisation pattern is consistent with previous studies highlighting that waste pickers and residents near dumpsites tend to delay medical consultations due to financial constraints, lack of healthcare infrastructure, and the normalisation of occupational hazards (Made et al., 2020). Over time, such populations may develop adaptive behaviours, relying on self-treatment or traditional medicine to cope with injuries and chronic conditions commonly associated with prolonged exposure to waste environments.

Hospitalisation trends further underscore the vulnerability of these communities to both physical and infectious diseases. While 62.8% of respondents had never been hospitalised, 21.5% reported hospital admissions due to illnesses predominantly linked to poor air quality, direct exposure to pathogens, and general environmental stressors such as respiratory ulcers, bronchitis, diarrhoeal infections and tuberculosis. These findings mirror the pattern observed in other low-income waste environments, where exposure to landfill sites and poor sanitation contributes to high rates of respiratory and gastrointestinal diseases (Udofia et al., 2017; Akinrogunde et al., 2019; Uhunamure et al., 2021; Maluleka et al., 2025). Additionally, 15.7% of hospitalisations were injury related, encompassing fractures, burns and wounds acquired through daily waste-handling activities, further confirming the occupational risks associated with informal waste work.

The significant association between healthcare visits and the prevalence of reported diseases ($p = 0.004 < 0.05$) reinforces the link between environmental exposure and adverse health outcomes. This suggests that those most affected by landfill-related illnesses are more likely to seek medical care, albeit under constrained circumstances. However, the large proportion (69.4%) of respondents who chose not to disclose their hospitalisation causes may indicate underlying issues such as fear of stigma, distrust of healthcare systems, or limited understanding of disease causation. Overall, these findings point to systemic health inequities and the absence of structured healthcare support for communities residing near landfill sites. The low frequency of healthcare utilisation, coupled with the high burden of illness, highlights the urgent need for targeted interventions such as mobile health clinics, occupational health awareness campaigns, and formal inclusion of waste pickers in municipal health monitoring programmes. Such strategies would not only enhance disease prevention and treatment but also strengthen the overall resilience and well-being of vulnerable landfill-dependent populations.

The normality tests conducted using the Kolmogorov–Smirnov (K–S) and Shapiro–Wilk methods indicated that the data on both the perceived impacts of landfills and the occurrence of disease or condition-related symptoms deviated significantly from the normal. Specifically the Shapiro–Wilk test results were statistically significant for the impacts of landfills ($p = 0.000 < 0.05$) and for disease or condition symptoms ($p = 0.001 < 0.05$), confirming non-normal distributions. As a result, the median was

identified as the most appropriate measure of central tendency for these variables. The findings show that 50% of respondents held neutral perceptions regarding the impacts of landfills, as reflected by an overall median of 3.33, which is closer to the midpoint (3) on the Likert scale. This neutrality may suggest uncertainty or ambivalence among community members, possibly due to limited awareness of the long-term environmental and health implications of landfill exposure, or because the perceived benefits, such as income generation through waste picking, may offset negative perceptions. Conversely, the median score of 1.45 for disease or condition symptoms, which is closer to 1 than to 2, indicates that 50% of respondents experienced such symptoms only once every two years. This relatively low frequency may reflect either underreporting due to health perception biases, reliance on self-medication practices, or a genuine absence of acute health conditions among some respondents. To assess the internal consistency and reliability of the measurement instruments, a reliability analysis was performed. The Cronbach's Alpha coefficients for all constructs exceeded the conventional threshold of 0.70, confirming strong internal reliability and demonstrating that the measurement scales yielded stable and consistent results. This statistical robustness strengthens the validity of subsequent interpretations and supports the reliability of the observed associations between landfill impacts and health outcomes.

5.5 Perceived morbidity among residents living proximate to landfill sites

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interpretations and supports the reliability of the observed associations between landfill impacts and health outcomes.

5.6 Conclusion

The study demonstrates that communities living near landfill sites in the Free State are predominantly socioeconomically vulnerable, with high unemployment, low income, limited education, and long-term residential exposure. Landfills were frequently located within inadequate buffer distances, increasing residents' exposure to environmental pollutants, odours, smoke, vectors, and hazardous waste. Poor waste management practices, including mixed and hazardous waste disposal, open burning, and inadequate site security, pose significant environmental, animal, and human health risks. Reported injuries, respiratory, gastrointestinal, musculoskeletal, and eye problems highlight both environmental and occupational health burdens. Limited and irregular healthcare utilisation further reflects systemic health inequities. Overall, the findings underscore a persistent nexus between landfill proximity, environmental degradation, and adverse health outcomes within a One Health context.

CHAPTER SIX – CONCLUSION

6.1 Introduction

This chapter synthesises the main findings of the study and outlines key conclusions drawn in relation to the research objectives. It also offers recommendations for policy, practice and further research. The discussion integrates the environmental, human and animal health dimensions of waste-related challenges through a One Health framework, emphasising their interconnectedness in shaping community well-being and sustainable waste governance.

6.2 Conclusion

The original contribution made by the dissertation to knowledge in the field is the self-perceived exposure of people living on and next to unmanaged and burnt landfills and the health impact of these vulnerable groups. The findings of this study reaffirm and extend the existing literature on the intersection between waste management, environmental degradation and public health outcomes within developing contexts. In the Free State province, landfill sites classified as ‘general’ are functionally receiving mixed and hazardous waste streams, including e-waste, medical waste, industrial residues and abattoir by-products. This misclassification underscores systemic weaknesses in institutional oversight, monitoring and enforcement of waste management regulations.

Furthermore, the study highlights how socioeconomic disadvantage, historical spatial inequalities, and limited municipal capacity converge to produce disproportionate exposure to environmental risks for communities residing in proximity to landfill sites. Residents living adjacent to these waste facilities are particularly vulnerable to respiratory, dermatological, and gastrointestinal health outcomes associated with environmental pollution, odour nuisance, leachate infiltration and open burning.

Despite these challenges, the study recognises the resilience and adaptive strategies of affected populations, particularly in informal settlements. However, their vulnerability remains compounded by low health literacy, poor access to health services, and minimal participation in local waste-governance processes. The lack of integrated waste-management planning, encompassing environmental monitoring,

community education, and public-health surveillance, further exacerbates the risk of cumulative exposure.

The environmental conditions are observed rather than quantified, and no exposure gradients or dose–response patterns were explored. Additionally, the results cannot be generalised to all landfill sites in the Free State due to the study’s limited sample size (18 sites), however, they provide a critical empirical reference point for understanding sub-provincial, waste-health linkages. The study thus contributes to the growing evidence base that supports integrated, participatory and multisectoral approaches to waste governance under the One Health approach.

6.3 Recommendations

6.3.1 Legislative revision on waste and landfill classification

The South African government should develop and enforce a comprehensive national guideline or by-law for the collection, segregation and disposal of household medical, e-waste and chemical waste. The Departments of Health, Forestry, Fisheries and the Environment (DFFE), together with the local municipalities, should be reviewed regularly (e.g. every 5 years) to ensure accurate waste designation and compliance. Strategies in line with waste management hierarchy and sustainable development plans (SDGs) need to be adopted for management and divert waste from landfills, of which most are already past their standard operational period.

6.3.2 Community-based public health interventions

Provisions of appropriate containers for waste generators, such as needle sharps and colour-coded waste receptacles, effective separation-at-source and community participation and collection to permitted drop-off facilities can assist in the diversion of hazardous wastes from landfill sites. Municipalities can implement community outreach programmes focused on raising awareness about waste-related health risks, especially targeting informal settlements near landfill sites. The community members can also benefit from participation in a Digitised Community Awareness and Self-Monitoring Tool (DCASMT) for educational and awareness purposes and environmental health surveillance.

6.3.3 Proposition for a digitised community awareness and self-monitoring tool

The findings of this study reveal a need for an integrated and participatory approach to environmental and public health monitoring within local communities in the vicinity of landfills in the Free State. Challenges such as limited awareness of waste-related health risks, weak regulatory enforcement and disintegrated reporting mechanisms have collectively hindered effective prevention and early response strategies. To address these challenges, this study proposes the establishment of a Digitised Community Awareness and Self-Monitoring Tool (DCASMT). This is a mobile and web-based system designed to strengthen local municipalities through community participation, digital monitoring and data-driven decision-making.

6.3.3.1 Conceptual basis

The DCASMT function is in support of the One Health approach, which recognises the intrinsic interconnection between environmental, animal and human health systems (Destoumieux-Garzón et al., 2018; WHO, 2024b). The model aligns with existing South African legislative frameworks such as the Occupational Health and Safety Act (Act No. 85 of 1993), the Children's Act of 38 of 2005 Regulations, the National Environmental Management: Waste Act (Act No. 59 of 2008), and the Health Act (RSA, 1977), all of which emphasise the promotion and protection of public and environmental health. Within the context of landfill management, the proposed tool seeks to operationalise these principles by enhancing surveillance, improving public awareness, and fostering shared accountability for environmental health risks.

The DCASMT has two primary functions: firstly, awareness creation, aimed at improving community knowledge, attitudes, and behaviours related to waste exposure and hygiene; and secondly, self-monitoring, which enables residents to document and report environmental, and health indicators associated with landfill proximity. By combining participatory data collection with immediate feedback, the model bridges the gap between local lived experiences and municipal or provincial response mechanisms (Li et al., 2025).

6.3.3.2 Functional framework

The proposed DCASMT comprises six interconnected components designed to promote collaboration, transparency and responsiveness, which are the Awareness

and education hub, environmental self-monitoring dashboard, health symptom tracker, vector and animal observation unit, Feedback and Response System, and Data Integration and Analytics Portal. The functions of each component are described below.

Awareness and education hub

It provides accessible multimedia resources such as videos, infographics, and voice-over tutorials in multiple local dialects to promote environmental health literacy. It will operate similarly to an application called MomConnect, which is a national-level mobile health information messaging programme from the National Department of Health that connects new mothers to health services and provides them with vital health information via SMS and WhatsApp messages (Pillay & Motsoaledi, 2018). The awareness and education hub will push notifications to disseminate urgent information on seasonal risks, such as vector proliferation during warmer months.

Environmental self-monitoring dashboard

This component enables residents to log observations related to odours, smoke, open burning, illegal dumping, or visible leachate discharge. Reports are geo-tagged and time stamped to facilitate spatial and temporal tracking. The aggregated data can be visualised through heatmaps or graphs to help identify environmental hotspots, consistent with the participatory Environmental Geographic Information System (EGIS) of the Department of Forestry, Fisheries and the Environment (DFFE).

Health symptom tracker

It supports self-reporting of symptoms linked to waste exposure, as well as any changes in vital signs (body temperature and breathing rate), and the development of new symptoms such as respiratory irritation, diarrhoea, skin rashes, or eye problems. By integrating digital reminders and basic symptom trend analytics, the system encourages early healthcare-seeking behaviour and links users to nearby clinics or mobile health teams.

Vector and animal observation unit

It integrates the One Health dimension by allowing users to report the proliferation of rodents, flies and mosquitoes; signs of unfamiliar rodents or wildlife; changes in the

behaviour and health of domestic animals; and dead animals near landfill sites. This information can be shared with veterinary and environmental units to detect zoonotic or vector-borne disease patterns.

Feedback and response system

It facilitates accountability by linking community reports to the appropriate municipal or environmental health authorities. Users receive acknowledgement and progress updates once reports are reviewed, which promote transparency and community trust. Additionally, a community-health scorecard can display resolved versus outstanding cases, fostering shared ownership of public-health interventions.

The data integration and analytics portal will provide municipal, agricultural, health officials and policymakers with aggregated, anonymised data. Real-time dashboards allow for tracking environmental and health trends, generating alerts for recurring hazards, and guiding evidence-based decision-making. This feature strengthens institutional responsiveness, while reducing irregular information between residents and authorities.

6.3.3.3 Monitoring domains and indicators

The DCASMT operates across the five key monitoring domains aligned with the study findings and One Health principles below, which can collectively generate an integrated dataset that can inform early warning systems, health education campaigns, and targeted environmental interventions.

Environmental health: Frequency of open burning, odour intensity, proximity to leachate, illegal waste disposal, and water contamination events.

Animal Health: Incidence of rodent and mosquito sightings, reports of sick or dead livestock, and animal carcass disposal practices.

Human health: Self-reported symptoms such as respiratory, gastrointestinal, and skin problems; injury occurrences; and cases of chemical poisoning.

Waste Governance and Safety: PPE availability among landfill site workers, including waste pickers, waste-picker associations such as SAWPA, the condition of landfill fencing, and the presence of unauthorised site access.

Community Engagement: Number of active users, completion rates for educational modules, and municipal response times to community alerts.

6.3.3.4 Implementation Strategy

The implementation of the DCASMT can be structured in four sequential phases.

Phase 1 – Design and pilot testing: The tool should be co-developed with local communities, waste picker organisations, and environmental health practitioners to ensure contextual relevance and usability. Initial pilots could be conducted in selected Free State districts where landfill proximity and informal settlement density are the highest.

Phase 2 – Capacity building: Training programmes for community health workers and waste-picker associations will strengthen local capacity to use the system effectively and sustainably.

Phase 3 – Digital deployment: The tool will be launched via mobile and web application platforms, and with SMS functionality to ensure access in low-connectivity areas

Phase 4 – Evaluation and scaling: The pilot phase should be followed by evaluation of usability, data reliability, and integration potential with municipal environmental and health information systems. Findings from the pilot can inform nationwide adoption under the oversight of the Department of Forestry, Fisheries and the Environment and the Department of Health.

6.3.3.5 Expected Outcomes

The DCASMT offers a transformative pathway towards improved environmental governance and public-health resilience. It enhances community awareness by providing accessible, localised education; strengthens participatory monitoring through real-time reporting; and promotes institutional responsiveness via integrated data analytics. By facilitating early detection of health and environmental risks, the model contributes to reducing disease burden and exposure in vulnerable landfill-adjacent populations.

Moreover, the model reinforces environmental justice by positioning communities not merely as passive beneficiaries, but as active partners in the protection of their own health and environment. The DCASMT therefore embodies the practical application of the One Health framework in South Africa's waste management context, linking digital innovation, public participation and evidence-based governance for sustainable environmental health outcomes.

6.4.4 Further research

Longitudinal and biomonitoring studies: Incorporation of direct environmental and health exposure measurements of environmental contaminants (air, water and soil) and biological exposure markers in affected populations.

Assessment of intervention effectiveness: Evaluate the impact of waste management interventions, such as digital community awareness and self-monitoring models (DCASMT), to guide scalable and evidence-based policy adoption.

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APPENDICES

Appendix 1: Observation visuals



Annexure 1.1: Households are situated very close to the landfill in Harrismith



Annexure 1.2: Households are situated very close to the landfill site in Maqhekung, Phuthaditjhaba



Annexure 1.3: informal settlements situated along landfill fencing in Bethlehem



Annexure 1.4: RDPs and informal settlements situated very close to the Winburg landfill site



Annexure 1.5: Informal settlements (shacks) on the landfill in Odendaalsrus



Annexure 1.6: Informal settlement situated on the Sasolburg landfill site



Annexure 1.7: Vandalised galvanised steel fencing with razor wire topping in the Harrismith landfill site



Annexure 1.8: Precast concrete panel fencing vandalised in the Viljoenskroon landfill site



Annexure 1.9: Barbed wire fencing with litter blown in all directions through it in the Vredefort landfill site



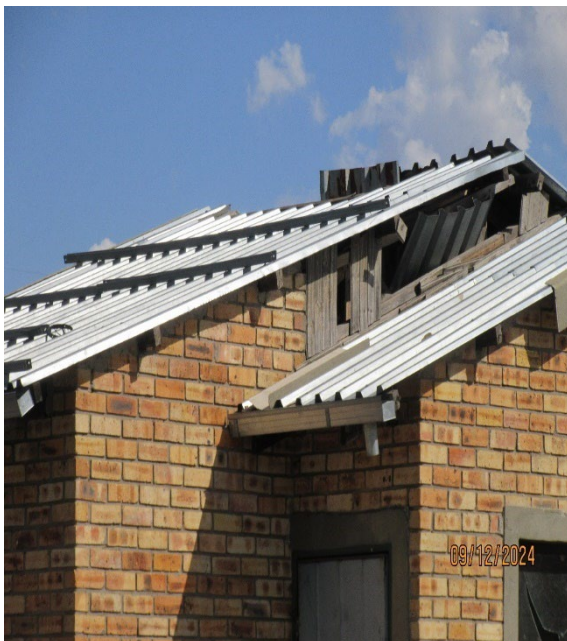
Annexure 1.10: Diamond link wire mesh with razor wire topping, well-maintained in the Sasolburg landfill site



Annexure 1.11: The workers' office and ablution facility were burnt and vandalised at the Theunissen landfill site



Annexure 1.12: Fitted container serving as a landfill workers' office in Sasolburg



Annexure 1.13: The landfill workers' office roofing was vandalised in Winburg



Annexure 1.14: A functional landfill site office with ablution facility, running water and electricity in Bethlehem



Annexure 1.15: Workflow procedure and emergency response information were available in the Odendaalsrus landfill site office



Annexure 1.16: School-age children were identified in the Bothaville landfill site



Annexure 1.17: School-age children were identified in the Virginia landfill site



Annexure 1.18: A registered waste picker with partial personal protective equipment (overall and reflectors) in the Odendaalsrus landfill site



Annexure 1.19: A waste picker working without any sort of personal protective equipment in the Viljoenskroon landfill site



Annexure 1.20: A non-functional weighbridge in the Winburg landfill site



Annexure 1.21: A newly constructed but non-functional weighbridge in the Bethlehem landfill site



Annexure 1.22: A bulldozer was used to move and spread waste in the Odendaalsrus landfill site



Annexure 1.23: A bulldozer was used to move waste blocking the roadway to the sides in the Sasolburg landfill site



Annexure 1.24: A water tank truck was used to manage dust in the Bethlehem landfill site



Annexure 1.25: A bulldozer was used to move waste in the Harrismith landfill site



Annexure 1.26: Discarded pills observed in the Theunissen landfill site



Annexure 1.27: Discarded pills observed in the Winburg landfill site



Annexure 1.28: Injection needles and syringes were identified in the Theunissen landfill site



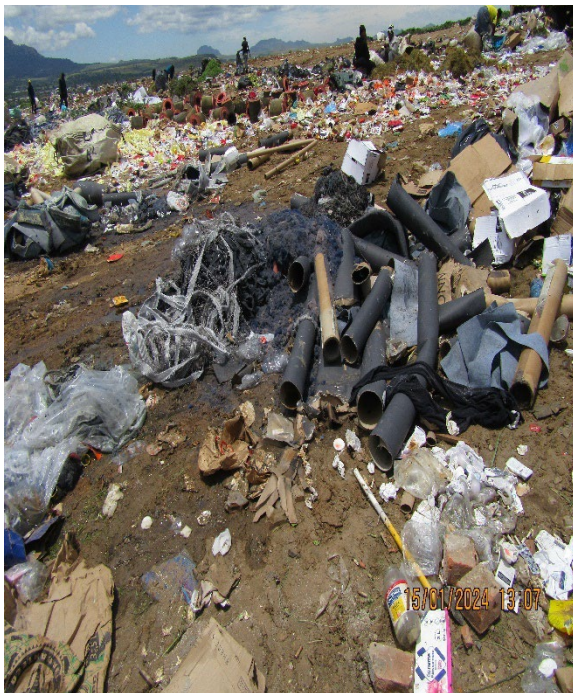
Annexure 1.29: A discarded inhaler was observed in the Winburg landfill site



Annexure 1.30: Disposable diapers and sanitary pads in Maqhekung, Phuthaditjhaba



Annexure 1.31: Unused liquid medication discarded in Winburg



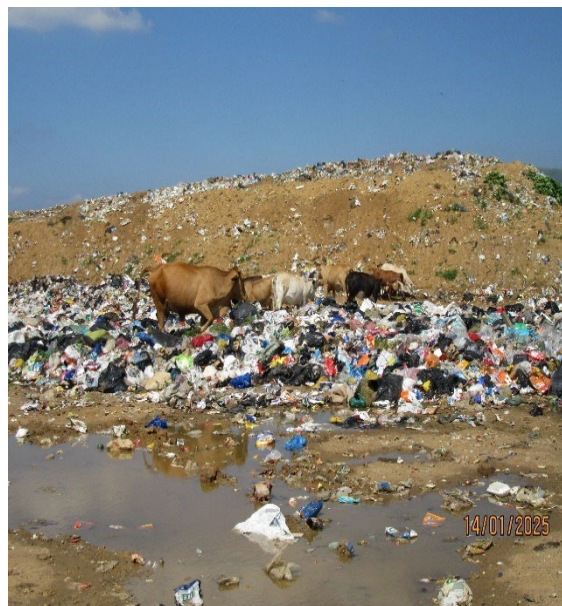
Annexure 1.32: Industrial waste and residues observed in the Harrismith landfill site



Annexure 1.33: Aerosols are paint containers disposed of in bulk in the Vredefort landfill site



Annexure 1.34: A flock of birds (seagulls) were noticed gathering fleshly disposed waste in the Sasolburg landfill site



Annexure 1.35: Cattle were observed feeding on waste in the Pereng, Phuthaditjhaba landfill site



Annexure 1.36: Cattle were observed feeding on waste in the Wesselsbron landfill



Annexure 1.37: Pigs were feeding on food waste in the Frankfort landfill



Annexure 1.38: Pigs feeding on abattoir (bones and hides) waste were observed in Theunissen



Annexure 1.39: A whole sheep carcass was decomposing openly in the Vredefort landfill site



Annexure 1.40: A resident was preparing a discarded dead chicken from the Vredefort landfill site for consumption



Annexure 1.41 Animal hides packed in recycling bags, Bethlehem landfill site



Annexure 1.42: Swarms of flies were observed covering after-slaughter blood waste, which was discarded in the Vredefort landfill site



Annexure 1.43: Rat from Viljoenskroon landfill site trapped in residential area



Annexure 1.44: Waste tyres and burnt tyre debris were identified in the Bothaville landfill site



Annexure 1.45: Tyre waste piles identified in the Harrismith landfill site



Annexure 1.46: Plastic and tyre waste were submerged in leachate in the Bethlehem landfill site



Annexure 1.47: Leachate flowing from waste in the Vredefort landfill site



Annexure 1.48: E-waste cleaning by combustion at the Parys landfill site entrance gate.



Annexure 1.49: Waste heaps were burning in the Sasolburg landfill site



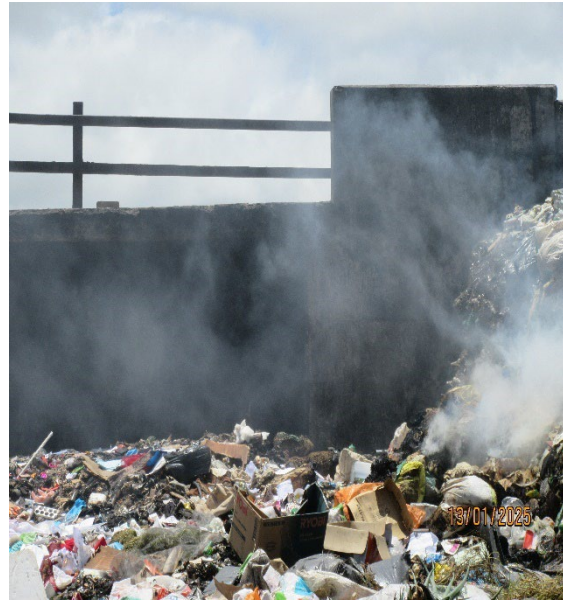
Annexure 1.50: Waste tyre burning in the Heilbron landfill site



Annexure 1.51: Waste burning in the Virginia landfill site



Annexure 1.52: Waste burning in the Vredefort landfill site



Annexure 1.53: Waste burning in the Parys landfill site

Appendix 2: Information sheet



Department of Life Sciences

INFORMATION SHEET

Project title: Environmental and public health impacts of waste in the Free State Province

Description of the study

The research project is conducted by Ms Mamello Agnes Motaung, who is currently studying towards a Doctor of Philosophy in Environmental Health qualification at the Central University of Technology, Bloemfontein campus. You are invited to participate in this research project because you may possess information, knowledge and/ or records required to meet the research objectives. The purpose of the study is to assess environmental risks and the consequent health impacts of waste on community members.

Participation in this research project

The researcher or a trained research assistant will request you to complete a questionnaire. The person handing out the questionnaire will verbally ask for your permission before participating and request that you to sign a written consent form. You will then tick the appropriate answer where options are listed or write answers in the spaces provided on the questionnaire and hand it back to the researcher immediately after completion. The questionnaire takes about 20 minutes to complete. The researcher will determine or inquire about a suitable time in which this questionnaire can be completed by the respondent to avoid unsuccessful data collection. Only adults of 18 years and above will be included in the study. The questionnaires will be provided and answered in common languages in the Free State (English, South Sotho and Afrikaans) and translations to other languages of preference will be done where needed. The researcher will also acquire permission to take any photos and videos.

Anonymity and confidentiality

To ensure your anonymity, your identity and contribution will be protected and not revealed in a report or articles about this research project. Participants will be coded in numerical values during capturing in an Excel sheet. To ensure confidentiality, the

questionnaires will be kept locked away safely by the principal investigator after data capturing.

Risks involved in this study

The researcher acknowledges that there may be direct or indirect risks in participating in this study. Human interactions and discussing own life experiences may carry a risk to some extent, be it discomfort, anxiety or any other psychological or unknown triggers. To minimize risks an application will be submitted for ethical approval from the University of Free State Ethics Committee to ensure sound ethical practices, validity, and appropriateness of collection instruments. Participation in the study will be solely voluntary and the researcher will, and participants possess full rights to refuse and to withdraw from participation at any time.

Benefits of this research

This research is not designed to help you with your personal needs but may assist the researcher in understanding more about the environmental risks and public health impacts through your knowledge and lived experiences. The provision of truthful information in this study may help the researcher reveal vital information for a better understanding of the extent of the problem which will assist in taking appropriate measures in the future.

Questions and clarifications:

The research is being conducted by Ms Mamello Agnes Motaung, a student at the Central University of Technology, Bloemfontein campus, Free State. If you need further clarification about the research project itself, please contact Ms Mamello by cellphone number: 0636718996 and/ or email: pmakhoahle@cut.ac.za and mmamello13@gmail.com.

In the case of other questions regarding this study, including your rights as a research participant or misconduct during data collection that you may wish to report, please contact:

Prof. Pakiso Makhoahle

Senior Lecturer/ Research Study Promoter

Health Science Department

T: (+27)733012657 | E: pmakhoahle@cut.ac.za

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University of Free State

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Bloemfontein 9300 | South Africa

Appendix 3: Informed consent

FACULTY OF HEALTH AND ENVIRONMENTAL SCIENCES

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CONSENT FORM

Project title: Environmental and public health impacts of waste in the Free State Province

The study has been described to me so that I clearly understand what I have to do, and I agree to participate in the above research study. The questions I asked have been answered. I understand that my name will not be used or revealed in any report and that I may stop participating in the study anytime I choose without giving a reason and that I will not be punished in any way for discontinuing.

Please mark with a cross (X) on your preferred option:

___ I agree to be (videotaped or photographed) during my participation in this study.

___ I do not agree to be (videotaped or photographed) during my participation in this study.

Appendix 4: Residents' questionnaire

FACULTY OF HEALTH AND ENVIRONMENTAL SCIENCES



Questionnaire no:

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RESIDENTS' QUESTIONNAIRE

TITLE: ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS OF WASTE IN THE FREE STATE PROVINCE

Mamello Agnes Motaung is currently studying for a Doctor of Philosophy in Environmental Health qualification at the Central University of Technology, Free State. The purpose of the study is to assess the state of the area you live in (near disposal sites) and to determine the environmental and health impacts of waste that you are experiencing in your area. This questionnaire is prepared for academic purposes only and no personal information will be disclosed from the study.

Please answer truthfully to obtain the correct research results. The names of the participants will be kept confidential, and please be aware that there is neither a correct nor an **incorrect answer**.

Your participation in this study is valued and highly appreciated because the outcomes of this research may help the efforts made by the responsible bodies or individuals to resolve or mitigate the problems of solid waste management in the area.

Instructions

Please use a pen and mark each answer with "X" or/ and answer detailed questions in the spaces provided. A space at the end of your questionnaire is provided for comments. Thank you for your cooperation and participation in the study.

I give consent to the Central University of Technology, Free State, to use the information collected for the study only.

YES | NO

Position

Email or contact number

Signature

Date

SECTION A

This set of questions relates to the personal background of the respondent.

1. What is your gender?

Male	
Female	

2. Please indicate, how old are you?

.....

3. Please indicate in which country were you born.

South Africa	
Zimbabwe	
Swaziland	
Lesotho	
Namibia	
Botswana	
Nigeria	
Democratic Republic of Congo (DRC)	
Others (please specify):	

4. If you were born in South Africa, please indicate the province in which you were born.

Gauteng	
Free State	
Kwazulu-Natal	
Eastern Cape	
Limpopo	
Mpumalanga	
North West	
Northern Cape	
Western Cape	

5. Please indicate, in which district you reside.

Motheo District	
Febzile Dabi District	
Lejweleputswa District	
Thabo Mofutsanyana District	
Xhariep District	

6. Please indicate, in which municipality you reside.

6.1 Mangaung Metro Municipality	
Fezile Dabi District Municipality	
6.2 Moqhaka Local Municipality	
6.3 Mafube Local Municipality	
6.4 Metsimaholo Local Municipality	
6.5 Ngwathe Local Municipality	
Lejweleputswa District Municipality	
6.6 Masilonyana Local Municipality	
6.7 Matjhabeng Local Municipality	
6.8 Tokologo Local Municipality	
6.9 Tswelopele Local Municipality	
6.10 Nala Local Municipality	
Thabo Mofutsanyana District Municipality	
6.11 Maluti-a-phofung Local Municipality	
6.12 Dihlabeng Local Municipality	
6.13 Mantsopa Local Municipality	
6.14 Nketoana Local Municipality	
6.15 Phumelela Local Municipality	
6.16 Setsoto Local Municipality	
Xhariep District municipality	
6.17 Kopanong Local Municipality	
6.18 Letsemeng Local Municipality	
6.19 Mohokare Local Municipality	
6.20 Naledi Local Municipality	

7. Please indicate, what is the highest school or tertiary qualification that you have completed.

Primary (Grade 1 to Grade 7)	
Junior Secondary (Grade 8 to Grade 10)	
High School (Grade 11 to Grade 12)	
Tertiary (certificate, diploma, basic degree)	
Postgraduate (Honours degree and above)	
7.1 If you selected tertiary and postgraduate (Please mention your qualification):	
.....	

8. In which town do you live?

.....

9. Please indicate your employment status.

Employed	
Unemployed	
A grant/ pension recipient	
9.1 If you are employed, please indicate what your occupation is:	
.....	

10. Please select your type of housing.

Private single house	
Multi-storied apartment (complex)	
The Reconstruction and Development Programme (RDP) houses	
Backroom of the main house	
Shack house	
Others (please specify):	
.....	

11. Do you have children under the age of 18 years in your household?

Yes	
No	

12. If you answered YES in question 11, please indicate how many children are present in your household.

.....

13. Please indicate the number of members in your household.

1 to 3	
4 to 6	
7 and more	

14. Please mention the number of sleeping rooms (bedrooms) in your household.

.....

15. Please indicate how long you have been staying in this area.

Less than 1 year	
1 to 5 years	
6 to 10 years	
11 and 15 years	
Above 15 years	

16. Please mention or estimate your household's combined monthly income.

.....

SECTION B

These set of questions relate to the residents' environment and livelihood. The section allows the residents to enlighten on the conditions of their environment and their perceptions about it.

17. Please indicate, where do you access your drinking water? (May select more than 1 option)

17.1 Tap water provided by the municipality	
17.2 Treated groundwater/well	
17.3 Non-treated groundwater/ well	
17.4 Reservoir/ tanker	
17.5 Purchased still water (water refill station, bottled water)	
17.6 Other (please specify):	

18. What are your energy sources for heating in your household? (Mark all applicable)

18.1 Wood	Yes		No	
18.2 Paraffin	Yes		No	
18.3 Methane gas	Yes		No	
18.4 Electricity	Yes		No	
18.5 Solar panels	Yes		No	
18.6 Other (please specify):	Yes		No	

19. Please indicate the type of toilet you use in your household. (Mark all applicable)

19.1 Flushing toilet connected to the municipal sewage pipeline	Yes		No	
19.2 Flushing toilet connected to a septic tank	Yes		No	
19.3 Pit latrine	Yes		No	
19.4 None	Yes		No	

20. Please indicate which of the following rodents and vectors cause a nuisance in your household.

RODENT/ VECTOR				
20.1 Ants	Yes		No	
20.2 House flies	Yes		No	
20.3 Cockroaches	Yes		No	
20.4 Mosquitos	Yes		No	
20.5 Bugs	Yes		No	
20.6 Lice	Yes		No	
20.7 Rats/mice	Yes		No	
20.8 Birds	Yes		No	

20.9 Worms	Yes		No	
20.10 Snakes	Yes		No	
20.11 Stray cats and dogs	Yes		No	
20.12 Others (please specify):	Yes		No	
.....				

21. Please indicate your level of agreement with the statements about the impacts of landfills on the quality of the immediate environment, health, and livelihood of you and your household. (Mark with a cross on your preferred option where, (Mark with cross on your preferred option where 5=STRONGLY AGREE, 4=AGREE, 3=NEUTRAL, 2=DISAGREE and 1 = STRONGLY DISAGREE).

ISSUES/ STATEMENTS	5	4	3	2	1
21.1 Odours from the site are unbearable.					
21.2 Smoke fog from waste burning that affects our daily chores.					
21.3 Local water sources are contaminated.					
21.4 Compromised environmental aesthetics (e.g. eyesore waste heaps, leachate, and smoke).					
21.5 There is an increase in road accidents due to smoke fog					
21.6 Loss of property or goods (e.g. housing, car,) from uncontrolled fires.					
21.7 Residents opt to sell their properties or move to other areas because of the unbearable living conditions.					
21.8 Rented tenants not staying longer in this area and renting business compromised.					
21.9 Lack/loss of business (our businesses are not busy and flourishing).					
21.10 Flooding during storms (drains blocked with waste).					
21.11 Poor crop production.					
21.12 High cases of chemical poisoning in children.					
21.13 Sudden death in animals.					
21.14 High vector infestation (e.g. mosquitos, flies, cockroaches).					
21.15 High rodent infestation (e.g. rats, snakes).					
21.16 High cases of gender-based violence (e.g. rape, beatings).					
21.17 This area is noisy.					
21.18 High crime rate.					
21.19 Other (please specify):					
.....					

SECTION C

This set of questions enlightens on the injuries sustained and diseases and conditions acquired by residents when living in this area.

22. Please indicate if you or your family members have ever been injured while living in this area.

Yes	
No	

23. Please indicate if you or your household members have sustained any of these injuries while living in this area.

INJURY				
23.1 Head injuries	Yes		No	
23.2 Fractures (broken bone)	Yes		No	
23.3 Vehicle/pedestrians' accidents	Yes		No	
23.4 Amputation (e.g. loss of finger or limb)	Yes		No	
23.5 Cuts or punctures of skin (e.g. knife/glass cut, nails) from handling waste	Yes		No	
23.6 Gunshots	Yes		No	
23.7 Animal attack/bites (e.g. stray cats, dogs, snakes, etc.)	Yes		No	
23.8 Other (please specify):	Yes		No	

24. Please rate your current general health condition.

Very good	
Good	
Average or fair	
Poor	
Critical/worsening	

25. Please indicate the occurrence of these signs and symptoms in you and your household (Mark with a cross on your preferred option where: 5-DAILY, 4-WEEKLY, 3-MONTHLY, 2-YEARLY, 1-ONCE EVERY 2 YEARS, and 0-NEVER.

DISEASE/ CONDITION SYMPTOMS	5	4	3	2	1	0
25.1 Respiratory problems – difficulty breathing, chest pain, nasal irritation, continuous coughing, and sputum.						
25.2 Reproductive problems – miscarriages, difficulty in falling pregnant, fibroids in women, children born with physical deformities or disability.						
25.3 Gastrointestinal symptoms – nausea, vomiting, watery or bloody faeces, stomach pain.						
25.4 Skin problems – allergies, bites, rashes, sores, blisters.						
25.5 Musculoskeletal problems – muscle aches, painful joints and back, arthritis.						

25.6 Vision problems – poor sight, partial blindness, cataracts, allergies (itchiness and redness).						
25.7 Hearing problems – partially/impaired hearing- not hearing clearly).						
25.8 Dental problems – tooth decay, bleeding gums, change of teeth colour).						
25.9 Depression – prolonged stress and tiredness, anxiety (feeling unsettled)						
25.10 Other mental health disorders or symptoms in adults – schizophrenia (having false images or scenarios), forgetfulness, easily angered, acting out of character.						
25.11 Mental health disorder or symptoms in children (e.g. extreme hyper/hypoactivity, slow development, speech problems and cognitive abilities)						
25.12 Sudden falling and/or seizures – falling followed by jerking movements of arms and legs, loss of consciousness.						
25.13 Cardiovascular symptoms – heart attack, low/high blood pressure).						
25.14 Blood sugar level disorder – dryness in the mouth, increased thirst, frequent urination, changes in appetite).						
25.15 Cancer-related symptoms – lumps in body parts, degeneration of tissue (parts of the body looking older than order/losing shape); change of skin colour and texture.						
25.16 Stroke – numbness in the face, arm, and legs; loss of balance or coordination.						
25.17 Weight loss in a short period.						
25.18 Fatigue (extreme tiredness/weakness).						
25.19 Jaundice – yellowing of eyes, skin, mucous membrane; dark urine and pale stools.						
25.20 Fever – high temperatures and heavy sweats)						
25.21 Headache or Migraines						
25.22 Acute sickness and death without being sick for a long						
25.23 Other (please specify):						

26. Please indicate when last you or your family visit healthcare facilities.

A few hours ago	
A few days ago	
A week ago	
Two weeks ago	
A month ago	
2 – 3 months ago	
6 months ago	
Others (please specify):	

27. Have you and/ or your household member been hospitalised for any injury or illness?

Yes	
No	
27.1 If your answer is YES , please indicate for what injury or illness and for how long you and/ or your household member were hospitalised.	
.....	

28. Please indicate if you or any of your family members smoke (e.g. cigarettes/ snuff)

Yes	
No	

29. Please mention to whom you report during a disaster in your residential area (e.g. landfill fires, floods).

.....

GENERAL COMMENTS

**THANK YOU FOR YOUR COOPERATION IN COMPLETING THE
QUESTIONNAIRE**

Appendix 5: Checklist

CHECKLIST FOR ENVIRONMENTAL EVALUATION OF THE LANDFILL SITE

General Information					
District name:					
Local Municipality name:					
Town name:					
Classification of the disposal site					
Are minimum landfill requirements meet?	Yes	Partially	No	N/A	Comments
1. Access and controls					
1.1. Are signs erected in the appropriate official languages indicating distance and route leading to the landfill site					
1.2. Does the route leading to the site allow two-way traffic.					
1.3. Is there a sign at the gate indicating what type of waste can be disposed and site operating hours?					
1.4. Does the site have security personnel for control?					
1.5. Is the landfill site fenced?					
1.6. If YES in question 1.5, is the fence 1,8m high around the landfill to keep out people and animals					
1.7. If YES in question 1.5, what type of fence is used?	Defender litter fence				
	Barbed wire fence				
	Cement pallets				
	Other:				
1.8. Are waste collection vehicles inspected upon arrival to confirm the type of waste entering site?					
2. Resources					
2.1. Are there offices and ablution facilities?					
2.2. Is there running clean water on site?					
2.3. Is there a weighbridge on site?					
2.4. Do site facilities have electricity?					

2.5. Are there landfill gas monitoring equipment?					
2.6. Is there a retention dam for leachate control?					
2.7. Is there an emergency assembly and emergency control equipment on site, e.g. fire hydrants?					
2.8. Are there qualified staff (site supervisor and landfill managers)?					
2.9. Are staff members wearing proper protective equipment (gloves, masks, overalls, eye shields)?					
3. Site operation					
3.1. Does the responsible authority have a clear waste operating management plan?					
3.2. Does the responsible authority have an emergency evacuation plan?					
4. Nuisance control					
4.1. Are there fire burning on site/ visible smoke?					
4.2. Is litter contained inside landfill?					
4.3. Does leachate trickle from waste and flooding the area?					
4.4. Is litter blown by wind from landfills sites to households/ immediate environment?					
4.5. Does the active landfill area have minimal birds, insects, rodents?					
4.6. Dust, odours and noise controlled?					
5. Prohibited waste					
5.1. Is medical waste disposed on the site?					
5.2. Is animal waste (carcass, stomach contents bones and blood) disposed on site?					
5.3. Is disposal of waste tyres occurring?					
5.4. Is disposal of e-waste occurring?					

6. Waste reclamation and permissions					
6.1. Are there controlled recycling activities on the landfill?					
6.2. Are there facilities available for recycling on site?					
6.3. Are there infants and school age children waste picking on site?					
6.4. Are there domestic animals and pets scavenging on site?					
7. Distance from the landfill site					
7.1. Is the distance of residential areas from landfill site within safe limits?					
7.2. Are there residents living on the landfill.					
7.3. Is the distance of natural water sources from landfill site within safe limits?					
7.4. Is the distance of agricultural fields from landfill site within safe limits?					
7.5. Is the distance of schools and public institutions from the landfill site within safe limits?					

Appendix 6: Biostatistician approval letter

Maryn Viljoen
Statistics Consulting Services

082 823 5731
maryn.viljoen1@gmail.com

Protocol & research methodology consultation | Ethical consultation | Database construction & capturing of data
Analysing data using statistical software packages (SAS Version 9.2) | Statistics consultation services to analyse and interpret data
Conveys results with statistical tables & figures where needed

The Chairperson: Health Sciences Research Ethics Committee (HSREC)

For Attention: Mrs. M.G.E. Marais
Block D, Room 104
Francois Retief Building
Faculty of Health Sciences
University of the Free State

29 September 2022

Title: "Environmental and public health impacts of waste in the Free State province."

Researcher: M.A. Motaung (216007880)
Doctor Of Philosophy in Environmental Health
Department of Life Sciences
Faculty of Health and Environmental Sciences
Central University of Technology
Bloemfontein

I have seen and read through this protocol. I gave input and recommendations and will be the biostatistician responsible for the analysis of the data.

Maryn Viljoen
M.Sc. Risk Analysis (UFS)
maryn.viljoen1@gmail.com
082 82 35 731

Appendix 7: Letters of approval from the Health Science Research Ethical Committee (HSREC)



Health Sciences Research Ethics Committee

12-Sep-2024

Dear Miss Mamello Motaung

Ethics Clearance: **ENVIROMENTAL AND PUBLIC HEALTH IMPACTS OF WASTE IN THE FREE STATE PROVINCE**

Principal Investigator: **Miss Mamello Motaung**

Department: **CUT - Central University of Technology**

[Submission Page](#)

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-HSD2023/1726/0110**

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.

Research conducted in any Department of Health facility: Researchers are required to sign and return the HSREC approval letters to the provincial Department of Health where they applied. It is also a requirement for researchers to submit electronic copies of their final research findings, and/or make a presentation of their findings and recommendations at departmental research days when and where indicated.

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(2020); 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; International Council for Harmonisation (ICH) Harmonised Guideline, Integrated Addendum to ICH E6(R1), Guideline for Good Clinical Practice (GCP) E6(R2), 2016, SAHPRA Guidelines as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

The Principal Investigator (PI) bears final responsibility for the RIMS application. In the event of any misconduct or improper activities perpetrated by a third party, the PI will be held vicariously liable. The HSREC will bear no responsibility or liability for any actions of a PI and/or third party or breach of confidentiality caused by the PI and/or third party.

For any questions or concerns, please feel free to contact HSREC Administration: 051-4012650/9860 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. C. Armour (Barrett)

Chairperson: Health Sciences Research Ethics Committee

Health Sciences Research Ethics Committee

T: +27 (0)51 401 2650/9860 | E: ethicsfhs@ufs.ac.za
IRB 00011992; REC 230408-011; IORG 0010096; FWA 00027947

Block D, Dean's Division, Room D104 | P.O. Box 339 (Internal Post Box G40) | Bloemfontein 9300 | South Africa
www.ufs.ac.za



Appendix 8: Letter of approval from the Department of Health



health
Department of
Health
FREE STATE PROVINCE

04 September 2024

Ms M Motaung
External Association
Central University of Technology

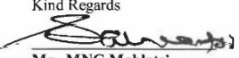
Dear Mr Motaung

Subject: ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS OF WASTE IN THE FREE STATE

- Please ensure that you read the whole document, Permission is hereby granted for the above – mentioned research on the following conditions:
- Participation in the study must be voluntary and written consent by each participant must be obtained.
- Serious adverse events to be reported to the Free State department of health and/ or termination of the study
- Ascertain that your data collection exercise neither interferes with the day to day running of **selected facilities (see page 2)** nor the performance of duties by the respondents or health care workers.
- The DOH expects that the researcher will be the responsible data manager according to the POPI Act. The responsibility thus lies with the researcher to ensure that the processing of all participant's personal information and research data is lawful according to the stipulations of the POPI Act (Protection of Personal Information Act 4 of 2013).
- Confidentiality of information will be ensured and please do not obtain information regarding the identity of the participants.
- Department of Health to be fully indemnified from any contravention of the POPIA Act as you conduct this study.
- **Research results and a complete report should be made available to the Free State Department of Health on completion of the study (a hard copy plus a soft copy).**
- Progress report must be presented not later than one year after approval of the project to the Ethics Committee of the University of the Free State and to Free State Department of Health.
- Any amendments, extension or other modifications to the protocol or investigators must be submitted to the Ethics Committee of the University of the Free State and to Free State Department of Health.
- **Conditions stated in your Ethical Approval letter should be adhered to and a final copy of the Ethics Clearance Certificate should be submitted to sebecelats@fshealth.gov.za / lithekom@fshealth.gov.za before you commence with the study**
- No financial liability will be placed on the Free State Department of Health
- **Please discuss your study with Institution Manager on commencement for logistical arrangements.**
- Department of Health to be fully indemnified from any harm that participants and staff experiences in the study
- As part of the feedback, you will be required to present your study findings/results at the Free State Provincial Health Research Day.

Trust you find the above in order.

Kind Regards


Mr. MNG Mahlatsi
HEAD: FREE STATE HEALTH

Date: 5/09/2024

Head: Health
PO Box 227, Bloemfontein, 9300
4th Floor, Executive Suite, Bophelo House, cnr Malland and, Harvey Road, Bloemfontein
Tel: (051) 408 1646 Fax: (051) 408 1556 e-mail khusemi@fshealth.gov.za / lithekom@fshealth.gov.za / chikobvup@fshealth.gov.za

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