SOLID WASTE MANAGEMENT AND SELECTION OF A SOLID WASTE DISPOSAL SITE IN THE MANKWENG CLUSTER, POLOKWANE LOCAL MUNICIPALITY, SOUTH AFRICA.

By

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RESEARCH DISSERTATION

Submitted in fulfilment of the requirements for the degree of

MASTER OF SCIENCE

in

GEOGRAPHY

in the

FACULTY OF SCIENCE AND AGRICULTURE

School of Agricultural and Environmental Science

Department of Geography and Environmental Studies

at the

UNIVERSITY OF LIMPOPO

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2023

DECLARATION

I declare that **SOLID WASTE MANAGEMENT AND SELECTION OF A SOLID WASTE DISPOSAL SITE IN MANKWENG CLUSTER, POLOKWANE LOCAL MUNICIPALITY, SOUTH AFRICA** is my own work and that all the sources that I have used have been properly indicated and acknowledged by means of complete references. Additionally, this work has not been submitted previously for any degree at this or any other university.

Full names: Tsakani Germina Selomo

Signature: Selomo.

Date: 11 November 2022

ABSTRACT

Solid waste management (SWM) has become a major concern due to its rapid generation rate, especially in developing countries. It is projected that the quantity of waste generated will keep on rising with an increase in population. The solid waste (SW) generation rate is relatively influenced by various factors associated with population growth, urbanisation, and economic growth. This includes South Africa as most of its big cities are experiencing intense poor waste management (WM) and lack of landfill space. Therefore, accurate planning of a region's SWM system requires knowledge of the waste quantity, generation rate, and composition. Most studies on SWM have been focused on big cities whilst neglecting rural towns and villages, thus creating information and knowledge gap. Consequently, this current study aims to investigate the management of SW in the Mankweng cluster and find a potentially suitable area for a solid waste disposal site. The objectives of the study were to (i) to evaluate household solid waste management practices and perceptions, (ii) forecast the municipal solid waste generation and (iii) identify a potentially suitable landfill site using a Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) in Mankweng Cluster. The study adopted a mixed-method approach whereby both qualitative and quantitative methods were explored. A total of 240 households in ward 25 (urban) and ward 27 (rural) participated in this study. The data was collected using semi-structured questionnaires, field observations, and waste-weighing measurements. Furthermore, complementary data was obtained from secondary data sources such as government documents, and internet sources for forecasting and identification of a location for a suitable landfill site. Qualitative data was analysed using the thematic approach and quantitative data was analysed using statistical methods such as descriptive statistics, correlation, regression (i.e., forecasting) and GIS-based AHP. The results of the study show that majority of the SW produced was organic food waste (53% and 61%) based on their weight in ward 25 and ward 27, respectively. An estimated SW generation rate of 0.27kg/cap/day and 0.13kg/cap/day was observed for ward 25 and ward 27, respectively. Respondents from both wards indicated that improper WM practices lead to, amongst to other things, illegal dumping. Furthermore, the respondents stated that illegal dumping occurs because of ignorance, lack of knowledge and unavailable waste collection services. They recommended that the municipality should build recycling facilities, install disposal bins on hotspots for illegal dumping, and promote good SWM practices. The results further showed that the multiple linear regression model used for forecasting waste generation rate in Polokwane Local Municipality yielded coefficient of determination (R^2) of 0.88, with RMSE of 50690.2 ton/year and $P<0.000$. The model was significant ($P \leq 0.05$) and was then used to forecast future solid waste generation rate. The model showed that in future the amount of municipal SW is set to increase leading to the need for construction of a new landfill. In addition, the results for site selection for a new landfill estimated that roughly 67% of the area in Mankweng cluster is suitable for the construction of a disposal site. However, the outcome of the study demonstrated the effectiveness of integrating GIS-based multicriteria decision analysis and community perceptions in the selection of suitable landfill site. In conclusion the study emphasises the value of waste separation, collection, recycling, and awareness in achieving a sustainable SWM.

Keywords: Solid Waste Management; Waste Composition; regression model; GIS; MCDA; Weighted Overlay

ACKNOWLEDGEMENT

- I would like to thank the Almighty God for his endless love, mercy, and grace.
- Special thanks to my supervisor Dr JM Letsoalo and co-supervisor Mr FM Mashao, for never giving up on me during my rough path towards the end of the completion of this dissertation. Your constant unwavering guidance and encouragement are what pulled me through during my difficult times. Your dedication, support, and guidance throughout is highly appreciated.
- Special thanks to Dr N Mathebula for the support and guidance in the completion of this research.
- Words of gratitude to funding sponsor NRF. Your financial assistance helped greatly in the completion of this research.
- My heartfelt gratitude to my wonderful and supportive family, my mom Moyahabo M. Selomo, grandmother Makoma Kapa, aunty Mokgadi N. and Masale N. Selomo for their sacrifices and understanding throughout the entire period of my Masters dissertation. I thank my caring and supportive siblings too, Matome, Ronny, Mashabise, Kamogelo, Makatikela, and Tshegofatsho, who always reminded me that I need to finish so I can be with him.
- Special thanks to the community of Mankweng cluster for participating in the research study.
- Words of gratitude to the Polokwane local municipality especially the office of waste management and economic development for data provision.
- Sincere words of gratitude to the following for the exceptional contribution, encouragement, and support during my studies. My friends (Tumelo B. Machethe, Job Mamabolo, Slindile N. Ncube, Present Nthoke, William Matsane, Frans Maekela, Jerry Gomba, Trudy Lebo Rashijane, and others), thank you for your support and encouragement.

DEDICATION

This work is dedicated to my family. No gratitude is enough to express my appreciation to my dearest granny Mamoyahabo Selomo for being a role model and an inspiration. Her being an informal waste reclaimer in our local community impacted greatly my work and interests. Countless gratitude to my superwoman, my mom MmaModipa Selomo, your support, love, care, and words of encouragement made me pull through.

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LIST OF ABBREVIATIONS

AHP:	Analytical Hierarchy Process
DWAF:	Department of Water Affairs and Forestry
DRDLF:	Department of Rural Development and Land Reform
GIS:	Geographical Information System
HSWM:	Household Solid Waste Management
IWMP:	Integrated Waste Management Plan
MSW:	Municipal Solid Waste
MSWM:	Municipal Solid Waste Management
NWMS:	National Waste Management Strategy
PLM:	Polokwane Local Municipality
SAWIS:	South African Waste Information System
StatSA:	Statistics South Africa
SW:	Solid Waste
SWM:	Solid Waste Management
TREC:	Turfloop Research and Ethics Committee
WMH:	Waste Management Hierarchy

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CHAPTER ONE

Introduction

1.1 Background

Solid waste (SW) is any type of waste that is not liquid or gas which is tossed as undesired and useless and comes from both human and animal activity (McDougall, white, Franke, and Hindle, 2008). Industrial, residential, and commercial activity in a particular are produce SW, which can be handled in a variety of ways. Since they fall into one of four categories—sanitary, municipal, construction and demolition, and also industrial waste sites—landfills are frequently categorised into these groups. Plastic, paper, glass, metal, and organic waste are just a few of the waste types that can be categorised based on the substance they are made of. Additionally, hazardous wastes can be categorised according to their radioactivity, flammability, infectiousness, poisonousness, or non-toxicity. It may also be important to consider the waste's origin classification, such as industrial, household, business, institutional, and or demolition. To ensure environmental best practices, SW must be treated methodically regardless of its origin, substance, or potential for hazards. Solid waste management (SWM) must be considered when planning for the environment because it is an important component of environmental hygiene (Senekane, Makhene, and Oelofse, 2022).

SWM is a discipline that deals with managing the generation, storage, collection, transport or transfer, processing, and disposal of SW materials. It attempts to effectively solve a variety of population health, ecological, economical, visual appeal, engineering, and other environmental factors. Within its scope, SWM includes activities related to planning, administration, finances, engineering, and law. Solutions may be found in the complex interrelationships across fields including public health, regional and urban planning, cultural studies, topography, sociological, economics, communication and sustainability, demographics, and engineering. Depending on the region, the type of generator—residential, industrial, urban, rural, developed, or developing—and the methods used to regulate SWM, there are a variety of options. The management of non-hazardous waste is the responsibility of local government organisations. Contrarily, the management of hazardous waste is usually the responsibility of the individuals who produce it, as it is controlled by municipal, state, and even international authorities (Jha, Dwivedi, and Modhera, 2022).

1.2 Problem statement

According to Cobos Mora and Solano Pelaez (2020); Haas et al. (2015); Liu and Wu (2011), rapid population growth, urbanisation, consumption habits, poor recycling, reuse, and energy recovery (3Rs) processes contribute to the upsurge of solid waste (SW) generation. This leads to a lack of landfill capacity prior its life span is depleted mainly because the landfill site fills up more quickly. Moreover, suitable land areas for a landfill establishment become scarce in developing countries (Letlape and Gumbo, 2017; Ligneris, 2013). South Africa is suffering from high waste generation per capita owing to hasty urbanisation and the improvement of the population's socioeconomic standard. Identification of socio-economic and household demographic characteristics that stimulate waste generation, collection, transportation, treatment, and disposal method is significant in waste management (WM) planning (Tsheleza et al. 2019). It is inevitable that when waste has undergone all other WM methods (such as avoidance, 3Rs, and treatment such as incineration) and was not completely handled, its destination is disposal.

In the context of Limpopo province in South Africa. The province also experiences these SWM challenges due to similar reason mentioned above in its various municipality. Most of municipalities in Limpopo province face serious challenge of historical backlog of improper waste services due to limited financial budget constraints, poor and limited proper infrastructure, equipment (DEA, 2011), which lead to undesirable conditions towards human well-being, animals, and the environment (Worku, 2016).

Polokwane local municipality which the study area belongs to, experienced, and still experiences an increase in urbanisation due to population growth, immigration of people and more within the municipality. Currently the municipality has two operational landfill site, with the landfill site closer to the study area left with a year lifespan prior closure. While the other landfill was newly opened in July 2021 to service the Aganang cluster and Moletji cluster (Polokwane Local Municipality IDP, 2019/2020). There are reported challenges of mismanagement of HSW in areas that lack SW services, mainly the rural areas, while urban areas suffer waste collection backlogs due to poor damaged collection trucks and severe illegal littering.

Currently, the Mankweng cluster is recognised as an economic growth point in the Polokwane Local Municipality. In the future, this will result in an influx in population, and a rise in economic activities with more land used for agriculture, agro-processing, tourism, and human settlement (Polokwane Local municipality IPD, 2019/2020). Furthermore, the cluster has two types of settlement (villages and townships) with different WM services provided. Moreover, the cluster faces serious cases of illegal dumping of SW in various illegal spots, MSW collection is irregular especially in the villages, and there is no formal timetable for emptying of skip bins, and this led to the bins overflowing with waste causing people to throw their waste next to the bins or burn them in the bin. Additionally, there is informal waste recovery by waste reclaimers taking place within its boundaries (Polokwane Local Municipality IDP, 2019/2020). Therefore, this research attempts to investigate SWM in terms of perceptions, practices, and waste generation forecast to make recommendations on how to improve their SWM system. Furthermore, the study will attempt to execute a methodological framework to conduct a suitability analysis of a landfill site using the Geographical Information System-based multicriteria decision support approach to locate suitable candidate sites and select the best alternative landfill sites in the Mankweng cluster. This allows the stakeholders to know of certain candidate land spaces that are suitable for a landfill site establishment. These potential areas can be marked as reserved lands for an establishment in the future to avoid occupation of those areas by other development activities.

1.3 Rationale

In the growing city townships of South Africa, the biggest problem is municipal solid waste management (MSWM) (Rasmeni & Madyira, 2019). For instance, Buso et al. (2015); Gondo (2012); Rasmeni and Madyira (2019); Tsheleza et al. (2019), indicated that SW disposal management is a serious problem in municipalities of Gauteng and in some local municipalities in the OR Tambo District municipality (Eastern Cape) because of population growth, development of cities and towns that lead to failure to site new landfills owing to the scarcity of appropriate land space for a waste disposal site. In worse cases, some of the landfills are even within and or near the vicinity of the residential areas (Buso et al., 2015; Rasmeni and Madyira, 2019). This is no different to rural settlements. Especially those that function as main regional access and development corridors as they are characterised by higher rates of growth in relation to population and economic activities. As a result, rural settlement sprawling poses a severe impact on water reliance, biodiversity, waste, and energy (CSIR, 2008). Given the above, it is evident that there was poor spatial planning of land and land-use change for the present and future of those areas as they seem to have not involved WM in their planning (Chitapi, 2013). Sureshkumar, Sivakumar and Nagarajan (2017), indicated that proper planning in WM, especially for the disposal method is very essential, due to less land available to prevent disposal of SW in inappropriate sites due to underprivileged governance and land use planning sites (Ajibade et al. 2019; LaGro Jr, 2013). Moreover, spatial planning anticipates long period changes and then tries to eloquent a logical and flexible growth path that encourages a sustainable and reasonable future (Capetown.gov.za, 2013; Gorzym-Wilkowski, 2017).

Polokwane local municipality is recognised as significant in terms of economic and public services, functions, and a centre to all expansion corridors in the Limpopo province as it includes the capital city of Polokwane (Polokwane local municipality IDP 2019/2020). Moreover, the Mankweng cluster is within a corridor that connects the Polokwane City and Tzaneen named the Development Corridor 1 comprising the Pretoria/Gauteng, Pietersburg, Mankweng and the Tzaneen area. This means there will be a new establishment and expansion of various economic development activities which will require land especially the unoccupied spaces (Polokwane local municipality IDP 2019/2020). This study attempts to integrate WM with spatial planning of land by trying to know solid waste management (SWM) practices and to identify a potentially suitable area for a SW disposal site within the Mankweng cluster. Performing situational analysis and forecasting of waste generation in this area will assist in the development of potential best strategies in managing SW in the area to make the future better.

1.3.1 Aim:

The study aims to investigate the management of solid waste in the Mankweng cluster and find a potentially suitable area for a solid waste disposal site.

1.3.2 Objectives

The objectives of the study are to:

i. Evaluate the household solid waste management practices and perceptions in the Mankweng Cluster.

ii. Forecast the municipal solid waste generation in the Polokwane Local Municipality.

iii. Identify a potentially suitable landfill site using a Geographic Information System (GIS) and Analytical Hierarchy Process (AHP).

1.3.3 Research questions

i. What are the household solid waste management practices and perceptions in the Mankweng cluster?
ii. Can the municipal solid waste generation in the Polokwane Local Municipality be forecasted?
iii. Can potentially suitably landfill site be identified using a Geographic Information System (GIS) and Analytical Hierarchy Process (AHP)?

1.4 Study area

The Mankweng cluster is found in Polokwane Local Municipality (PLM) under the Capricorn District of Limpopo province, South Africa (Figure 1.1). The Mankweng cluster has nine wards (wards 6, 7, 25, 26, 27, 28, 30, 31, and 34). The cluster has both urban and rural settlements, with wards 25 and 26 recognised as a township, and wards 6,7,27,28,30,31, and 34 are rural settlements (StatSA, 2011 and Municipal Elections, 2016). The areas of study focus are ward 25 and ward 27. Wards 25 and 27 are neighbouring settlements separated by the R71 road. Ward 25 is a township with activities that include the businesses and mall, police station, hospital etc. This ward receives door to door waste collection service once per week. The ward has a population of 25868 and household number of 7936. Ward 27 is a ward that is comprised of villages. The ward had a population of 20902 and household of 5487. This ward receives waste picking waste collection service alongside the main road (R71), on illegal dumping hotspots areas by the EPWP people, and communal bins collection by the municipal trucks. The study will focus on waste generated at household with an exclusion of business waste, institutional waste, and other hazardous waste streams.

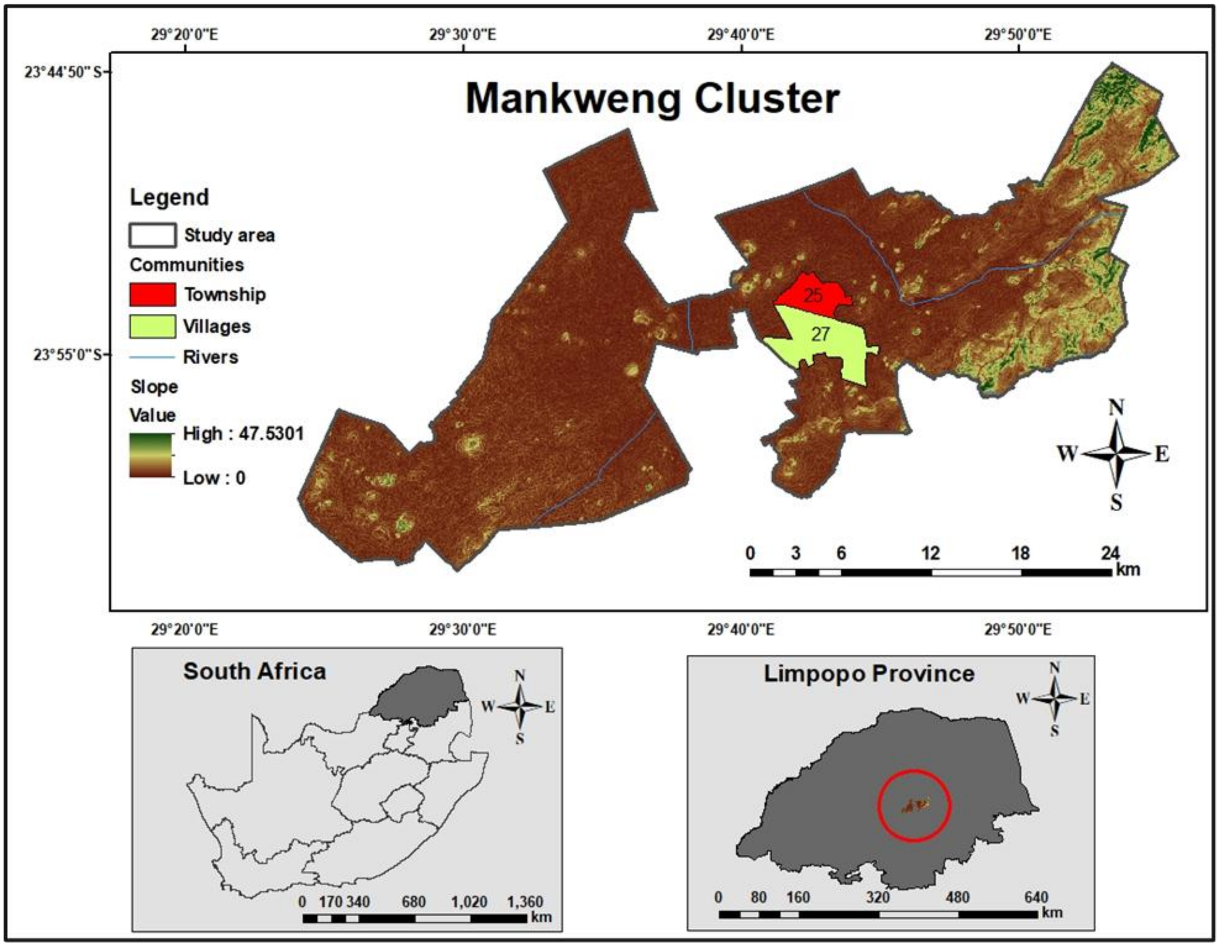


Figure 1.1: Study area map

1.5 Significance of the study

The study will add value to the body of literature knowledge on environmental management regarding the rural parts of South Africa's SWM. The study will also try to shed light on rural areas' waste-generating rates, behaviours, and perceptions. This will likely provide the local municipality with information about the main types of waste that are generated within its borders, the causes of poor WM practices, and suitable ways to reduce illegal and legal waste disposal while promoting the 3Rs. Moreover, it will attempt to forecast waste generation in the region. Additionally, the study will try to determine whether the cluster still has any acceptable open spaces for future landfill development. Finally, this study will be useful to WM stakeholders, project planners and managers in decision-making in land use planning and WM in the study area.

1.6 Ethical consideration

Before beginning data collecting, the researcher received ethical approval from the Turfloop Research Ethics Committee (TREC) of the University of Limpopo and other pertinent authorities. Other crucial ethical considerations for the study included getting respondents' informed consent and ensuring them of the confidentiality and anonymity of the information they provided.

1.7 Limitations of the study

i. Resource and time constraints

One of the main contributing factors the researcher found herself collecting data from a sample not so big enough or as intended, is limited resources (Lenth, 2001, Lakens, 2022). In this study the funding was inadequate to travel for the period required to cover minimum sample size of 10% between the two study communities. This was particularly because, given the size of the two communities 10% of the households translated to a total of more than 700 households. The researcher could only make a limited number of trips out of which she was able to cover 240 households across the study area, with 113 households sampled from ward 27 and 127 from ward 25. Without needing to justify small sample size, according to Laken (2022) this is not uncommon, lack of resources is the primary reason resulting in sample sizes that are always limited by the available resources.

ii. Willingness to participate in the study.

Most people were not comfortable in disclosing how they treat their waste. Others were not willing to give out their waste for measurement purpose. The researcher had to take the waste measurements in the respondent’s home. Moreover, the researcher also explained to them that the information they are asked for is for educational purpose. The researcher further explained to them that no harm will come to them in participating in the study, and that they will be treated with anonymity to protect their privacy.

iii. Unavailability of people in the sampled households

Most respondents in the township were not available during the week for work reasons and others. The researcher decided to make visits on weekends too. Additionally, if there was no one in the sampled house, the next one was used as the next k^{th}.

1.8 Definition of terms

Buffer zones- are the limitation distances from one feature to another. (DWAF, 1998)

General waste- is waste that, when correctly managed, does not constitute a substantial harm to public health or the environment. (DWAF, 1998)

Landfill – a specified area that is either owned by the government or private owners but has been designated for waste burial or dumping. (DWAF, 1998)

Qualitative method- is a non-numeric method of inquiry used in various academic areas to gain a deeper knowledge of human behaviour and the factors that influence it.

Quantitative Method- means Statistical or mathematical tools used to conduct a systematic empirical analysis of social phenomena as a research method.

Recycle- refers to a waste reclamation process that involves separating waste from a waste stream for future use and processing the separated material into a product or raw material. (DWAF, 1998)

Solid waste management – implies controlling the production, storage, collection, transfer, and transportation of solid waste, as well as its treatment and disposal. (DWAF, 1998)

Waste- denotes any excess, undesired, rejected, thrown, abandoned, or disposed of substance that the generator has no further use for the objectives of production, whether that substance can be reduced, re-used, recycled, or recovered. (DWAF, 1998)

1.9 The organisation of the study

This dissertation consists of six chapters. Excluding the first chapter which focused on the general introduction and the last chapter containing a synthesis of the research work, this dissertation has three stand-alone potential papers (Chapter 2, 3, 4, and 5). The papers are yet to be published in different journals, and they answer each objective of the study. Consequently, each paper has an individual Introduction, Material and Methods, Results, and Discussion section. These research chapters attempted to conform to a general style in the dissertation, there may be some overlapping and repetition in some of the sections. Therefore, detailed explanation of the chapters is as follows:

- ✓ Chapter two focus on the literature review that motivates the research problem of the study. The literature broadens from local to international context, it discusses geographical information system and remote sensing tools that assist in managing solid waste. Additionally, it discusses future direction of this technologies.
- ✓ Chapter three is the potential paper that addresses the practices and perceptions of solid waste management. This chapter addresses chapters one and two.
- ✓ Chapter four is the potential paper that focus on forecasting of waste generation. This chapter address objective three in the study.
- ✓ Chapter five which is the last potential paper addresses the last objective of the study that focuses on site selection of a disposal site in the Mankweng cluster, and it addresses objective 4.

Summary of the chapter

This chapter begins with the background of the study, research problem, followed by the study's aim and objective, research questions, significance, limitations incurred during the study, explanation of the terms, and the organisation of the research study. The focus of the following chapter is a review of the relevant literature.

CHAPTER TWO:

GIS applications on solid waste management in the developing countries: a review of progress and future prospects.

Abstract

Solid waste management (SWM) challenges are at the top of the global environmental agenda due to the persistent rise in population growth, urbanisation and consumption grow that increase waste generation rises at a rapid speed. Sites for the disposal of solid waste (SW) are gravely harming the environment in developing nations. Everywhere in the developing world, poor SW disposal has a critical influence on the environment. Undertaking regional waste management (WM) studies have become easier in recent decades thanks to the development of new methodologies known as Geographic Information Systems (GIS). The application of these strategies to SWM aids in the timely capture, handling, and transmission of essential data. These methods can also be used to obtain information from a remote location at a reasonable cost. This paper presents an overview of GIS strategies for WM collection and disposal issues in the environment.

Keywords: Solid Waste Management; Waste Generation; Integrated Solid Waste Management; Circular Economy, Waste collection, Landfill, GIS, Remote Sensing

2.1 Introduction

Globally, the generation of SW has become a substantial issue. This is the case since everything eventually turns to waste. The high population density, economic growth, and industrialisation are both contributing to rise in the rate of SW generation. As outcome, managing SW has become a significant concern in developing nations like South Africa, China, India, and Kenya, as well as other regions of the world. This chapter delivers an overview of various contributions to the literature on SWM integrated plans, SW generation and projection, household solid waste management

(HSWM) practices and attitudes, the significance and use of GIS, the difficulties, and potential directions of GIS use in SWM, and more.

2.2 Solid waste

Any item or material that is not helpful to humans is waste (Nkosi, 2014). Human activities generate waste products, which are typically ignored since they are deemed useless. Solid, liquid, or gaseous wastes are the most common types. SWM systems incorporate all efforts intended to reduce waste's negative effects on health, the environment, and the economy. On a world-wide, regional, nationwide, and local scale, the effects of unlawful or unmaintainable waste disposal on terrestrial and water resource, and the atmosphere add to a diversity of environmental difficulties and the hazardous threshold (Zhou et al., 2017). In the past, waste was not considered a concern since people believed that the world could transport and bury the waste produced. People, for example, used to throw waste anywhere and in whatever way they could. Some people used to live near a potentially hazardous illegal waste disposal site (Driscoll, 2013). Oceans are another example as they were thought to be dumping grounds because humans thought the waste would be swallowed by the ocean and cleaned up (Driscoll, 2013). However, this has been and is still being proved wrong due to the undesirable influences waste has on the environment, society, and the economy.

The impact of waste mismanagement on humanity served as a wake-up call. Through the work of Rachel Carson's Silent Spring (1962) and Barry Commoner's The Closing Circle (1971), a growing public awareness of environmental challenges began to gather traction as a reaction call. In the 1970s, the "Not in My Back Yard (NIMBY)" movement arose because of this (Driscoll, 2013). It is a concept that has been used to describe local, public groups that are attempting to prevent the placement of unacceptable land use in a specific neighbourhood, or nation. It was born out of community opposition to the placement of environmentally dangerous facilities (Driscoll, 2013). These worries boiled over in the aftermath of the well-publicized Love Canal event in Niagara Falls, New York, in which an elementary school was erected over a biochemical waste disposal. The chemicals leached into the water bodies, causing a slew of health issues that sparked considerable community outrage and eventually national media courtesy

(Dricscoll, 2013). The narrative of Love Canal triggered a nationwide outcry against the location of hazardous waste plants (Brook, 1994; Driscoll, 2013). A New Paradigm for WM has arisen in response to the dilemma, focusing on resource efficiency and environmental minimisation.

2.3 Integrated Waste Management plan as a tool

SW has become a vital issue nowadays. Research has found that urbanisation, improving living standards, rapid population growth, and economic growth are the key drivers of SW generation increase (Bhat et al., 2018). Its impact on different factors such as environmental, economic, social, political, financial, and institutional has led to it being one of the aspects of the world that is focused on (Banerjee et al., 2019). Depending on their source, SW can be divided into three categories: municipal solid waste (MSW), industrial solid waste (ISW), and biomedical solid waste (BSW). Recently, MSW has been difficult to manage both in economically developed and developing states (Kundariya et al., 2021). Household waste (HW), waste from construction and demolition projects, sanitation waste, and street general waste are all included in MSW. Municipal solid waste management (MSWM) issues not only have negative environmental effects but as well as endanger the public's health and cause several other socioeconomic issues. WM involves managing waste from the source to the last destination for normally disposal of. It becomes necessary to provide legislation to define the rights and obligations of the parties concerned and to forecast their respective attributions to support sustainable WM and environmental protection. There is a distinctive variance in WM between the developing and developed states. One of the most widely used methods for MSWM is integrated solid waste management (ISWM), which enables an integrative examination of the intricate and multifaceted WM system (Bagchi, 2004). ISWM is described as '*the selection and implementation of acceptable methodologies, technologies, and management programmes to achieve specified WM goals and objectives'* by Tchobanoglous et al. (1993). The United Nations Environmental Programme (UNEP) (1996) defined "Integrated waste management' as '*a framework of reference for designing and implementing new waste management systems and for analysing and optimising existing systems"*. To achieve maximum benefits relative to cost contribution, ideal resource usage, extreme recovery of reusables and recyclables, environmental and health requirements, and social tolerability, the ISWM comprises of a hierarchy of a corresponding set of activities (Godfrey et al., 2019; UNEP, 2018). ISWM is a strategy that may be applied to create a sustainable SWM system that is appropriate for a certain location and its unique set of circumstances and that is both economical and socially acceptable (McDougall, 2001). In its most basic form, ISWM incorporates the WM hierarchy (Turner and Powell, 1991) by considering both direct and indirect effects of the transportation, collection, handling, and disposal of waste (Korhonen et al., 2004). It serves as a foundation upon which new WM systems can be envisioned and implemented as well as existing systems can be optimised (United Nations Environmental Programme, 1996).

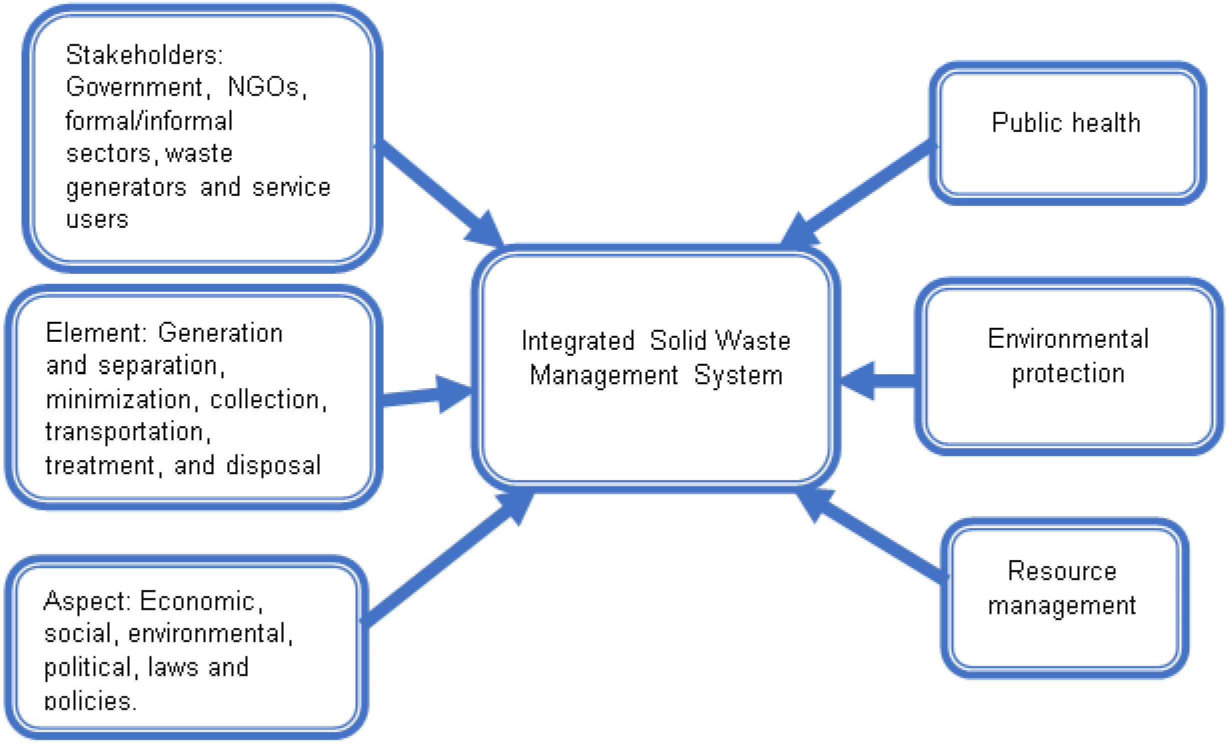


Figure 2.1: Illustration of an outline of integrated solid waste management

2.3.1 Concept circular economy

The “circular economy” (CE) model is not a new concept. The economist Kenneth Boulding first introduced the concept of circular economy in 1966 in his essay titled "The Economics of Coming Spaceship Earth" (Boulding, 2013). The environmental economists Pearce and Turner then expanded on it in their publication "Economics of Natural Resources and the Environment" (Jensen, 1998). The CE is intended to '*improve global competitiveness, replace unsustainable economic growth, and create new jobs'*, according to the European Union (EU) (European Commission, 2011). CE uses the 3Rs approach, which entails a resource flow loop for the efficient use of resources while boosting the economy (Geissdoerfer et al., 2017). In addition, it increases waste recycling while simultaneously lowering environmental pollution and the cost of the manufacturing system (Andersen, 2007; Rathore and Sarmah, 2020). Nevertheless, it just began to pick up momentum recently. The implementation of the CE idea and increased generation of renewable energy are priorities for the world's leaders (Korhonen et al., 2018).

Despite the similarities amongst these widely reported projects, when viewed as a whole, both subtle and not-so-subtle variations are visible. The zero-waste idea, for instance, lays a lot of emphasis on the objective of reducing solid waste generation and increasing waste deviation from the traditional processes of combustion and landfilling (Silva et al., 2016). Contrarily, the CE strategy places focus on revising industrial methods and products themselves so that by-products and discards are employed as feedstocks in methods and manufactured goods (Kirchherr et al., 2017). Both ideas contemplate the stages of a material's upstream life—its extraction, processing, and manufacturing—and also its end-of-life management. System design for recirculating energy and material flows is the responsibility of the upstream partners to develop closed-loop systems and avert waste generation (Bocken et al., 2016; Geissdoerfer et al., 2017; Kirchherr et al., 2017; Korhonen et al., 2018). The management of the materials generated upstream at the end of their valuable lives is the responsibility of downstream stakeholders. Because resources are consumed, and waste is inevitably generated even in closed-loop systems, the CE and zero-waste concepts are both constrained by the laws of thermodynamics (Genovese et al., 2021; Korhonen et al., 2018). According to the zero-waste paradigm (Silva et al., 2017; Zaman and Lehmann, 2013), local governments should refrain from placing waste in landfills or burning it. According to the literature review, some studies characterise the CE as comprising incineration for energy recovery in waste handling systems, whereas MacArthur (2013) argues that for a real CE, both landfill and incineration are seen as system leaks and unacceptable (Anshassi, Laux, Townsend, 2019). The 4R framework, also known as the CE concept, is used by many countries, including those in the European Union, to prioritise reduction, reuse, 3 (including energy recovery through waste incineration) (Ghisellini et al., 2016; Kirchherr et al., 2017; Malinauskaite et al., 2017).

2.4 Waste generation

2.4.1 World statistics of waste generation rate

The generation of MSW is directly impacted by continuous population growth, rapid industrialisation, and urbanisation (Mushtaq et al., 2020; Parveen et al., 2020). According to Zaman and Swapan (2016), the study covered 168 nations with a combined 3.36 billion people. An estimated 1.46 billion tonnes of MSW were produced yearly or at 435 kg per person. Compared to those in low-income nations, people in high-income nations generate more waste. The distribution of waste generated (per capita) across various nations is depicted in Fig. 2.4.1. People's ability to buy more because of a greater GDP stimulates more consumption, which leads to more waste being generated. Kuwait has a rather high rate of waste generation per capita (480 kg/person on average globally), which may be a statistical anomaly resulting from the inclusion of building and demolition debris as MSW (Zaman and Swapan, 2016).

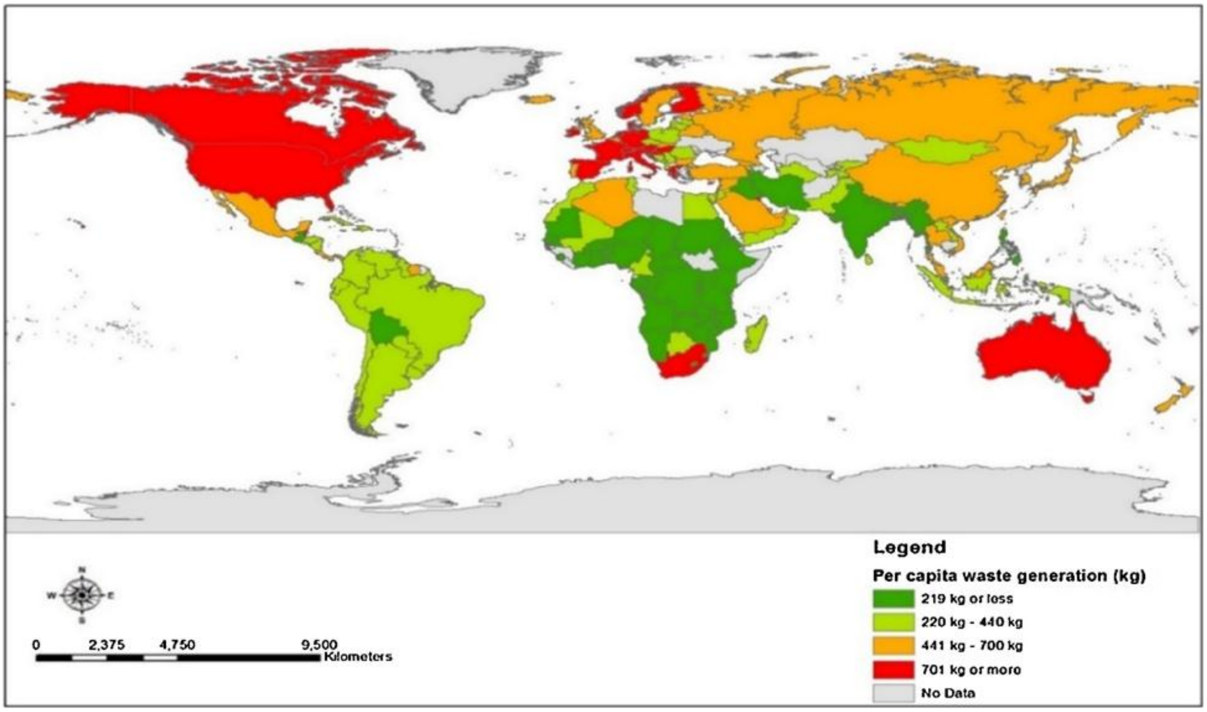


Figure 2.2: Global statistics of waste generation rate (source: Zaman and Swapan, 2016)

2.4.2 Waste generation in Africa

The negative impacts of the mismanagement of SW will worsen swiftly for Africa because of rising MSW levels anticipated because of population growth, urbanisation, and shifting consumer habits (van Niekerk and Weghmann, 2019). By 2040, the population of Africa is anticipated to rise to 2 billion from roughly 1.2 billion people in 2015. Approximately 40% of Africans currently reside in cities as of 2014 (van Niekerk and Weghmann, 2019; UNEP, 2018). The number of waste increases along with population growth and urbanisation. In 2015, urban Africa generated 124 million tonnes of waste annually. It is anticipated to reach 368 million tonnes by 2040 (United Nation Environment Programme UNEP, 2018). Statistics on the quantity of waste produced in Africa are centred on urban regions because there is so little information on waste generation and handling in rural areas. It is projected that waste generation is significantly lower in rural areas due to lower consumption rates, poorer purchasing power, and more frequent reuse patterns. In 2012, Africa's average rate of SW generation per capita was only between 0.78 kg and 0.8 kg, much lower than the global average of 1.39 kg/capita/day (van Niekerk and Weghmann, 2019; UNEP, 2018).

Nevertheless, the amount of waste generated differs greatly amongst nations and areas. South Africa and North African nations produce significantly more waste per capita per day than the rest of the African countries (UNEP, 2018) see figure 2.4.2 (a). This is mostly a result of these countries' higher levels of consumption and purchasing power. But the types of waste produced, and the quantities generated in Africa are starting to alter as consumer and manufacturing patterns change. More individuals adopt Western consumption habits as their affluence rises, which raises the quantity of waste generated. African waste generation has also increased because of international waste commerce and illegal waste trafficking from high-income nations to the continent (van Niekerk and Weghmann, 2019; UNEP, 2018).

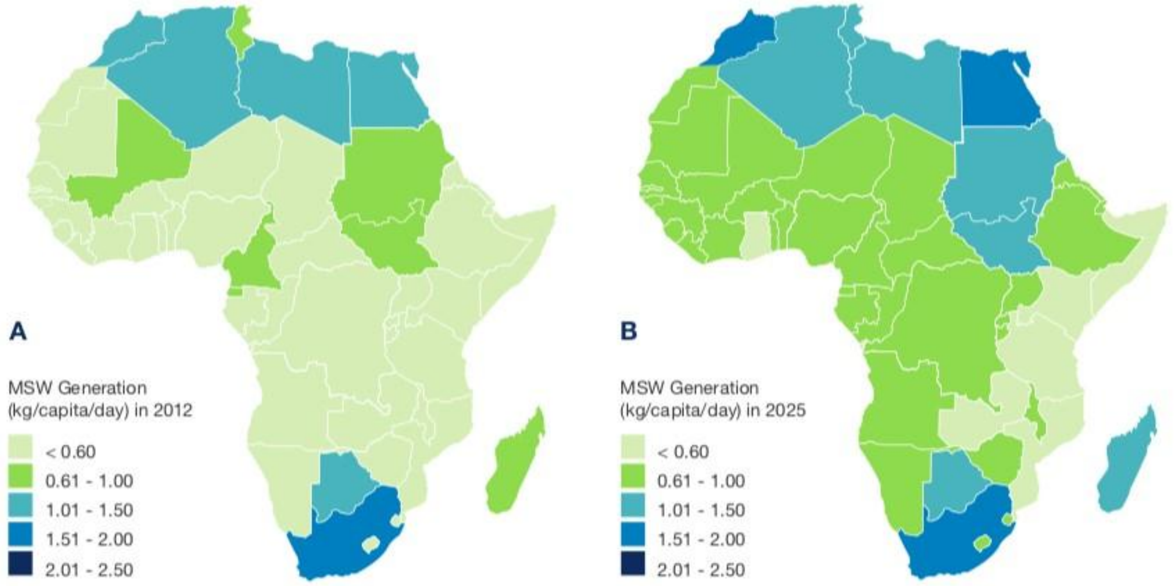


Figure 2.3: Africa's municipal solid waste generation rate statistics (source: van Niekerk and Weghmann, 2019)

African countries are either less developed or least developed economically see figure 2.4.2. (b). As such they face significant challenges in collecting, transporting, and disposing of MSW. Furthermore, several reasons such as rising income, rapid economic expansion and urbanisation, variations in consumer behaviours, and rapid population growth contributed to daily waste generation (Zhou et al., 2017). This puts more strain on communities' service delivery and WS infrastructure, such as landfills (Dlamini et al., 2019). These factors intensify municipal issues such as the deficiency of monetary resources, functional challenges, and legislation execution. Thus, most metropolises and municipalities are failing to bargain basic WM services and continue to rely on landfill waste disposal as their primary WM technique (DEA, 2018a).

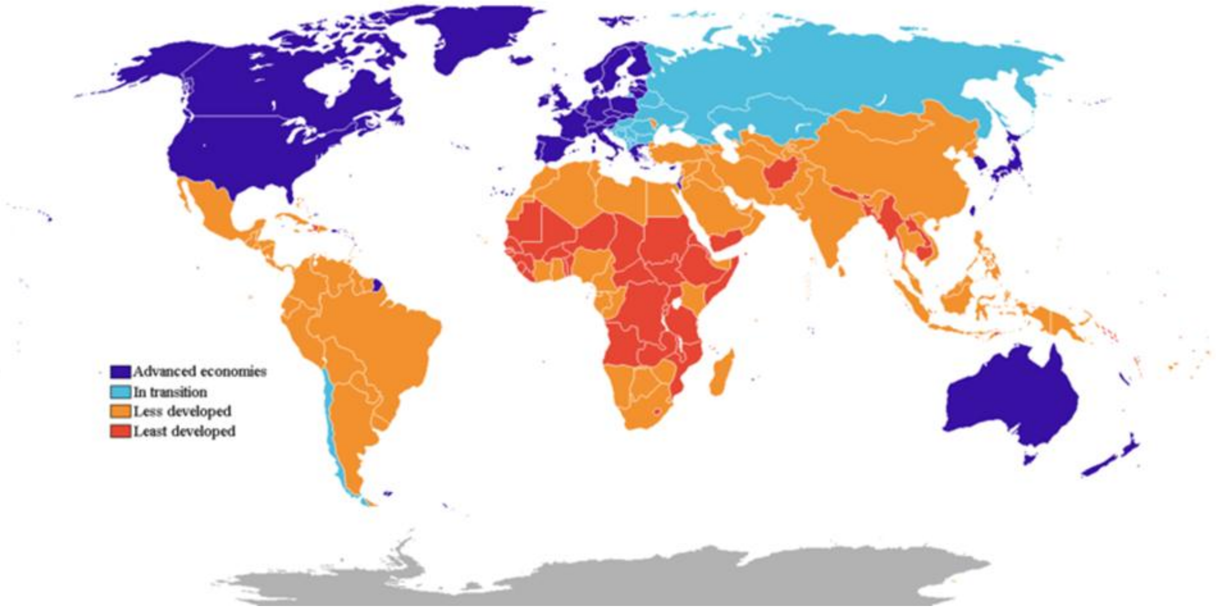


Figure 2.4: Global countries in terms of economic level (source: Zaman and Swapan, 2016)

2.5 Impact of solid waste management

Owing to the expanding population and activities, urbanisation, and industrialisation, waste has become an environmental issue in the globe today. It is critical to understand that the danger and environmental risk posed by waste have compelled us to take steps to safeguard proper waste disposal and management. Waste disposal is another key aspect of the WM system that requires special attention to avoid pollution. Disease transmission, fire dangers, olfactory irritation, air and water effluence, visual annoyance, and economic loses are among the most prominent problems related to improper dumping. The success of SW disposal is determined by site selection, and the current global trend of WM issues derives from unmaintainable waste disposal methods, which are eventually the product of deprived planning (Khan and Samadder, 2015; Polasi, 2018).

2.6 The role of GIS in solid waste management

SWM includes numerous stages, starting with waste production and ending when the waste has reached its destination or has reached the point where it poses no hazard to the environment. These stages chronologically include waste generation at the stream, waste separation and sorting at the source, waste collection and transportation, and waste treatment and disposal. The global adoption of Geographic Information Systems (GIS) and its development have greatly improved WM systems (Chalkias and Lasaridi, 2011). However, GIS and Remote Sensing (RS) have not been effectively used in most developing cities (Harerimana et al., 2016). Though a few studies have been done integrating these technologies into a planning process to improve the efficiency of MSWM it remains under-utilized (Singh, 2019).

GIS is a technological system that enables the entrance, operation, analysis, and presentation of data related to specific locations on the surface of the earth (Ali, 2020). GIS contains maps, aerial photos, and satellite images (Singh, 2019; Vahidnia et al., 2009). The technology incorporates a device capable of gathering, processing, controlling, restoring, analysing, and showing data, offering an analytical platform for data synthesis. The gathering of geographic information and the direct use of that information for analysis and representation on maps are made easier with the use of GIS and advanced associated technologies (such as GPS and RS). Using GIS technology, which depends on spatial data for planning and operation, people can assess the locations of various things to determine their relationship in terms of spatial features (Banerjee et al., 2020). GIS has been successfully used in a wide range of sectors, including urban utility planning, transportation, resources protection and management, medical sciences, forestry, geoscience, natural catastrophe prevention, and various environmental modelling and engineering applications (Omali, 2021; Paul et al., 2020; Tao, 2013). Since the inception of the technology, the study of complex WM systems—in particular, the location of WM and disposal facilities and the optimisation of waste collection and transport—has been a preferred area of use for GIS (Ali et al., 2021; Chalkias and Lasaridi, 2011; Singh and Behera., 2019).

The domains of landfill placement, waste collection and transportation optimisation are where GIS-enabled modelling on WM is most frequently used, and these topics are covered in more detail in the next section. In addition, GIS technology has been applied to improve WM in coastal areas (Sarptas et al., 2005), estimate SW generation using regional demographic and socioeconomic data (Vijay et al., 2005), and anticipate waste production at the regional level (Farahbakhsh and Forghani, 2019).

2.7 The GIS applications on waste collection and transportation

Waste collection and transportation is one of the systems of SWM. This system faces great challenges due to various factors. The household SW, which is the key element of MSW, is an inevitable everyday matter (Zhu et al., 2020). Although most municipalities offer waste collection and transportation waste treatment amenities and landfills, collection of waste is still backlogs are a challenge (UNEP, 2020). Lack of work force and poor malfunctioning infrastructures that are caused by a lack of sufficient funds become the trigger to poor waste collection (David et al., 2020; DEA, 2012; UNEP, 2020). The malfunction of waste collection vehicles causes irregular waste collection, leading people to dump waste illegally and this ends up costing the municipality money to clean up the dumped waste (Ayeleru et al, 2018; UNEP, 2020). Researchers such as Adeleke et al. (2021); Kubanza and Simatele (2020); Ferronato, et al. (2021) have dealt with the issues with the current MSW collection and management plan. The main issues with SW collection and management, according to their assessment, are a deficiency of information regarding the collection time and area and a sufficient method for monitoring and following the waste-carrying trucks in real-time. According to the CSIR (2011) and the DEA (2018b), transportation is a significant expenditure that devours a significant amount of each municipality's WM budget. Furthermore, dump sites with sufficient airspaces are typically located faraway from where waste generation source (DEA, 2018a). The distance covered by the truck from the collection point to the dumpsite adds to the MWM budget's transportation costs. This necessitates the development of cost-effective waste transportation methods.

Karadimas and Loumos (2008) anticipated a technique for calculating the best number of waste bins and their allocation, as well as estimating MSW generation. Using a spatial Geodatabase combined into a GIS setting, this technique was assessed in a portion of the municipality of Athens, Greece. The overall number of waste containers was lowered by more than 30% after they were reallocated. This cut in collecting time and distance has a direct positive impact. Chalkias and Lasaridi (2009) used ArcGIS Network Analyst to create a model to increase collection of waste and transportation efficiency in the Municipality of Nikea in Greece, by reallocating waste collecting containers and optimizing vehicle routes regarding distance and time travelled. The initial results showed that, when compared to the present empirical collecting organization, all the scenarios investigated generated savings regarding both collection time (3.0% -17.0%) and journey distance (5.5% - 12.5%). Arebey et al. (2011) created a method to track the SW bin and waste-transporting trucks. In its development, the suggested system includes a variety of connection tools, for instance GIS, radio frequency identification (RFID), a global positioning system (GPS), and a general packet radio system (GPRS). Since the tracking devices installed in the trucks acquire position data in real-time via GPS, it does not require the truck driver to locate the waste-carrying trucks. Hareesh et al. (2015) have established a SWM evaluation model grounded on the GIS analysis tool (QGIS), which can be used by MSWM stakeholders for everyday procedures such as collection/transport and fuel consumption scheduling.

2.8 The GIS application on landfill siting

Sanitary landfilling is an inevitable part of the MSWM system (Amirsoleymani, Abessi, and Ghajari, 2022; Javaheri et al., 2006). Because it must consider economic, technological, environmental, and social concerns, landfill siting is not merely a tough and boring task (Chang et al., 2008; Singh, 2019). Financial considerations are crucial since they include costs associated with the maintenance and operation of the disposal facility.When deciding where to locate landfills, environmental factors should be considered because they may have an impact on the nearby area's ecology and biophysical condition (Kontos et al., 2003; Singh, 2019).The biggest obstacle to successfully discovering disposal sites has been identified as community opposition to finding an area to deposit waste (Polasi, 2018; Singh, 2019). To choose a landfill for the disposal of SW, a sizable amount of spatial and non-spatial data must be processed and evaluated considering the many factors affecting a site's suitability (Weldeyohanis, Aneseyee, and Sodango, 2020). The ecosystem may be less contaminated if landfills are placed in the right locations. Implementing landfills has become increasingly challenging because of local opposition and environmental degradation. Due to these, most cities in emerging nations struggle with a shortage of land that is ideal for disposal of waste (Alkaradaghi et al, 2019). Given the severe environmental effects of SW, disposing of SW, and finding the undeveloped area is a problem that all emerging nations face (Othman, 2017).

Proper technology is needed to manage and manipulate a lot of data. In this situation, GIS and satellite RS data are essential tools for quickly processing, analysing, and manipulating massive amounts of spatial and non-spatial data. In a SWM system, data is gathered from many sources, and RS and GIS procedures are utilised for database model, database development, and database operation, which results in the analysis of altered data (Ali, 2020; Singh, 2019). Analytic Hierarchy Process (AHP) has proven to be a very helpful decision-making method in complex decision-making processes including multiple theme layers and their pairwise comparison. Therefore, most studies on the identification of appropriate sites are based on GIS and AHP (Ayiam et al., 2019; Balew et al., 2020; Chang et al, 2008). Hence the GIS technique is time-conservative and cost-efficient to carry out the analysis function with ease (Mohammedshum et al., 2014).

The use of GIS and AHP approaches in the selection of a potential landfill site in the Béni Mellal-Khouribga region revealed that the integrated use of GIS and AHP can assist the town planners, local and regional stakeholders in finding better solutions to manage SW (Ayaim et al., 2019; Kamdar et al., 2019; Karimi et al., 2020). Adewumi et al. (2019) applied the GIS and AHP techniques in their study to choose an optimal disposal site in Lokoja, Nigeria. The outcome is serving as a guideline in the site selection of a landfill in large cities in developing nations (Adewumi et al., 2019; Kareem et al., 2021). Additionally, Agrawal et al. (2020) in their study to select a suitable landfill location for the city of Sultanpur considered eight sites with the help of GIS and AHP.

Furthermore, a landfill suitability index was computed to help in the final site decision of the proposed landfill sites (Agrawal et al., 2020).

In another study, Karimi et al. (2020) used a GIS grounded technique to find the best location for MSW landfills in Regina, Canada, considering spatial, environmental, and economic constraints. They decided that landfills should be situated away from protected areas, water sources, and urban areas, as well as close to roads. Multi-Criteria Decision-Method (MCDM) and GIS approaches were used by Barakat et al. (2017) to find a suitable landfill site in Morocco. The project's goal is to show how landfill sites can have a negative impact. In the study, ten criteria were used and 10% of the study area has been determined to be in the most appropriate class. The GIS and MCDM techniques were used in the study by Ayaim et al. (2019) to find appropriate land space for MSW landfills in Ga South, Ghana, and the AHP technique was used to weigh and integrate the criteria. Rahimi et al. (2020) used GIS fuzzy logic and MCDM to find suitable MSW landfill locations in Mahallat, Iran. Table 2.1 below summarises the studies on the use of GIS for WM in developing countries.

Table 2.1: Summary of GIS applications on solid waste management in the developing countries

Study application	GIS-based approach	Location	Results	Reference
Site suitability (landfill, storage, waste treatment facilities)	GIS-based and MCDA	Robe town, Ethiopia	41.02 km2 (651.12%) of the area was unsuitable, 16.27 km2 (20.28%) was low suitable, 10.53 km2 (13.12%) was moderately suitable, 7.54 km2 (9.40%) was highly suitable and 4.88 km2 (6.08) was very highly suitable.	Balew et al. 2020
	AHP and SAW method (GIS-based)	Al-Musayiab Qadhaa, Babylon, Iraq	Two suitable candidate landfill sites were identified that satisfy the requirements with an area of 7.965–5.952 km2	Chabuk et al. 2017
	GIS fuzzy membership functions. And MCDA	Oita City, Japan	an area of about 13.36 km2 from the entire study area is the most suitable and the remaining two options are still suitable for the intended purpose	Babalola 2018
	GIS fuzzy membership functions. and MCDA Network Analyst Tool	Nasiriyah, Iraq	According to the AHP and Fuzzy models, the total surface areas of suitable sites are 4.4 km^2 and 13.35 km^2, respectively.	Abdulhasan et al., 2019
		Ahvaz, Iran	Only about 0.01% (85.63 ha in 16 pieces) of Ahvaz County are completely suitable with the fuzzy value of one. About 2.67% (21,531 ha in 114 pieces) of Ahvaz County has an excellent level for landfill siting.	Chabok et al. 2020
		Kanpur, India	This study found the reductions in haul distance as 27.78 ± 10.2% for the selected network.	Singh and Behera, 2018

Waste optimised transport routes and Scheduling	Network Analyst Tool	Al Nuzha District, Irbid, Jordan	According to the model's findings, each round's travel distance is reduced by 2880,2 m, and the percentage of abandoned bins is reduced from 25% to 0%.	Hatamleh et al., 2020
	Building information modeling, GIS, and Life Cycle and Assessment	China	Integrating BIM with building waste management is feasible, promotes recycling, and can be used to compare different waste treatment schemes, which enables informed decisions and management	Su et al. 2021

2.9 Challenges of GIS applications on waste management in developing countries

Studies on systems grounded on spatial machineries have mostly concentrated on collecting, storing, analysing, and visualizing spatial data regarding bins, vehicles, sites, routes, and collection and have not been able to monitor waste bin status (Hannan et al., 2015). The literature on identifying technology-based systems focuses on attaining ID making it easier to detect and oversee the tasks of drivers and vehicles, although it is incompetent to address problems with bin status observation and challenges with geographical information. The identification and spatial information-related issues were not addressed in research on data attainment-based systems, which instead concentrated on data acquisition together with bin status monitoring. The combination of these three categories of technology with communication technology may result in statistical and inspection-related limited data on waste generation, collection, or recycling that were the focus of the previous study (Hannan et al., 2015).

The information on bin full levels is unclear, and for certain systems, the mass of waste is determined by means of a variety of weighing measurement methods upon admission into the disposal site, but little is known about measurement at the source site. The difficulties in resolving this problem lie in the model and establishment of intelligent waste bins that can continuously collect corporal status data on each bin, including its fill level, weight, volume, and environmental conditions. This necessitates the proper integration of data from temperature, humidity, volumetric, and/or camera sensors. RFID must be included as well to track each bin's identification. The smart dustbin should be designed in a system that may address every issue associated with an effective SWM system. Every time a waste disposal operation is performed, information on the status of the smart bin should be gathered using technologies like ultrasonic sensors and load cell sensors (Hannan et al., 2015). Most of the time, the present SWM systems are incompetent to give WM operators real-time dustbins status data (Andeobu, Wibowo, and Grandhi, 2022; Arebey et al., 2012; Zeb et al., 2019). With certain delays, some systems can deliver data of a semi-real nature. However, finding a solution to this problem is crucial for properly organising the timetable or route for waste collection. The key obstacle to resolving the problem is giving waste cans enough intelligence to enable them to instantaneously detect any operation linked to the loading or unloading of waste and to respond appropriately using one or more relevant sensing devices. Additionally, this issue needs the appropriate sensors to gather up-to-date bin status data and a reliable communication network to send the collected data to a control station quickly (Satyamanikanta and Narayanan, 2017)

2.10 Possible future directions in GIS application in solid waste management

According to Soni et al. (2019), planning is essential to have effective and positive management of SW generated. It is a critical element in management in a short-term and long-standing period. Kulisz and Kujawska (2020) in their study advised that in developing effective planning strategies and implementing sustainable development, identifying relationships between factors influencing the MSW generation and forecasting waste demand play a key role. Soni et al. (2019), emphasised that it is a vital prerequisite for efficient WM to compute an accurate forecast of the quantity of waste produced.

The forecast of the quantity of MSW promotes efficient strategic planning and functionality of the waste collection system (Soni et al., 2019). Hence, forecasting of MSW generation has gained recognition (Al-Salem, Al-Naseer and AL-Dhafeeri, 2018). SW predictions derived from projecting mathematical models are viewed as a critical tool for decision-makers, policymakers, and stakeholders to build effective and integrated SWM plans (Abbasi and El Hanandeh, 2016; Al-Salem et al., 2018). Before executing urban environment development and SWM schemes, studies employing regression analysis of SW generation are normally the initial stage in identifying environmental effects, designing sustainable preparation plans, and establishing comprehensive baselines (Al-Salem et al., 2018).

Modeling MSW generation based on inducing factors is a critical challenge in solid waste management because it allows for more precise projections of future MSW generation (Bosire et al., 2017). Before establishing MSWM plans, it is critical to have a comprehensive considerate of MSW status (Liu et al, 2019). According to Kulisz and Kujawska (2020), predicting the trends of waste generation in MSW production in fast-growing regions can be challenging, especially given the numerous factors involved, which include population growth and migration, the magnitude, and the trend of municipalities' households, or variations in the labour market. Suthar and Singh (2015); Trang et al. (2017); and Hidalgo et al. (2019), demonstrated that the amount of SW generated is mostly influenced by the sociodemographic and economic parameters. Moreover, these parameters are key players in defining the composition of urban waste in an area (Kulisz and Kujawska, 2020). Soni et al. (2019), advised that to develop an effective WM system, it is fundamental to make predictions about the amount of waste that is produced in the area. The advantage of making such a prediction leads to proper disposal in landfills, and recycling facilities, the development of efficient operating waste collection infrastructure (Soni et al., 2019). An excessive or deficient collection of SWs, and insufficient or more treatment and disposal facilities available are normally caused by the incompetency of inaccurate waste generation predictions (Sonia et al., 2019).

According to Abbasi and El Hanandeh (2016), there are various forecasting methods with a wide variety of factors or variables used in SW generation. The most used methods are descriptive statistical models, regression analysis, time series analysis, and artificial intelligence methods (Andeobu, Wibowo, and Grandhi, 2022). Additionally, more of the methods used for modelling the estimation of the present and the future SW generation rate is adaptive neuro-fuzzy inference system (ANFIS) (Soni et al., 2019), system dynamics (Popli et al., 2017), artificial neural networking (Soni et al., 2019), grey modelling technique (Intharathirat et al., 2015) and the multi-linear regression method (Al-Salem et al., 2018). These methods are beneficial in estimating the quantitative relationship between dependent and independent variables.

The beneficial use of GIS is the reduction of time and money required to select a location (Mansour et al., 2014). Additionally, it offers a digital database for long-term site monitoring. Moreover, GIS can assist in the maintenance of the data and facilitate collection processes. GIS in WM can help with the examination of optimal sites for transfer stations, scheduling of routes for waste transportation to treatment facilities and monitoring. (Rajaram et al., 2016; Suresh and Sivasankar, 2014).

2.11 Legislation framework

South African legislations

An identification, classification, monitoring, and waste management in South Africa is governed by laws, ordinances, and guidelines, which are periodically reviewed and amended where possible.

The Constitution of the Republic of South Africa, 1996 (Act No. 108 of 1996)

The constitution of the Republic of South Africa, 1996 (Act No. 108 of 1996) as the uppermost law of the South African nation functions as the framework that instructs and advises all other legislature and policy standard on how to administrate the environmental regulations through the three spheres of the South African government (Glazewski, 2005). Section 24 of the Bill of Rights below serve is the legal backbone of the environmental legislature, policies, guidelines at national, provincial, and local level to make sure regulations at these levels prevail.

Section 24 of the Bill of Rights contained within the Constitution of the Republic of South Africa. 1996 (Act No. 108 of 1996), states that everyone has the right to:

> *"(a) an environment that is not harmful to their health or well-being; and (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that – (c) prevent pollution and ecological degradation; (d) promote conservation; and (e) secure ecologically sustainable development and use of natural resources, while promoting justifiable economic and social development."*

Schedule 4 and 5 of the constitution states that local governments, i.e., municipalities, are responsible for WM within their jurisdiction. This includes the removal and transportation of waste, management of waste disposal facilities as part of the basic services that are expected to be provided to the community (IWMP Polokwane March 2016). Furthermore, Chapter 7 of the Constitution says the local government should encourage of socioeconomic development and promote a healthy and safe environment.

The National Environmental Management Act, 1998 (Act No. 107 of 1998)

The National Environmental Management Act 1998 (Act No. 107 of 1998) (NEMA) was enacted in November 1998. It is the main legislature in South Africa that oversees all the environmental related matters. NEMA encourages socioeconomic and environmental sustainability with an emphasis on preserving the environment. This law provides general control over environmental legislation and allows sustainable activities and the preservation of the environment to prevent environmental damage and its inhabitants.

National Environmental Management: Waste Act (59 of 2008) – this legislature focuses on waste. This statute requires local municipalities to provide WM services, also waste removal, waste storage, and waste disposal, that are available to the entire community and comply to national guidelines and regulations. Among its other functions it includes giving waste permits to a person on certain waste activities provided that the person may need approval from both NEMA and NEMWA for the fundamentals of similar activity; giving a framework on how to handle different waste types; how to minimise waste generation and a proper way of waste disposal. This law applies to all spheres of government in waste related issues. Moreover, all municipalities are required by the NEM:WA to create a variety of mandatory local-level instruments, including Integrated Waste Management Plans (IWMPs) and local waste collection requirements through plan strategies and bylaws that take into account the municipality's evaluation.

National Waste Management Strategy (2011)

The National Waste Management Strategy (2011) (NWMS) was published on May 4, 2012, to report the challenges of waste management in South Africa and put into effect the relevant set of guidelines and laws relating to waste management. The general objective of the NWMS is to diminish generation of waste also lessen the influence of every waste type towards the economic growth, well-being, and the quality of environment. These goals also assist local municipalities in drafting their Integrated Waste Management Plan (IWMP).

Goal	Description

1	Promote waste minimisation, reuse, recycling, and recovery of waste.
2	Ensure the effective and efficient delivery of waste services.
3	Grow the contribution of the waste sector to the green economy.
4	Ensure that people are aware of the impact of waste on their health, well-being, and the environment.
5	Achieve integrated waste management planning.
6	Ensure sound budgeting and financial management for waste services.
7	Provide measures to remediate the contaminated land.
8	Establish effective compliance with and enforcement of the Waste Act.

The National Domestic Waste Collection Standards of 2011

The National Domestic Waste Collection Standards (NDWCS) are intended to redress the unequal DSW service delivery that existed under apartheid governance, in compliance with section 7 of NEM:WA. Every household under a municipality's purview will receive Waste removal services. The provision of DSW services by a municipality also implies the performance of related obligations, including, among other things, the allocation of a communal collection point, the rate of DSW collection, the sorting of DSW at source, the collection of recyclables, the allocation of storage containers, refer to regulation 4(1-6) of the standard.

Landfill siting

Landfill siting is a complex process (Mohammad et al., 2018) as various factors and regulations are involved in the site selection procedure (Kareem et al., 2021). Landfilling means the disposal of waste on the ground, either in the excavations or when a landfill is built above the mark (Department of Water Affairs and Forestry DWAF, 1998).

The constant population growth and the associated anthropogenic activities have led to accelerated urbanisation in developing countries (Lin and Kao, 1999). The site selection process for a landfill is a complicated project in SWM systems because it is subject to government regulation and funding, population density increases, environmental awareness increases, public well-being is a concern, uncultivated land space availability decreases, and resistance to the construction of landfill sites (Lin and Kao, 1999). The primary goal of determining the best location for landfills is to minimise the negative economic, environmental, and ecological consequences (Chang et al., 2008). SW disposal must be disposed of in a properly constructed landfill that was constructed abiding by technical principles set by law that governs WM to protect the environment and the public's well-being (Kareem et al, 2021). Many landfills are designed to last a decade to three decades and must be monitored for 30 years after closure to certify that the environmental and surface settlement is not compromised but properly rehabilitated (Rajaram et al., 2016).

In 1994, South Africa implemented the Minimum Requirements for Waste Disposal (1st Edition) by means of Landfill. Its main goal was to require proper technical engineering and covering of dumpsites so that polluted effluent would not be discharged into groundwater and cause water contamination. Department of Water Affairs and Forestry (DWAF) introduced the second edition of the Minimum Requirements for waste disposal by landfill in 1998. This second edition aims to aid in achieving compliance in the areas of landfill permitting, siting, design, operation and management, monitoring, and landfill rehabilitation and aftercare (Novella, 2014). In terms of landfill siting, the second edition becomes more focused in this study. The site selection of a disposal site is discussed in Section 4 of the Minimum Requirements for Waste Disposal (second edition).

Landfills are classified in a variety of ways. Because landfills differ in size, kind, and possible environmental impact, a classification system has been established to distinguish them. The different landfill classes were then subjected to graded minimum requirements. According to section three of the waste disposal minimum requirements, the landfill classification system's objectives are to: create landfill classes that reflect the range of waste disposal needs; use the landfill classes as the foundation for grading Minimum Requirements for the cost-effective selection of landfills; and consider waste disposal situations and needs in terms of waste type, waste stream size, and the potential for significant leachate generation. The type of waste produced, the volume of the waste stream, and the likelihood of significant leachate generation are therefore used to categorise landfills. After a class has been given to landfill, it must only meet the conditions for that class (DWAF, 1998).

Section 4 documented the minimum requirements for site selection (DWAF, 1998). The selection of a landfill site is an essential phase in landfill construction. When a need for a disposal location is determined, the process of selecting a landfill site gets started. The categorisation system is then used to determine the kind of landfill required to meet this need based on the "givens," such as the quality and quantity of the waste and the likelihood of major leachate formation. If the intended landfill's class, necessary land area, and potential impact are known, potential locations can be found. This section identifies site selection factors as well as catastrophic defects that should be avoided.

Elimination of Areas with Inherent Fatal Flaws

The minimal condition, according to DWAF (1998), is that locations having an inherent Fatal Flaw cannot be developed for landfill site placement. Airports, floodplains, wetlands, unstable areas (including fault zones, seismic zones, and sinkhole-prone areas), areas near significant surface water bodies, areas of ground water recharge due to topography and/or highly permeable soils, catchment areas for important water resources, sensitive ecological and/or historical areas, areas with steep gradients, where slope stability may be a problem, and areas immediately upwind are among the Fatal Flaws factors (s). As a result, all facility types, as well as MSW disposal, construction and demolition waste disposal, fossil fuel combustion ash disposal, industrial and delisted waste disposal, must meet the standards outlined in the laws' sections (DWAF, 1998). The economic, environmental, and social aspects must all be considered while selecting a landfill site, according to DWAF (1998).

In essence, proper landfill site selection allows for a simple, cost-effective design that assuming proper site preparation, allows for proper operation (DWAF, 1998). Only when suitable alternative sites have been found and provided with proper deliberation should a landfill site be chosen (DWAF, 1998). This is because a landfill site's creation, operation, closure, and rehabilitation can have an impact on the environment, society, and economy (DWAF, 1998).

Focusing on the scope of the research study that household waste is the waste stream of interest. Household waste is recognised as general waste. Only Class B landfills developed in compliance with Sections 3(1) and (2) of this Norms and Standards (GNR 636) or as required by the Minimum Requirements for Waste Disposal by Landfill are permitted to dispose of General Waste (2ed Ed, DWAF, 1998).Moreover, the Polokwane local municipality has existing landfill sites recognised as General waste, medium sized with no significant leachate (G: M: B^-). As such, this type of a landfill is a listed activity in Category B, 4(8) and (9) of the List of waste management activities that have, or are likely to have, a detrimental effect on the environment (GNR 921). Therefore, as part of a WM licence application as contemplated by section 45 read with section 20(b) of this Act, a person who wishes to begin or conduct WM activity under this category must carry out a scoping and environmental impact reporting process outlined in the Environmental Impact Assessment Regulations made under section 24(5) of the NEMA 1998.

2.12 Conclusion

The beneficial use of GIS is the reduction of time and money required to select a location (Mansour et al., 2014). Additionally, it offers a digital database for long-term site monitoring. Moreover, GIS can assist in the maintenance of the data and facilitate collection processes. GIS in waste management can help with the examination of optimal sites for transfer stations, scheduling of routes for waste transportation to treatment facilities and monitoring. (Rajaram et al., 2016; Suresh and Sivasankar, 2014). To effectively manage our waste, modern methods like a global system of mobile, GIS must be used. To achieve sustainable SWM, there must be (a) an integrated plan of engagement of different stakeholders (such as policy makers, waste generators, government, and private investors); (b) IWM system regulations and guideline plans that are regionally orientated, (c) the use and integration of GIS and other technologies to manage SW. No waste treatment or technological method is entirely perfect to handle the waste. SW plan is not a size fit. Therefore, the establishment and implementation of WM strategies that are regionally orientated will help maximise the sustainable SWM of a region.

This chapter presented an overview of the literature on the components of SWM, the practices of SWM, solid waste generation and projection, and site selection of the landfill. The next chapter focuses on objective one and two of the study.

CHAPTER THREE:

Household solid waste management practices and perceptions in the Mankweng Cluster.

Abstract

Poor waste disposal practices hamper the progress towards integrated solid waste management (SWM) in households. Knowledge of current practices and perceptions of household solid waste management (HSWM) is necessary for accurate decision-making in the move towards a more sustainable approach. The study's objectives one and two were to evaluate SWM in two wards (ward 25 and ward 27) of the Mankweng cluster, Limpopo, South Africa. 240 participants for the study were chosen using a simple random sampling procedure. Observation and semi-structured questionnaire methods were used to collect the data, and Statistical Package for the Social Sciences version 26.0 was used for analysis. Results from the study show that majority of the SW was food waste (61% and 53%) based on their weight in the village and township respectively. An estimated SW generation rate of 0.27kg/cap/day and 0.13kg/cap/day were obtained for the ward 25 and ward 27 respectively. Most of the respondents (50%) did not practice the source waste separation or waste recycling. In ward 27, most respondents (70%) keep their waste in pit holes, while in ward 25, they utilise plastic bags and bins (88%). Waste collection is a door-to-door service, once per week in ward 25 and street sweeping is common in ward 27. Burning waste and illegal dumping are the two disposal methods most frequently used in ward 27 (46% and 38%). In both the wards, about 80% of respondents said that illegal dumping occurs because of ignorance, a lack of knowledge and unavailable waste collection services. Respondents recommended that the municipality build recycling facilities, install disposal bins on hotspots for illegal dumping, and promote SWM. This study emphasises the value of waste separation, recycling, and education awareness campaigns in achieving sustainable SWM.

Keywords: Households' Practices; Household Solid Waste Management; Waste Composition, Generation Rate

3.1 Introduction

Solid waste (SW) is described as moist waste (leftovers, leaves, meat residues), recyclable waste (paper, plastic bottles, metal, fabric), and non-recyclable waste in a rural household (Chen, 2010). Solid waste management (SWM) is the main issue in most municipal governments in the world. Because everyone is a waste generator, SWM is a concern in both urban and rural settings. It has been characterised as a worldwide issue that affects everyone and calls for long-term solutions since it influences on all people, households, regions, and authorities (Nyampudu et al., 2020). Household waste, which includes food waste, paper, metal, glass, plastic, and rags from inhabited areas, is one of the principal sources of MSW. The local municipality oversees SWM, which includes household waste (Fadhullah et al., 2022). The socioeconomic level and household characteristics have an impact on the amount of municipal waste created and how it is managed. The outcome is critical to comprehend the features and needs of different homes while developing a waste management (WM) strategy. The consequences of inadequate domestic SWM on society's health can be classified as causes for physical, biological, psychosocial, and ergonomic well-being concerns (Ncube et al., 2017; Ziraba et al., 2016). Biological vectors including flies, rodents, and insect infestations can reproduce in contaminated soil, air, and water. Diarrhoea, digestive difficulties, food poisoning, cholera, bacterial contamination; skin, and eye problems; and respiratory symptoms are all caused by these biological vectors (Norsa'adah et al., 2020).

Knowledge of the types and composition of waste generated, as well as the rate and quantity of waste generated, is essential for the proper planning of a region's solid waste management (SWM) system. The quantity and composition of Municipal Solid Waste (MSW) vary from one country, a region, and community to the next, and even from one society to the next. Differences in income, socioeconomic distribution, consumption patterns, and disposal habits of persons could all be contributing factors. Solid waste (SW) is a big burden for local governments since it keeps increasing, and most municipalities do not even keep track of waste generation, origin, or characteristics. Due to a lack of information, decisions about proper WM are made based on speculation and generalisations, resulting in waste mismanagement with major environmental repercussions (Abdulredha et al., 2020; Gebremedhin et al., 2018; Kunkel and Matthess, 2020).

A crucial management activity involves understanding the nature of SW generation, including its quantity, characteristics/composition, and calorific value. This results in the setup, implementation, and advancement of WM systems as they require appropriate alternative methods of handling and treatment (Abdel-Shafy and Mansour, 2018; Johnima et al., 2022; Papachristou, 2009). This variation of waste composition from one area to another is driven by a various of elements including lifestyle, economic situations, WM legislation, and market pattern. The quantity and type of MSW are crucial considerations when deciding how these wastes should be treated and managed (Abdel-Shafy and Mansour, 2018). Analyses such as physical and chemical composition, volume, and production are examples of characterisation studies that provide information for waste planning and management for advantageous use and disposal practices. The majority of MSW is generated by households (55% to 80%) and 10% to 30% by commercial zones (Miezah et al., 2015). The composition of SW is influenced by a variety of factors such as eating habits, cultural practices, climate, and socioeconomic status (Gupta, Yadav, and Kumar, 2015). Generation, storage, separation, collection, energy recovery, and disposal activities are all part of MSWM (Bertanza, Ziliani, and Menoni, 2018). Quantity and composition of waste generated are critical for WM system planning, operation, and improvement (Dehghanifard, and Dehghani, 2018). Poor WM has been linked to a rise in sanitation-related ailments that are respiratory and digestive related (Uhunamure, and Shale, 2021; Wilson et al., 2022; Yoada et al., 2014; Zolnikov et al., 2018). The composition and quantity of MSW change as the average local income rises (Ogwueleka, 2013). Economic growth has stemmed in a rise in food waste (Santeramo and Lamonaca, 2021; Wang and Wang, 2013). Due to increasing population growth and waste-generating patterns, developing countries in Africa with weak SWM face a significant threat to human and environmental health (David et al., 2020; Dladla et a., 2016). Understanding on SW generation and disposal for rural dwellers in developing nations such as China, Malaysia, India, and Africa have received less attention. Rural populations in emerging countries, on the other hand, are generating more SW per capita. Malaysia's yearly growth rate of per capita SW generation among rural dwellers is 2%, while China's rate is 8% to 10%. (Moh and Abd Manaf, 2014). With future economic growth and consumption capacity in developing countries, it is realistic to predict that the quantity of household SW will increase. In developed nations, models are available to forecast waste generation and waste minimisation behaviour; however, relatively little research has been done on generating models that are applicable to underdeveloped nations. As a result, without using data collected and analysed specifically for those countries, data and models created in rich countries may not be appropriate in circumstances of developing countries (Afroz, Hakani, and Tudin, 2011).

The collection of SW is a crucial component of WM strategy. It is among the most challenging problem that WM must deal with across the world (Odonkor, Frimpong, and Kurantin, 2020). Rodseth, et al. (2020), claim that in South Africa, the lack of domestic collection of waste reflects inequality. This is because while white-only suburbs are always maintained clean, most black citizens in townships and rural areas are compelled to discard their waste in public spaces and open community skips. Kamara (2006) and Rodseth et al. (2020), discovered that waste collection accessibility was found generally higher in the city centre and lower in the dispersed community in South African cities. There are some exceptions, such as plastic bags, even though the authority is dedicated to household waste management (HWM). As a result, WM institutional development is required to improve strong implementation skills.

Kamara's findings are backed up by statistics from Statistics South Africa (2011), which indicated that Limpopo, Mpumalanga, and the Eastern Cape had the lowest proportion of household waste refuse pickup in South Africa in 2012, at less than 44% respectively. In 2012, Gauteng and the Western Cape provinces had the greatest proportion of home waste removal, with over 90%. This indicates that metropolitan areas in South Africa get better collection and disposal services than rural areas. The door-to-door collection is popular in most developed nations, especially when it comes to household SW collection (Satterthwaite et al., 2019). Nonetheless, the adoption of this technology is constrained, particularly in poorer states, owing to a range of issues such as financial and population growth, as well as economic limits (Awuah, 2018; Bezama and Agamuthu, 2019). To make well-informed decisions as we move towards a more sustainable future, it is significant to know the present attitudes and behaviours surrounding household solid waste management (HSWM) (Fadhullah et al., 2022). Waste is typically buried and burned in rural and remote regions (Kamaruddin et al., 2016; Nxumalo et al., 2020, however permanent waste storage containers are found primarily along the sides of main roads in urban and semi-urban areas (Fadhullah et al., 2022). Education on proper SWM practices can prevent HSWM difficulties (Sultana et al., 2021). According to a previous study, most people in a Bangladeshi community (53%) are clueless about how to properly manage HSW (Sarker et al., 2012). Community members can have a significant impact on the efficient management of HSW.

According to Dlamini et al., (2017), SWM is among the utmost significant matters that South African municipal stakeholders must deal with. Monetary limitations, the system's difficulty and multiple perspectives, and the inefficient organisation are all causes for concern. The local municipal stakeholders are primary organisations tasked with ensuring the effective and efficient management of SW (South Africa, 2008). To reach recycling goals, local municipal authorities typically promote a reduction in HSW generation and encourage citizens to take on their duties instead of depending on local municipal waste collection services. Amidst South Africa's environmental rules and regulations, especially those pertaining to MSWM, Recycling and community participation efforts have received very little attention when it comes to waste reduction (Dlamini et al., 2017). In South Africa, the efficient handling of MSW combined with reduction has proven to be a challenging task. In terms of processing waste, South African environmental rules and regulations have also been carefully written and stated. This extends further to the integrated development plans and integrated waste management plans of some municipalities, which outline plans but do not carry them out. For instance, the Thulamela municipality in South Africa launched measures to deal with the disposal of certain waste types, such as disposable napkins (Mabadahanye (2017). However, given the limitations of inadequate waste collection on designated days, this initiative appears to be ineffective. This compromises the inhabitants' health and exposes pets to faeces, which also have a foul stench. Most local councils collect the waste once per week and at least twice per week in commercial districts. Because of the climate in South Africa or because of the heat, less frequent waste collection poses a health risk. No person is allowed to burn waste anywhere other than an approved incinerator run by the local government or a location selected by the local government for such purposes. This is according to one of the bylaws of Makhado Municipality Draft Environmental Waste Management. However, to recover valuable metals, waste pickers burn waste at landfill. SWM in South African cities now includes community engagement as a crucial component. For instance, informal waste pickers currently play a significant part in recycling and SWM in Johannesburg cities (Dlamini et al., 2019).

Two of the objectives of this study (objective i and ii) were to evaluate HSWM perceptions and practices in the Mankweng cluster, Limpopo province, South Africa. The Mankweng cluster was chosen because of the local municipality's current and future aspirations for economic, social, and environmental development. Some of the areas in the Mankweng cluster have waste collection services, while others do not. The cluster is quickly urbanising, with various development plans in place to help people in the Polokwane Local Municipality and other adjacent municipalities enhance their economic development and social status. As a result, a huge quantity of waste can be generated.

3.2 Methods and materials

3.2.1 Sampling

3.2.1.1 Sampling frame

The study focused on the two types of residential settlements and the provision of MSWM services by the local municipality. How communities and the municipality manage its waste is very significant. Two wards were selected from the nine wards (6,7,25,26,27,28,30,31,34) under Mankweng cluster because of their differences in the provision of municipal services. The main reason for their selection is that ward 25 is served by the municipality's fixed waste collection service, whereas ward 27 is served by the municipality’s EPWP for street waste picking. Ward 25 has a total population of 25868 people and a household number of 7936, while ward 27 has about 20902 people and about 5487 households (StatSA, 2012 and Municipal Elections, 2016). The sample frame of the study consisted of a total number of households from the ward 27 villages (5487), and ward 25 of the township (7936).

3.2.1.2 Sample size

Sample size was calculated using the Cochran’s formula, with a confidence level of 95%, with 5% margin error. A formula was used to determine the sample sizes of the wards. Ward 25 has a sample size of 367, while ward 27 has sample size of 360. However, in the study a sample size of 240 was used. 113 households from the ward 27 were surveyed and 127 households from the ward 25 were surveyed. This was influenced by the willingness of participating in the study, the unavailability of people during the week and working hours; other people were unwilling to give their waste for measurement. The researcher cessed to collect more data as the information started to repeat from different respondents. This indicated information data saturation.

3.2.1.3 Sampling method

Systematic random sampling and simple random sampling were used to select the required households from ward 25 and ward 27. A systematic random sampling was used in ward 25. This is because the households and streets of ward 25 reveal a grid pattern settlement. Therefore, the k^{th} value (skip) is the sampling interval. The following formula was used to determine k^{th} value: $K = N/n$, where n is sample size and N is population size. The k^{th} value in ward 25 was 22. The first household was randomly selected and thereafter the skip value was used each community. The simple random sampling was used in ward 27. That is because the household arrangement does not follow a grid pattern.

3.2.2 Data collection

3.2.2.1 Secondary data

Secondary data on the *status quo* on solid waste management of Polokwane local municipality was obtained from Polokwane local municipality Integrated Development Plan document in their website. Books and journals were consulted for supporting literature.

3.2.2.2 Primary data

Primary data was collected through questionnaires, field observations, and waste weighing measurements. A pilot study was used to validate the research questionnaire and the equipment.

i. Questionnaires

A semi-structured questionnaire was used to conduct a house-to-house survey to collect data on household socioeconomic variables and SWM practices. Age, gender, employment status, education level, household size, and income level were the socioeconomic factors of interest in this study.

There were both open and closed ended questions in the survey. The closed ended questions were structured to be simple for respondents to answer to get as many relevant responses as possible. At the conclusion of every survey, the respondents looked over the agenda to confirm that the information obtained during the survey appropriately reflected the respondent's views on the topics covered.

ii. Field observation

A technique for gathering information called field observation entails inspecting parameters or compiling the data needed to measure the variable being studied (Douglas, 2015). The researcher went to the study area and checked to see if the responses on the questionnaires were consistent. As part of the data collection and evidence, images were also collected. Field observations were conducted as a data collection method from February 21 to February 28, 2022, as recommended by researchers such as Bryman (2016) and Almasi et al. (2019), to get inclusive and accurate information on the study problem. The objective of field observation was to validate the outcomes of the interviews, identify undocumented difficulties, and identify unforeseen challenges that the community and local government as SWM service providers faced throughout the event. It allows the observer to detect unexpected occurrences, unstructured observation was used (Bryman 2016). Municipal solid waste storage, collection, transportation, and treatment were all noted as parts of the MSWM system. It is a good strategy to use when accurate information cannot be retrieved through questioning owing to the respondent's unwillingness to cooperate, and the researcher is more interested in the behaviour than the respondent's perception. This strategy was excellent for this study because residents may be unwilling to admit to illegally dumping SW in open locations. This issue can be solved by observation. Data from field observations were compared to data from interviews and documentary resources. Overall, this procedure significantly increased the validity of the collected data.

iii. Waste weighing measurements

Characterisation of the HSW generated in Mankweng wards was done once a week. To store waste, each household was given three plastic refuse bags. Food waste, garden waste, and other wastes (plastic, bottles, and metal) were separated from each household's waste. Every morning on the eighth day, the researcher collected the waste bags and gave each household a new plastic bag. After compaction, the segregated waste was weighed using an electronic scale and calibrated buckets to calculate the mass and volume of each waste composition. After sorting the wastes, the various components were weighed on a scale to determine the ultimate weight. The volume of the samples was measured using a container with a known volume and mass.

A record book of the waste generation data for measurement was used. A weighing scale (5kg), gloves, plastic bags, and bucket of known volume were used to determine the measurements.

3.2.3 Data analysis and presentation

i. Questionnaire

Descriptive statistics were used to evaluate quantitative data, whereas the narration was used to analyse qualitative data. Before being coded, processed, and analysed using descriptive statistics like frequency and percentage in the Statistical Package for the Social Sciences (SPSS) version 26 software, data were manually checked for correctness. The data was presented using pie charts, bar graphs and tables.

ii. Observation

Images were taken for data validation and presentation. The images included the waste type, processing and collecting of SWs, transport and disposal techniques, WM practices sideways the road, drainage channels, municipality bins, and vacant spaces were all observed at the household level.

iii. Waste weighing measurements

The percentage of each waste type in a sample was computed to determine the mass of each waste component. The equipment used to weigh the waste is the hanging electronic scale (50kg), bags for collection and weighing, gloves, and survey papers. Analysing the composition of waste is a procedure that is also used as a guide. The wastes were divided up into different sub-fractions, their weights were analysed, and the composition was shown as a percentage. The following equation illustrates how the percentage of weight was used to compute the measurement of household waste composition. Equation 1 was used to determine the waste composition in percentage.

$$Sorted\ waste\ composition\ (\%) = \frac{weight\ of\ the\ separate\ waste}{the\ total\ of\ mixed\ waste\ samples} \times 100 \qquad (1)$$

By examining the wastes generated by each household, waste generation was determined. The per capita waste generation is calculated as follows:

$$Generation\ Rate\ \left(\frac{\frac{kg}{capita}}{day}\right) = \frac{mass\ of\ solid\ waste}{number\ of\ people \times number\ of\ days} \qquad (2)$$

3.3 Results and discussion

The goal of this study was to assess the Mankweng cluster wards' HSWM practices and perceptions in the Polokwane local government.

3.3.1 Demographic and socio-economic characteristics

Figures 3.1–3.5 below, presents the socio-demographic and characteristics backgrounds of the respondents in the study. There is a total of 240 respondents, with 127 households from ward 25, and 113 household from ward 27. Ward 25 had most male respondents, while ward 27 had most female respondents. See figure 3.1. Figure 3.2 shows the age of the respondents in both the wards. It illustrates that ward 25 has most age group of 39-49 years. On the other hand, ward 27 has dominant age group of at least 50 years.

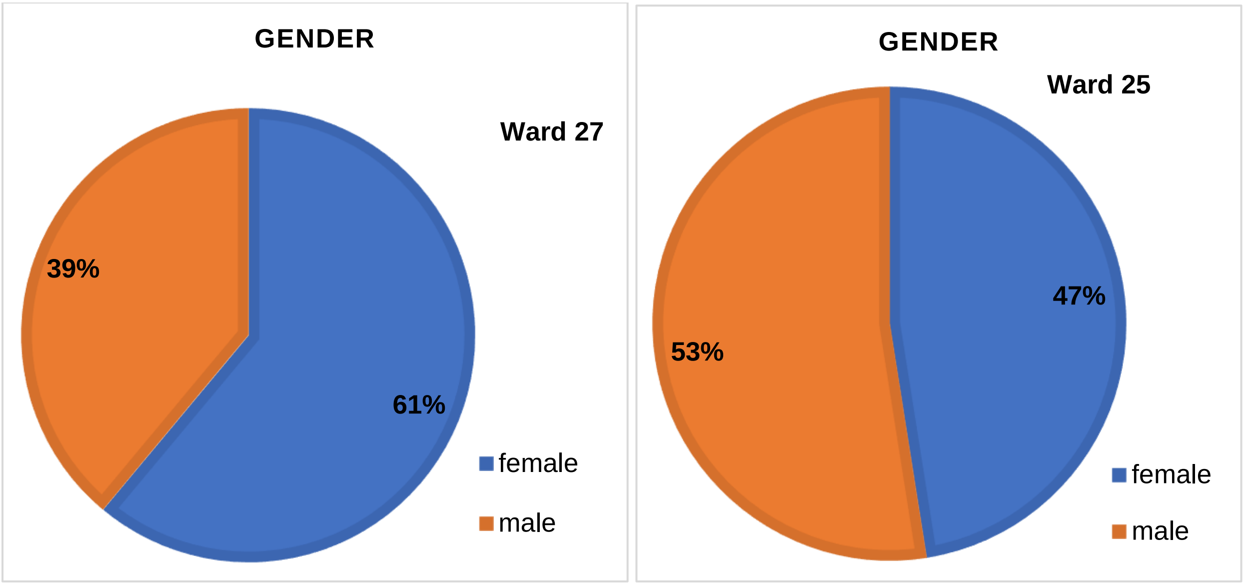


Figure 3.1: Gender

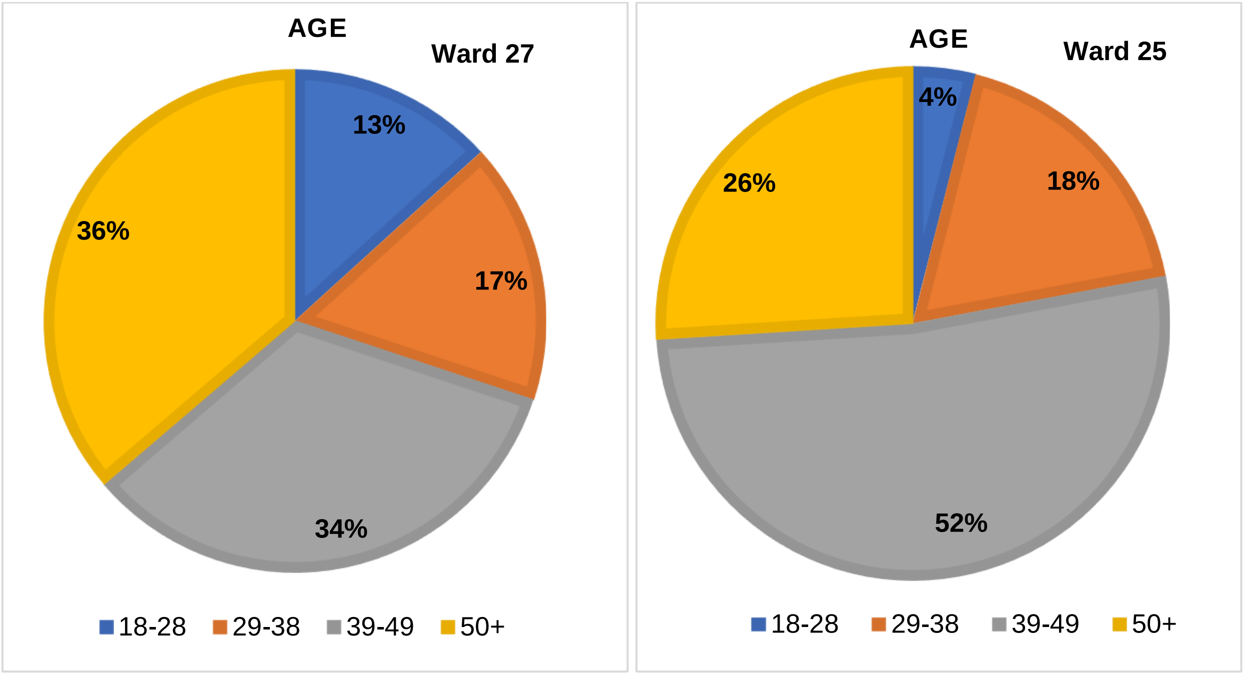


Figure 3.2: Age

The education level of both the wards is shown in figure 3.3. Most respondents in ward 25 have completed tertiary education level. On the other hand, most respondents in ward 27 have secondary education level. Figure 3.4 shows that most respondents of ward 25 are employed, while in ward 27, most respondents are unemployed.

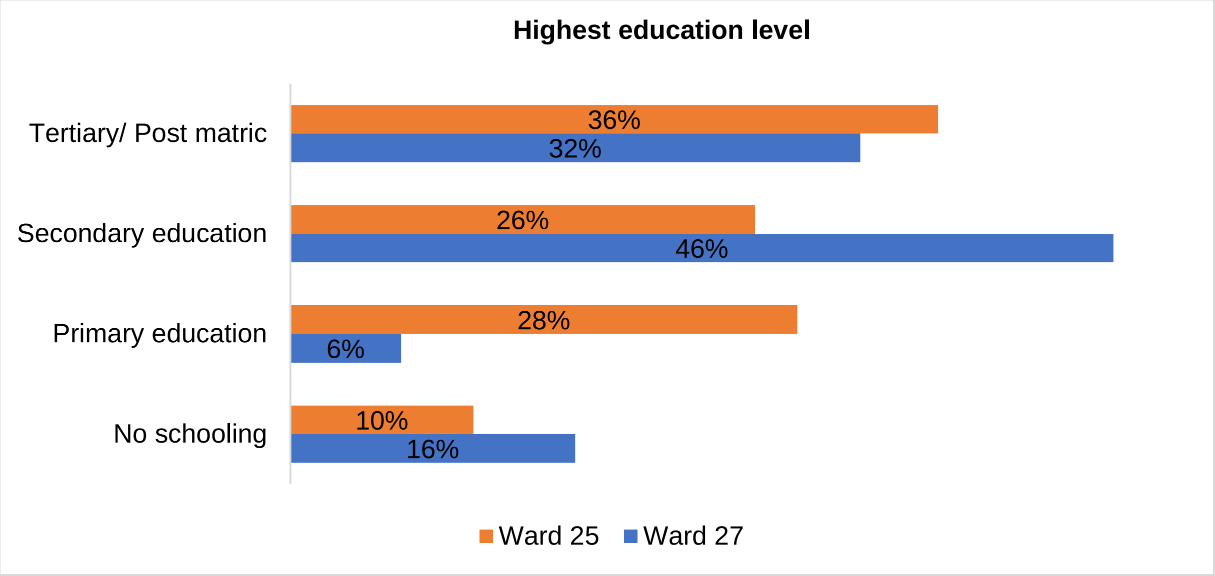


Figure 3.3: Highest education level

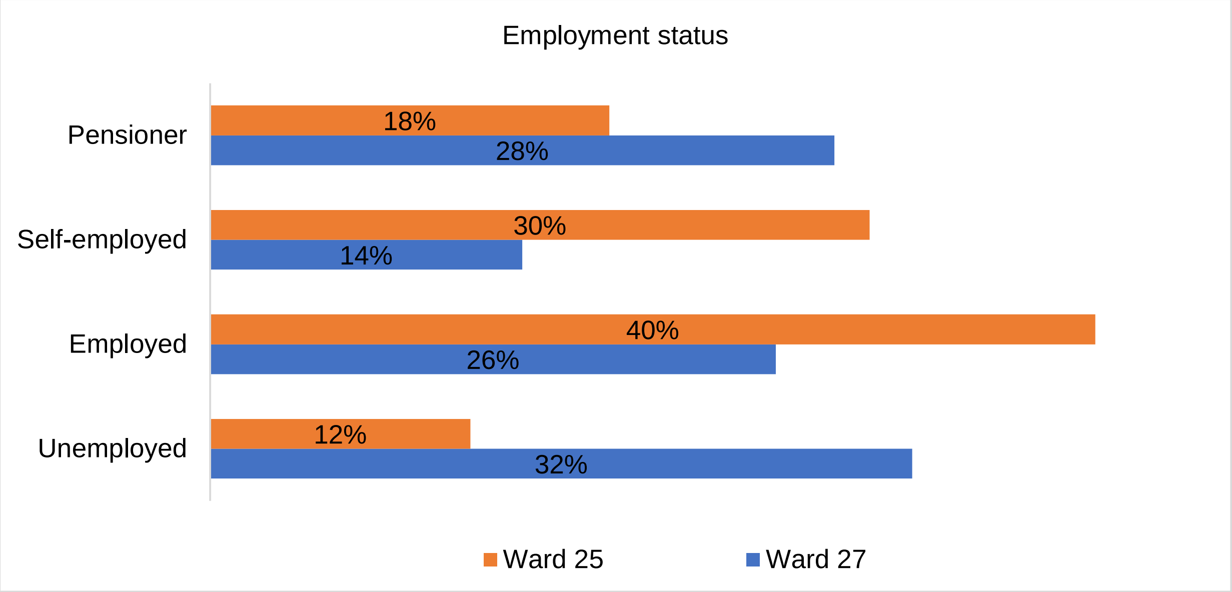


Figure 3.4: Employment status

The household income between these two wards differs significantly, probably because of the education level, employment, and economic activities. Figure 3.5 shows that the highest household income of respondents in ward 25 is at least R9000 per month. On the other hand, most respondents’ household income ranges from R10001 to R3000 per month.

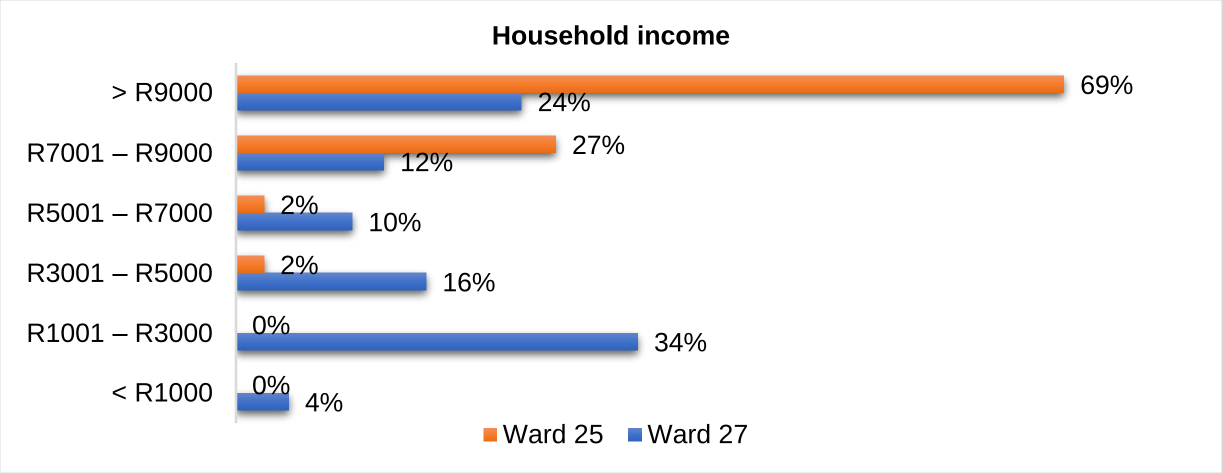


Figure 3.5: Household income

In the SWM category, respondents were asked to define waste. Their responses revealed that they have an idea of what waste is. Figure 3.6 shows the categorized definition of waste by the respondents. Most of them defined waste a useless material or product, used material or product and food remains.

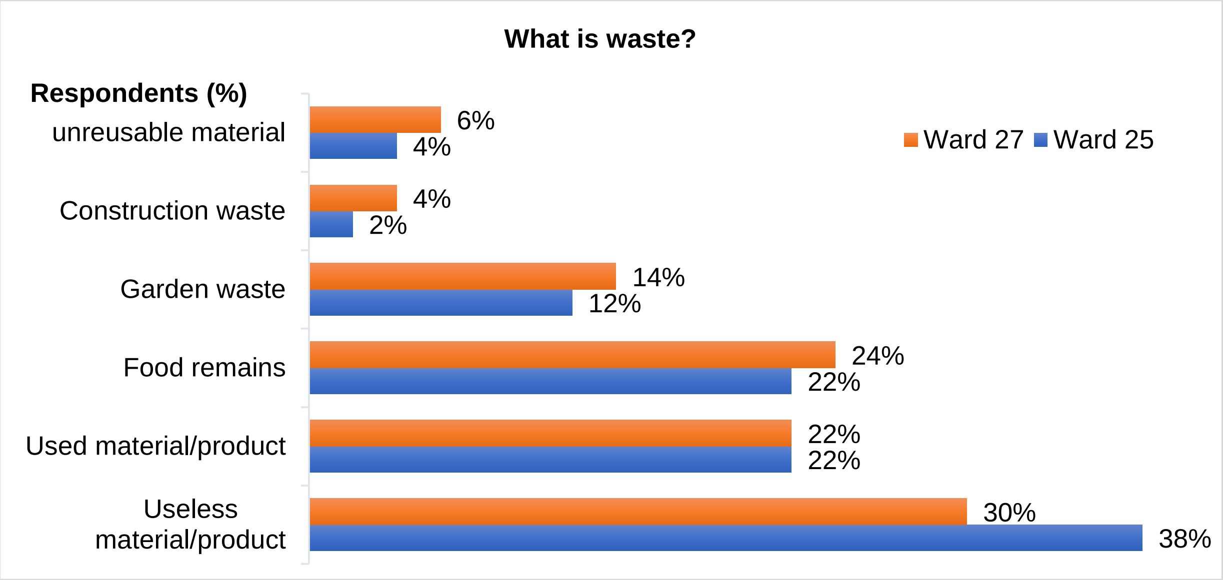
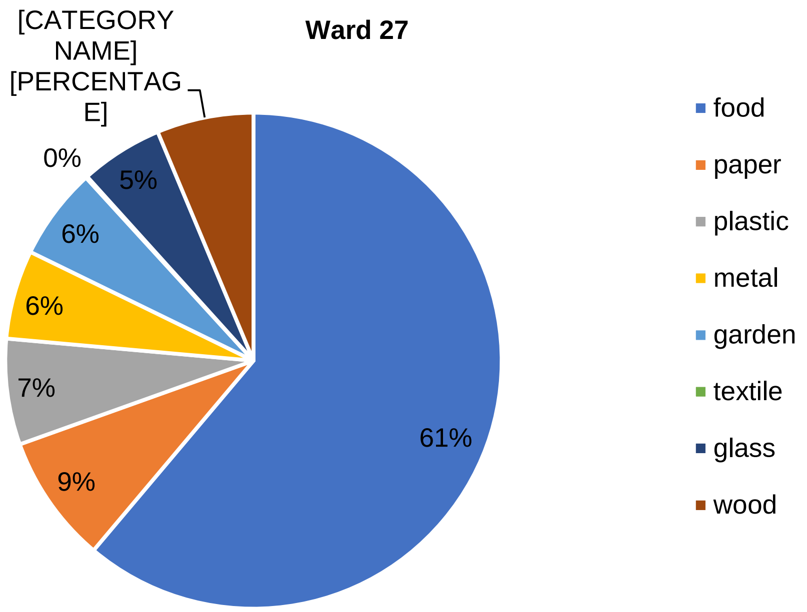


Figure 3.6: Represents the responds by community members in defining what waste is.

3.3.2 Waste management practices

3.3.2.1 Waste classification

The physical composition and characterisation were conducted to investigate the waste type and proportion generated in both ward 25 and ward 27. The generation rate (kg/capita/day) and the percentage by mass of each component were determined (see figure 3.7). The varied waste identified include food waste, paper and card boxes, plastic (bottles, containers, and bags), glass, garden waste, metal, textile, and wood. Some examples refer to figure 3.8-3.9. Food waste is the highly generated type of waste and accounts for nearly 61% and 53% of the total generated waste in the ward 27 and the ward 25 respectively. The high generation of biodegradable waste reflects household consumption habits, and many members of the household consume food, fruit, and vegetables. Paper and plastic are the second third highest waste generated followed respectively in ward 27. Garden waste is the second highest waste generated than plastic in ward 25. Glass and metal are both relatively the same amount in both ward 25 and ward 27. There is a significant generation of wood waste in ward 27 and no wood waste generation in ward 25. This may be due to people using fire to cook and to boil water. The ashes generated become wood waste. This is different from the township where electricity is used instead of wood. The high quantity of food waste in this study is like studies of Dikole and Letshwenyo (2020); Khair, Rachman, and Matsumoto (2019). However, this study resulted in contradiction with the result by Odonkor et al (2020) that indicated that plastic and rubber are the highest (N = 210) waste type generated followed by food waste (N= 177), and wood (N = 46).



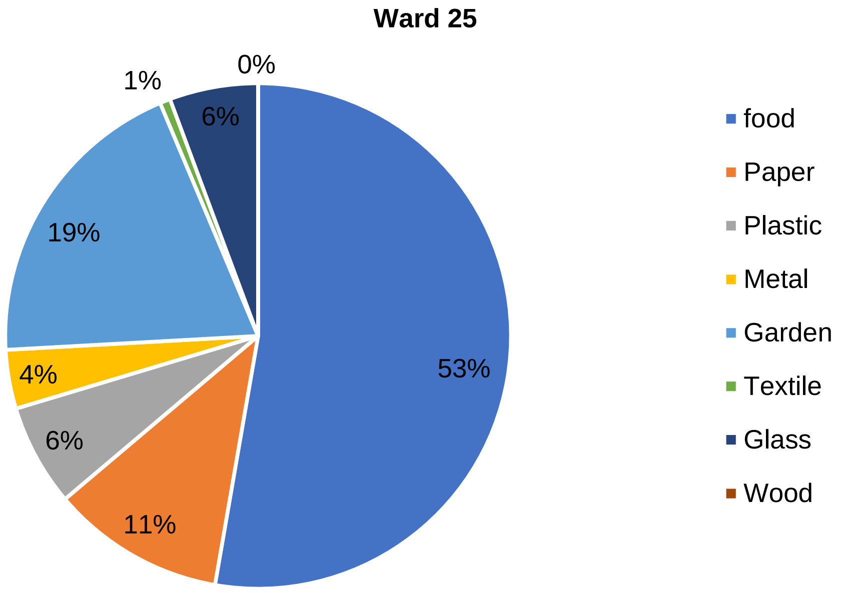


Figure 3.7: Waste composition of Mankweng wards

Figure 3.8: Food waste

Figure 3.9: Glass waste

Figure 3.10: food, paper, and plastic waste

3.3.2.2 Waste generation

For effective waste management procedures, particularly about collection, it is critical to have a clear understanding of the volume of waste generated at the home level. The main signifier of environmental burden is the generation of HSW, which is often determined in weight or volume (Kawai and Tasaki 2016). However, in this study, waste refuse bags were used to measure the HW quantity. In ward 27, most respondents indicated that they generate and dispose of one to two bags of waste per week (70%), and three to four bags of waste per week (28%) while in ward 25, one to two bags of waste per week (30%), three to four bags of waste per week (52%). At least five bags of waste are disposed of in both the ward 25 and the ward 27 (18% and 2%) respectively (see figure 3.11). Tsheleza et al. (2019), reported that moving from high-density informal habitat to low-density housing communities resulted in a minor rise in the typical number of bags per home per week. This concluded that in households in low-density housing communities generated more waste.

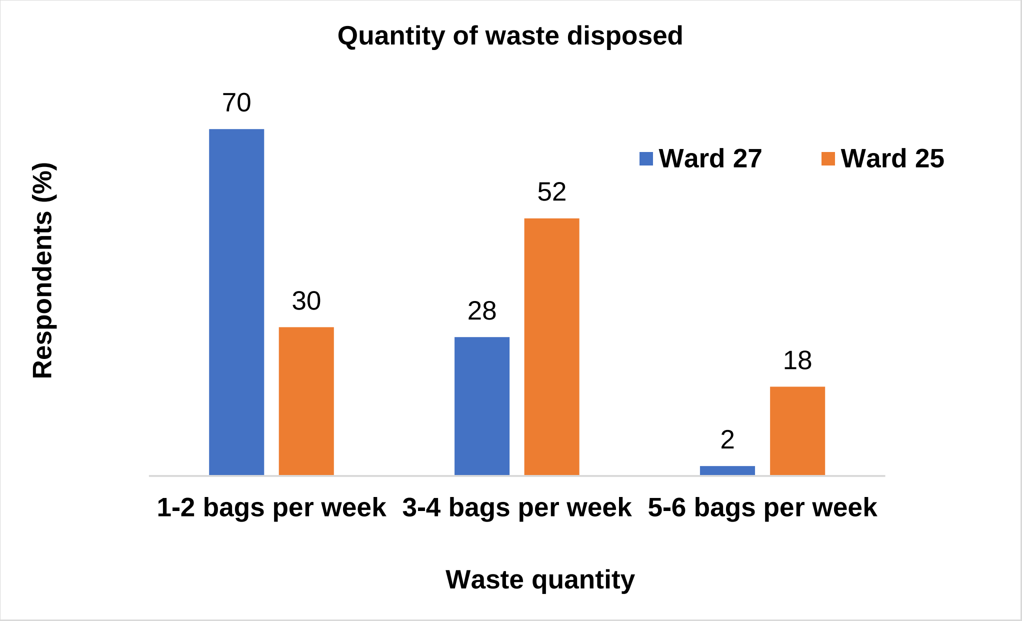


Figure 3.11: Waste quantity

The Household Solid Waste generation rate

Waste generation varied within a week with an overall generated quantity of 290.45 kg and 195.12kg in the ward 25 and ward 27 respectively (table 3.1). Figure 3.12 shows the waste generation rate by both the ward 25 and ward 27 households for four consecutive weeks. The bar graph illustrates that there is a higher SW generation in the ward 25 compared to the ward 27 in four weeks. The average SW generation in the ward 27 is 0.13kg/capita/day and 0.27kg/capita/day in the ward 25. The higher generation rate in ward 25 could be due to high income, and more economic activities. Differences in waste generation between the ward 25 and ward 27 may be influenced by lifestyles, eating and cooking habits, social and economic conditions, and the number of people living at home. Income inequalities, variations in household size, education level, and expenditure patterns may contribute in the HW generation. The SW generation rate of the outer zone, the middle zone, and the core zone of the Kebelles in Bahir Dar City, Ethiopia is 0.17kg/cap/day, 0.20kg/cap/day, and 0.28kg/cap/day, respectively, according to the Tassie (2018) investigation results.

An individual residing in an informal residence generated 0.40 kg of SW per day, but a person residing in a formal residence generated 0.56 kg per day in Mthatha city, South Africa. MSW generation per capita ranged from 0.09 kg per day to 5.50 kg per capita per day, with a mean of 0.94 kg per day (Tsheleza et al., 2019). With a per capita rate of 2 kg per day, South Africa is third in Sub-Saharan Africa among the nations that generate the most municipal waste, behind the Seychelles and the Comoros, which generate 2.98 kg and 2.23 kg per day, accordingly (Kawai and Tasaki, 2016). Furthermore, similar SW generation rates were observed by Aguilar-Virgen et al. (2010) in Ensenada and Premakumara (2011) in Cebu City, where more than 70% of the households' SW generation rates were just over 2 kg per day. The average daily generation of SW per capita in Sub-Saharan Africa is 0.65 kg, with a range of 0.09 to 3.0 kg (World Bank, 2012). The average quantity of waste generated per person in this study is within the range of that previously reported for Sub-Saharan Africa.

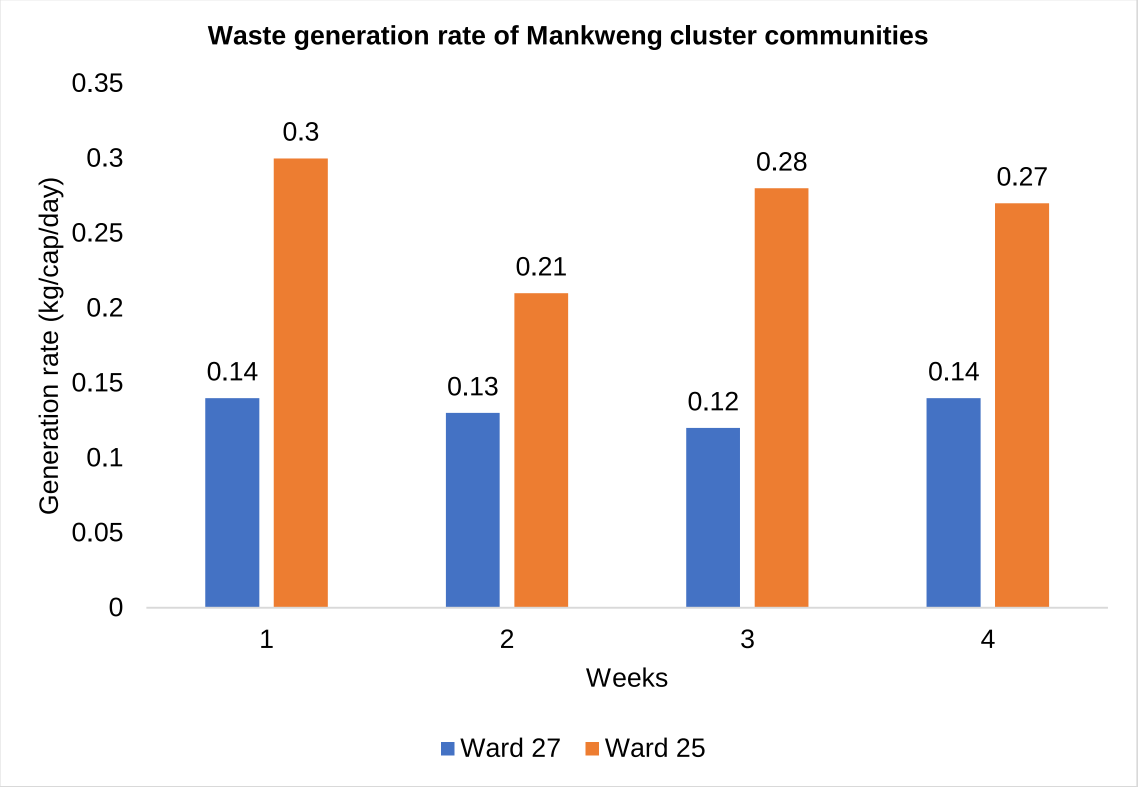


Figure 3.12: Bar graph showing the waste generation rate in Mankweng communities

Table 3.1: The waste generation of Mankweng communities

Week	Ward 27		Ward 25	
	SWG (kg/cap/day)	Waste quantity (kg)	SWG (kg/cap/day)	Waste quantity (kg)
1	0.14	53.22	0.3	75.74

2	0.13	46.49	0.21	72.84
3	0.12	43.5	0.28	71.74
4	0.14	51.91	0.27	70.13
Total	0.53	195.12	1.06	290.45
mean	0.13kg/cap/day		0.27kg/cap/day	
stan dev	0.01		0.04	

Studies show that the average quantity of waste generated per person varies throughout different African villages, towns, and nations. Lagos and Dhaka were reported to generate 0.48 kg/cap/day and 0.3 kg/cap/day of waste per person, respectively (Aguilar-Virgen et al., 2010). Individual lifestyles, seasonality, level of education, culture, affluence, urbanisation, and economic activity have all been blamed for the difference in per capita generations (Premakumara, 2011; Solomon, 2011). Understanding the trends in the generation of SW can help estimate resource needs and the material that might be recovered. Additionally, such information assists in developing collecting techniques and routes for a suitably sized waste disposal facility (Tsheleza et al., 2022).

3.3.2.3 Waste separation

Public participation is widely recognised as an essential element for the efficiency of WM programme, including waste reduction at source and recycling. It has gained significant focus around the world in past few years because of its economic and environmental consequences (Ayodele et al., 2018; Babaei et al., 2015). It is demonstrated from this study that waste separation is still a challenge. Regarding the HSWM practices, in the ward 27, about 76% of the respondents do not separate their waste prior collection or disposal, while the remaining 24% respondents separate their waste prior waste collection, or disposal. On the other hand, in the ward 25, about 84% of the respondents do not separate their waste prior collection or disposal, while the remaining 16% respondents separate their waste prior waste collection or disposal. This reveals that there is high waste separation and sorting in ward 27 than in ward 25. The findings from this study are consistent with those of Roos et al. (2021), with 16% of participants reporting that their households practice waste separation at the source, and

84% indicating that they did not conduct any sort of waste separation at all. Additionally, 83% households did not separate their SW in different types of prior disposal (Yoada et al., 2014). The respondents who separate their waste prior collection or disposal either reuse, recycle or sell them to waste reclaimers. Fifty-five percent (56%) and 26% of the respondents both ward 27 and ward 25 respectively highlighted that waste separation at source is difficult while 74% and 44% of respondents both ward 25 and ward 27 respectively said it is not difficult. The unavailability of the waste collection service and consumption of too much space by the type of waste container required for storage is the greatest challenge in ward 27. On the other hand, in ward 25, the consumption of too much space by the type of waste container required for storage, unavailability of the appropriate storage containers, the mix up of the waste type together during waste collection, and incentives offered for waste separation poses a great challenge to respondents in source separation of waste (Table 3.2). Strydom (2018) found that the desire to separate waste is frequently overpowered by the reality that it is possible to do so, with separation at source facilities and services being unavailable or insufficient. According to Roos et al. (2021), South Africans lack the information, positive attitudes, and societal pressure that would encourage behaviour The most effective strategy to encourage source separation would be to improve source separation services by providing communal waste-type storage bins. Separation of waste at the source could promote HSW recycling and therefore MSWM efficiency (Knickmeyer, 2020; Mian et al., 2017). Furthermore, owing to the upsurge in waste generation because of urbanisation and rising living standards, advice that there should be waste separation at the source has been issued (Fei et al., 2019).

Table 3.2: Why is solid waste separation at source difficult?

Why is waste separation at source difficult	**Ward 27 (%)**	**Ward 25 (%)**
No collection service provided	36	4
Consume too much space	32	28
Time-consuming	10	4
No appropriate storage containers	8	24
The waste type is mixed	6	22

Incentives for waste separation	2	14
Lack of knowledge	6	4

3.3.2.4 Waste storage

Waste storage is an important aspect as it has negative influences on society and the environment, regardless of being a temporary or permanent storage. In this case, the study is limited to temporary waste storage in a household prior collection or disposal. The study revealed that in ward 27, 70% of the respondents use pit holes excavated in the yard to store their waste while in ward 25, both the plastic bags and bins (44%) are equally used to temporarily store waste prior the collection of disposals (Figure .13). To provide and distribute skip containers to rural areas and rural transfer stations, a three-year contractor was hired in 2019–20. However, the project is facing budget limitation (Polokwane local municipality IDP 2019/2020).

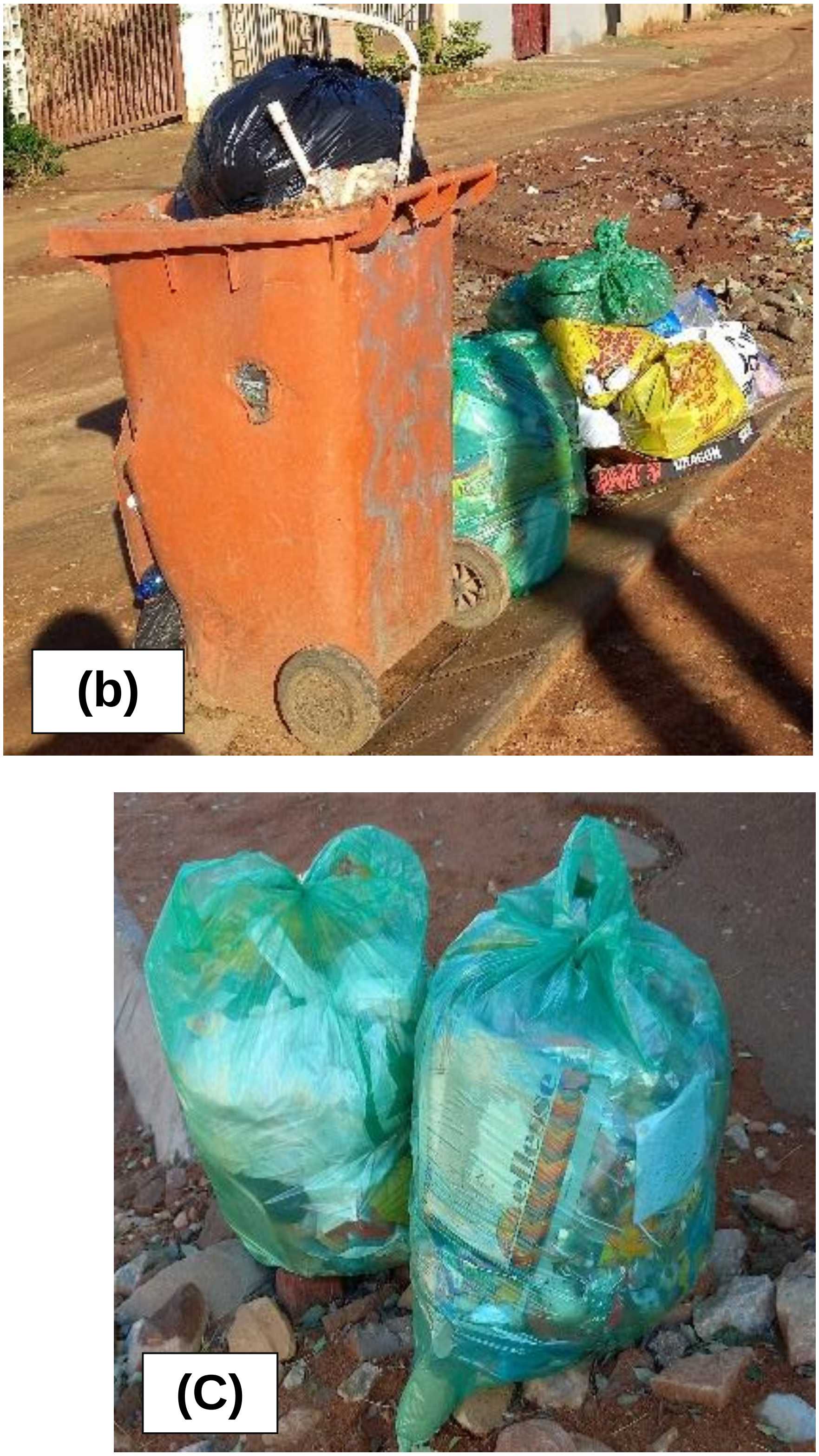


Figure 3.13: Storage containers used (a) plastic bins (c) plastic bags

3.3.2.5 Waste collection

According to the Polokwane local municipality IDP (2019/2020), all 45 wards are receiving EPWP litter picking and collection services. There is a need to expand the weekly waste collection service to other villages in other wards as it is now only available to 47 communities. However, the ward 27 respondents (74%) claim that waste collection service is not available while 26% say the waste collection service they receive is the collection of waste in communal bins located in schools and illegal dumping spots, collected by the waste pickers deployed by the EPWP see figure 3.14. Furthermore, 66% of the respondents claim waste collection service frequency is not sufficient while 34% say it is enough if they can handle the waste independently in their households. During field observation, the researcher notices waste on roadsides, waterways, and shrubs, indicating concern with the frequency of waste removal. Open canals and sewers are being clogged by dumping massive amounts of SW due to the lack of continuous SW collection systems (Abdel-Shafy and Mansour, 2018).

The presence of waste collection services and the type of waste collection method have a big impact on the type of waste storage container utilized in ward 25. Furthermore, 80% of the respondents say that “the once per week” waste collection frequency is sufficient while 20% say it is not sufficient. The suggestion is that at least another day should be added to the waste collection schedule refer to figure 3.15. According to Ngeleka (2010), 53% of respondents want waste collected twice a week as this will reduce illegal waste dumping in the area. Because they will be unable to keep the waste until the next collection, which will be in 7 days. The enumerated service users that pay the collection fee reported that they are satisfied with the collection frequency of once per week (32%), neutral (35), while 33% said they were dissatisfied (Seng, et al., 2018). Most respondents (72%) were "satisfied" with the SW collection method, while (28%) were "not satisfied.

Figure 3.14: Waste collection by EPWP waste pickers

Figure 3.15: Door to door waste collection service

3.3.2.6 Waste handling

The study findings disclosed that there is a huge difference in how waste is handled in both ward 25 and ward 27 from a missed collection or no collection service (Figure 3.16). The SWM is influenced by the presence of the SW collection service. The ward 27 mainly uses two methods to handle waste which are burning of waste and disposal of waste in illegal spot with no prior treatment. On the other hand, in ward 25 most respondents prefer to wait for the next collection service day or to transport the waste to the transfer station called Mankweng transfer station. Few of the respondents in ward 27 opt for transporting waste to a landfill or transfer station due to lack of proper transport and associated cost while in ward 27, most respondents do not have the option of burning waste or disposing it on the illegal spot as they have the benefits of receiving waste collection services. The household income and employment status in ward 27 allow the respondents to be categorised as the low-income group as their income is mainly from R1001 to R3000 per month. Most of these respondents indicated that they are unemployed and/or pensioners. Moreover, the unavailability of a waste collection service causes the respondents to burn the waste or dump it in illegal spot. In ward 25, most respondents indicated that they earn at least R7001 and more. Furthermore, they are either employed, self-employed, or pensioners. This enables them to have the ability to either transport their waste to the transfer station or designated disposal site by themselves. Moreover, their locality receives waste collection service, they can buy extra refuse bags to store waste until the next scheduled waste collection service. Burning of waste without precaution also generate contaminants, swelling the population's health concerns (Tue et al., 2016). In the Mexican municipality of Huejutla, about 24% of households burnt the overall waste generated was burnt, with 90% of those living in rural settlements with no MSW collection system. Black carbon (BC) is produced. This technique pollutes the environment and adds to the GWP (Reyna-Bensusan, et al., 2018). It is best to prevent open burning and substituted with proper and sustainable technology to reduce environmental contamination and public apprehensions, according to a review of scientific literature.

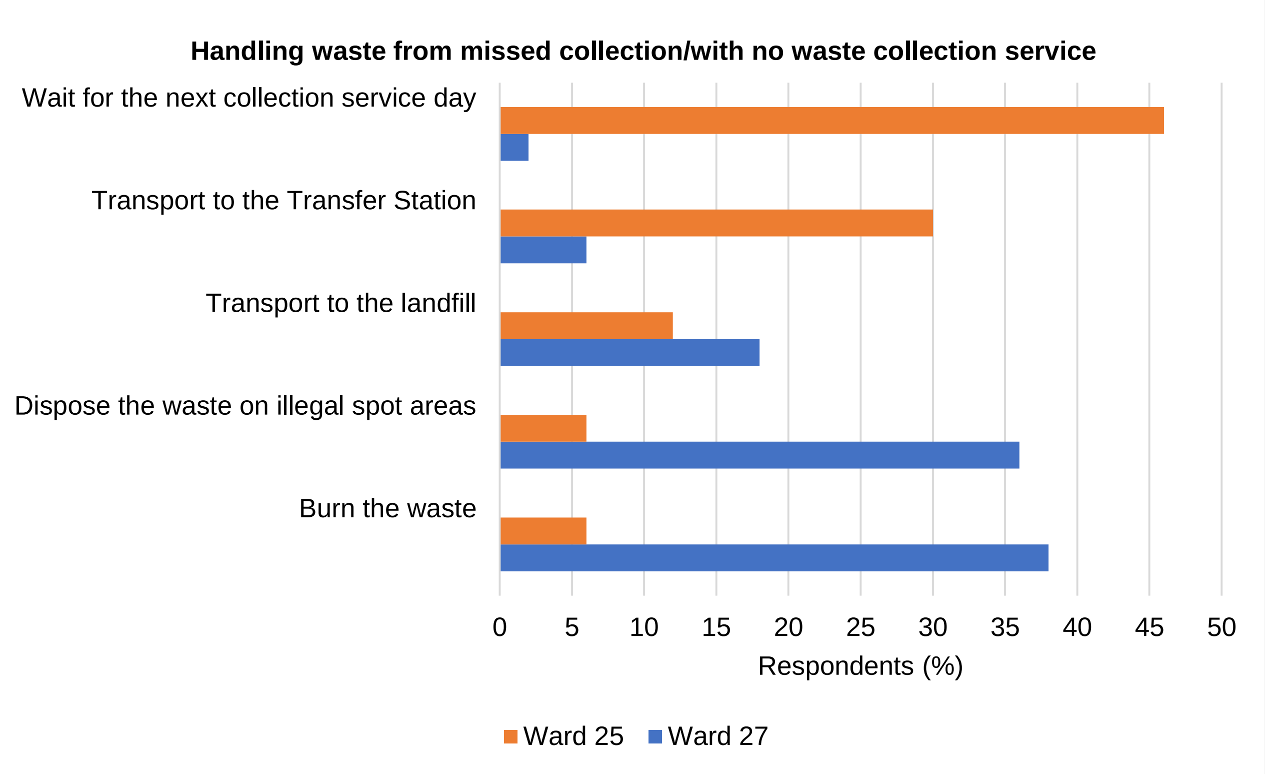


Figure 3.16: Handling of solid waste from a missed waste collection service or with no collection service?

3.3.2.7 Waste recovery and recycling

It is widely anticipated that increased education and awareness of recycling procedures and prospects will motivate households to separate and recycle their waste at source (Knickmeyer, 2020; Razali et al., 2020; Strydom, 2018). However, there are a diversity of features that can affect the effective contribution in waste separation methods at the source (Roos et al., 2021). Furthermore, according to Guo et al. (2021); Knickmeyer (2020) and Mian et al. (2017), recycling is a cost-effective substitute to progressively expensive treatment such as thermal treatment. Formal recycling plans are not available in both ward 25 and ward 27, according to both the respondents and the researcher's field observations (Mankweng cluster). This is like the analysis in Kerbala (Abdulredha et al., 2020), where despite the vast volumes of MSW generated in the city, predominantly throughout religious occasions, local institutions lack a strategy that advocates an MSWM hierarchy that must encompass waste minimisation through reduce, reuse, recycle and recovery. Plastic and metal make up most of the recyclable items. (Figure 3.17). Over the past ten years, the informal recycling industry has expanded significantly. Scavengers now actively search through and recover recyclable materials from collection places, transfer stations, and waste locations (Schoeman, 2018).

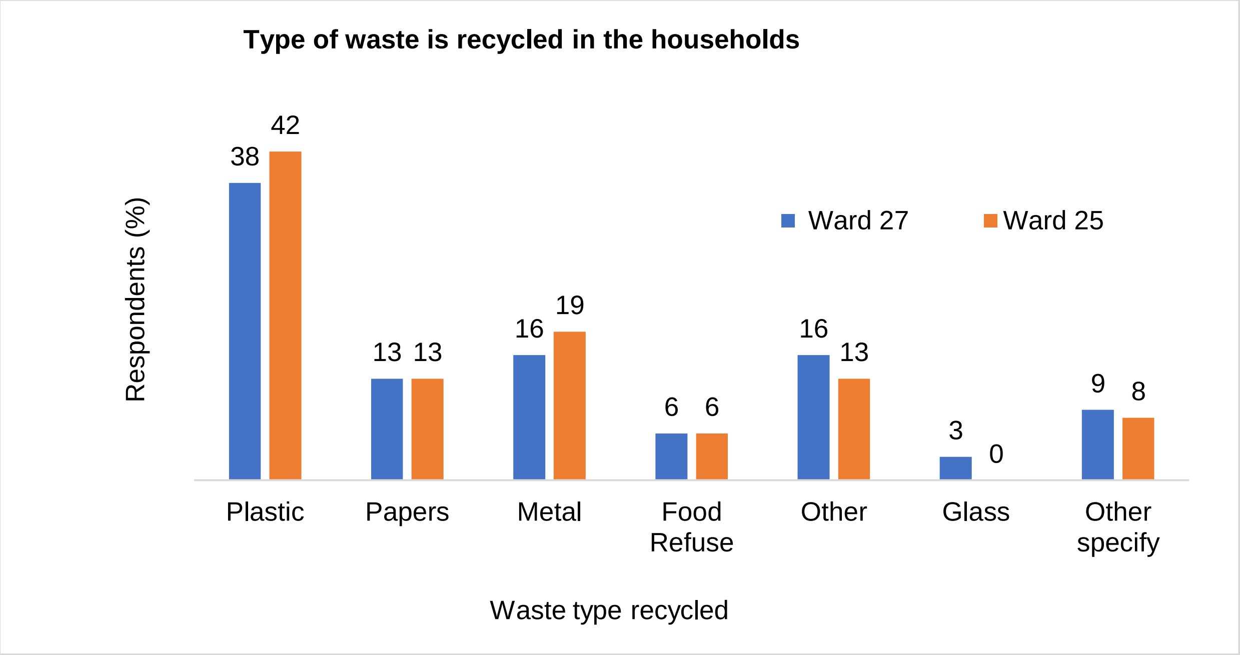


Figure 3.17: Type of solid waste is recycled in the households.

This presents a potential recycling opportunity as well as a compelling rationale for developing waste recycling markets. The recyclable HSW was mixed in with other types of waste in one container, picked up by a waste collection truck, and dumped in a landfill; there was no indication of separation at the source. To increase recycling and lessen waste carried to disposal locations, Mian et al. (2017) recommends that separation of waste, collection and recycling be included in municipal obligations. Additionally, Schwarz-Herion et al. (2020), reported that 90% of the German population participates in the waste separation plan, recycling programmes in most industrialised and successful nations, including Germany, began with education and community engagement.

3.3.2.8 Waste disposal

The environmental effect of WM is not restricted to open disposal. Table 3.3 illustrates the waste disposal method used by ward 25 and ward 27 community members in

Mankweng cluster. Most of the respondents (61%) from the ward 27 indicated that they dispose their waste on illegal spot. On the other hand, in ward 25, most respondents said that their waste is collected and taken to the landfill or transferred by the municipality waste service. Twenty percent (22%) of the respondents claimed that they dispose of their waste on illegal spot (see table 3.3). Waste is usually dumped at public depots in certain parts of Nasarawa State, Nigeria, followed by dumping in backyards and any open space (Ogah et al., 2014). For enhancing waste recovery and final disposal on a worldwide scale, educational as well as financial support are essential (Ferronato and Torretta, 2019).

Table 3.3: Type of waste disposal method do you used.

Type of solid waste disposal method	**(Ward 27)**		**(Ward 25)**	
	N	**%**	**N**	**%**
Bury the waste inside the yard	37	33	3	2
Dispose of waste on illegal spot areas like rivers, bushes, canals, etc	69	61	32	22
The waste is collected and taken to the landfill	8	6	97	76
Total	113	100	127	100

3.3.3 Waste perception on disposal sites

3.3.3.1 Perception on open and illegal dumps

Illegal dumping of SW

Ninety-four percent (94%) of respondents from ward 27 believe there is illegal SW dumping, while 84% of participants from ward 25 believe there is no illegal SW disposal. The researcher's field observations contradict the ward 25 settlement respondents' claims. Various types of SW were found discarded on unauthorised land areas such as under bridges, in bushes, under road signs, and alongside the communal skip bins, according to the study. See the below for further information (Figure 3.18). Respondents from ward 25 denied the allegations, indicating that they did not want to be associated with the illegal dumps and blamed passers-by. The findings are in line with those of

Ngeleka's research (2010), who found that 55% of respondents indicated that unlawful dumping occurs in their area, while 45% indicated that there is no illegal dumping. The vast numbers of individuals surveyed, however, denied having any participation in the situation. The blame has been placed on the neighbours and passers-by (Ngeleka, 2010). Additionally, the field observation made are like what Mohale (2021), ascertained that resident of Olievenhoutbosch township disposed of their waste alongside the bins placed by the municipality.

Various agents collect the illegally dumped waste. In ward 27, 66% of respondents reported that waste is handled and managed by natural agents such as wind, rain, soil, and sun, while 32% indicated that formal waste pickers from Polokwane Local Municipality collect waste from major roads and bridges, and 2% indicated scavengers collect illegally disposed waste. In ward 25, 82% of respondents indicated that the illegally disposed of SW is collected by formal waste collectors under the EPWP from Polokwane local municipality, while 14% and 4% of respondents believe that waste is handled, managed, and collected by nature and scavengers, respectively (Figure 3.19). The researcher's field observations found that the illegally dumped of SW is handled by formal waste collectors, nature, and scavengers. However, because scavengers are concentrated at the landfill site where all SW from the local municipality is disposed of, there are few scavengers in residences. Waste pickers collect recyclable and reusable HW in Dhaka, Bangladesh, by sorting through the waste in the bins. Scavenging operations were once again witnessed sorting at the open disposal sites, raising the danger of disease transmission (Ferronato and Torretta, 2019).

Causes of illegal waste dumping

The illegal dumping of waste is a challenging WM issue for governments around the world (Niyobuhungiro and Schenck, 2022). It poses threats to human well-being and the ecosystem (Du et al., 2021). The study reveals that ignorance of people, long distances to the landfill site and transfer station, no waste collection service and lack of knowledge in SWM are the most rated causes of illegal waste dumping in the Mankweng communities. Ignorance of people being the lead in both the communities. One respondent said that *“people dump waste on the streets, open spaces and under* *bridges and do not care because it is not within or close to their yards.”* Refer to figure 3.19. This type of ignorance was reported by Kubanza (2020), that although municipality does manage SW, the community’s involvement in SWM is limited and there is negligence of responsibilities by the community members towards SWM. Most of the respondents from both wards indicated that they lack knowledge on how to manage SW. However, the IWMP 2020 reported that there are communal skip bins distributed in these communities, a buy-back facility and transfer station in Mankweng cluster. Moreover, the EPWP pick up and sweep waste on the streets, roadsides, and illegal dump hotspots but community members still dump their waste alongside the bins (figure 3.19). This reveals the act of ignorance than lack of knowledge. These results are like the one reported one by Kubanza and Simatele (2020), where some participants are aware of the Garden site recycling centre and admit not to have used it, saying it is far. Other participants claimed that insufficient waste collection days and lack of enough bins to store waste generated in a week leads to people disposing waste in open areas to make space for waste generated prior the scheduled waste collection day (Kubanza and Simatele, 2020; Ngeleke, 2010). The ward 27 respondents strongly indicated that the unavailability of waste collection service is the root cause for illegal waste dumps in their area.

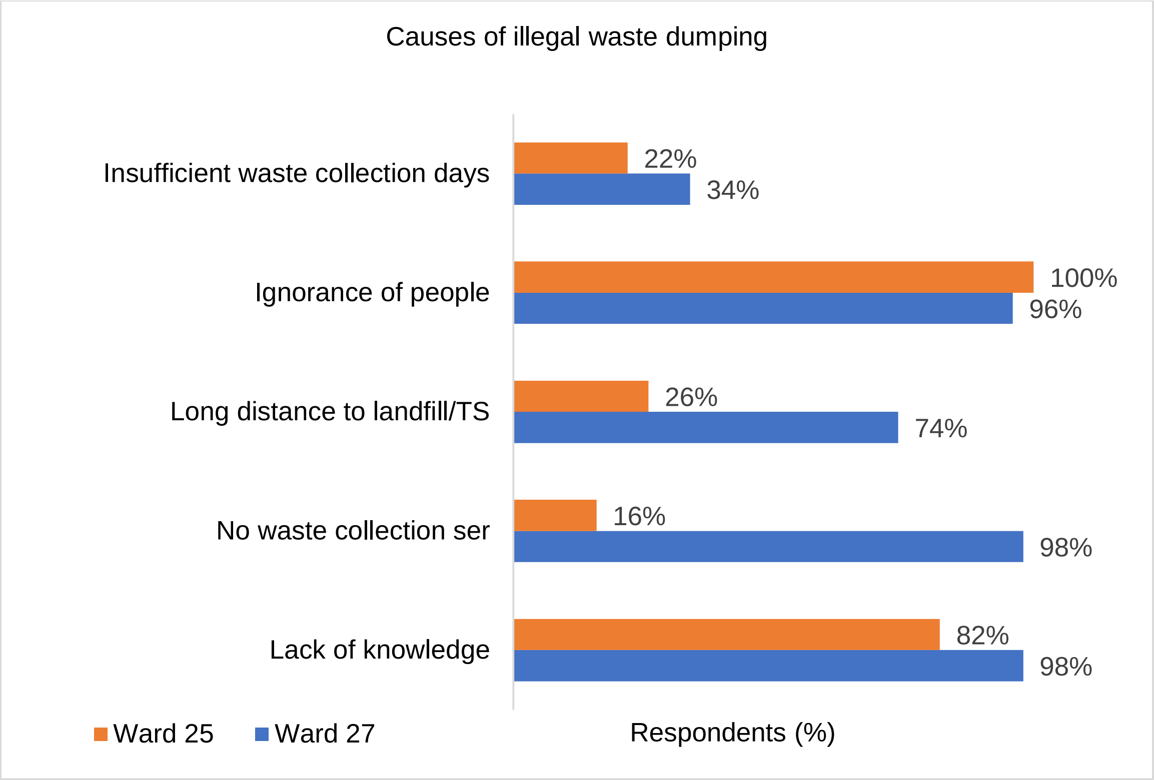


Figure 3.18: Causes illegal waste dumping

Figure 3.19: (a): images of illegal waste disposal and littering in different areas from field observation by researcher. (a) at bridges (b) alongside the communal bins (c) and (d) open space

Most ward 25 respondents suggested that the municipality should provide SWM education and awareness and provide temporary storage containers to households. On the other hand, most of the respondents from ward 27 suggested that the municipality must place bins at the illegal waste dumping hotspot, recovery/recycling facilities be built nearby and SWM education and awareness be provided to the community members. For the community to engage in recycling and SWM, SWM education is crucial. As a result of NGOs and civil society organisations assisting community-based organisations in educating people about the responsible management of SW and demanding improved MSWM, awareness has gradually increased (Kubanza and Simatele, 2019) refer to figure 3.20.

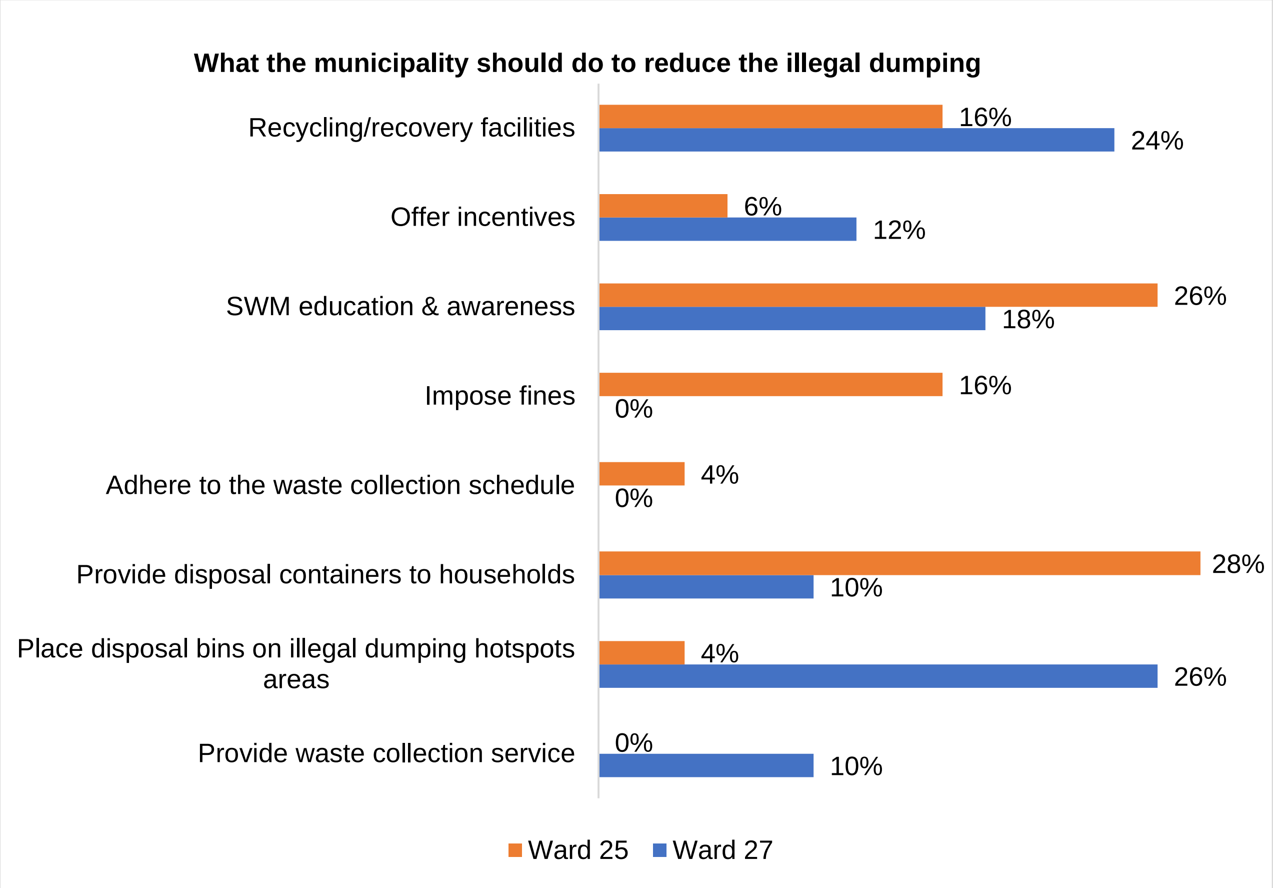


Figure 3.20: opinions of the respondents on what the municipality should do to reduce illegal dumping of solid waste.

As much as SWM is the responsibility of the municipality, citizens hold equal responsibility as the municipalities. Most respondents in both ward 25 and ward 27

(78%) indicated that they need SWM education and awareness to improve SWM in their areas. They also indicated that reporting illegal waste to municipal stakeholders will reduce the illegal dumping of SW (20% and 22% respectively). Few respondents (2%) in ward 27 indicated that there should be a waste collection service in their area (figure 3.21).

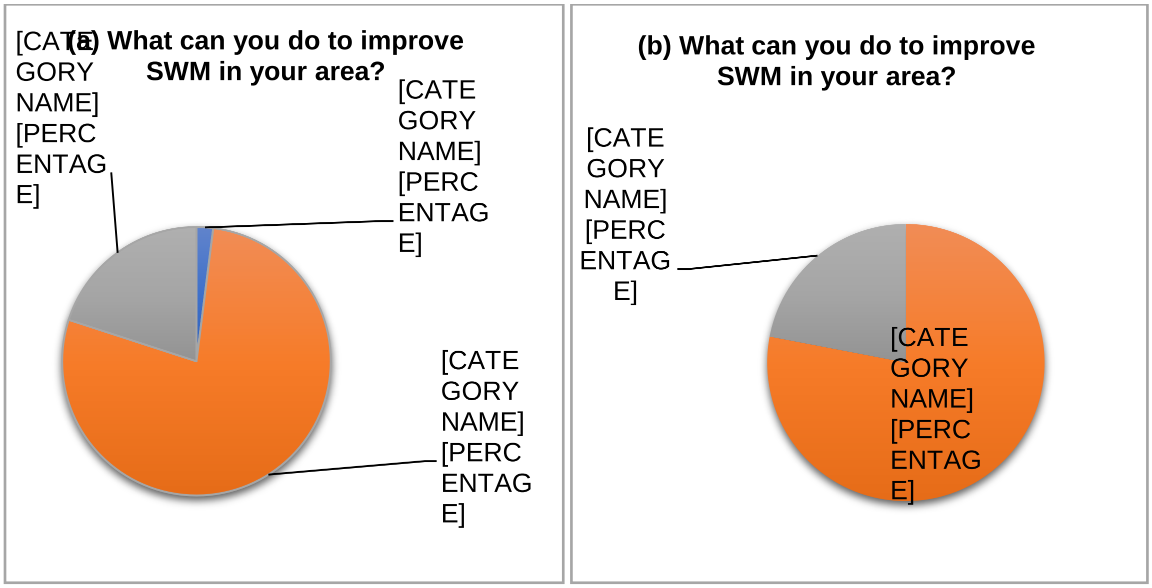


Figure 3.21: what can you do to improve SWM in your area? (a) ward 27 (b) ward 25

3.3.3.2 Perception on the location and construction of potential landfill.

According to the Polokwane local municipality IDP (2019/2020), one is active and expanding into one cell. One is currently under construction. However, there are still two years left in the working landfill's existence.

a) Distance to the nearest existing landfill

Figure 3.22 shows that most respondent (28%) in ward 25 believe that they are 34km away from the operation landfill site. While most respondents (20%) from the township believe they are 33km and 37km distance apart from the operating landfill. The operating Weltevreden landfill site is said to be 34km to Mankweng community (PLK IDP, 2019/2020).

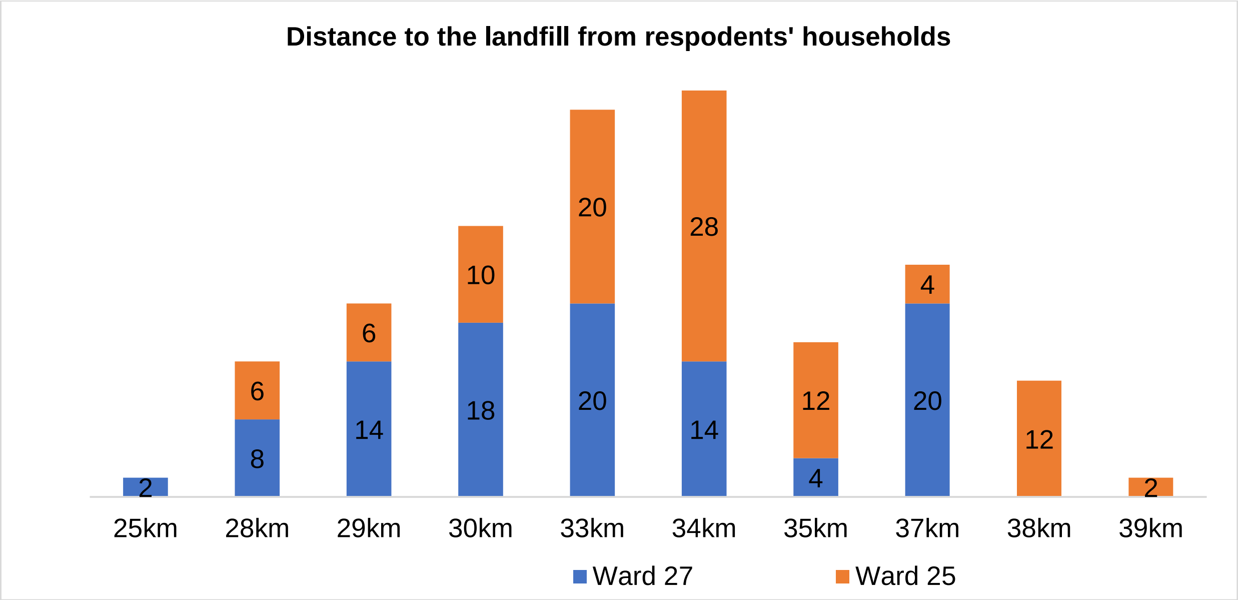


Figure 3.22: Distance to the landfill from respondents' households

b) Having potential landfill close to the residents' settlements

As required by the National Environmental Management Act (NEMA) Act 107 of 1998, sustainable development calls for the integration of social, economic, and environmental aspects in decision-making, planning, implementation, and evaluation (Rural Development and Land Reform, 2011). Urbanisation, industrialisation, population growth, and higher living standards all result in increased SW generation (affordability). This necessitates a redefinition of planning to better serve societal needs. The having potential landfill site close to community residents is being critiqued by the community members in social, environmental, and economical perspective.

Socially sustainable perspective

According to the survey, by Khumalo (2018), residents of the Sobantu rural community believe that having a dumping site nearby is a positive thing because it will encourage people to dispose of their waste in the proper location. The citizens of the township, however, have the opposite opinion. The assertion that a dump is present nearby is unpleasant to witness. These conflicting conclusions from the study area like those where most of the locals have protested before and continue to protest the closure of the nearby landfill site, while others argue that it has undoubtedly been a source of income for most of the underprivileged households. This demonstrates the dump site's acceptability and approval by the participants from the societies. One of the biggest draws for people to live close to landfill sites, whether or whether it poses a health risk, is the accessibility of infrastructure designed to support landfill operations. A further indication that people only perceive value in the dump site if there is progress to sound development is most of the respondents' aversion to leaving the neighbourhood. According to Babalola and Busu (2010), public opposition to waste disposal facilities is lower when they are situated away from residential areas. Thus, neither crowded urban or rural areas should be home to waste disposal facilities. Refer to figure 3.23.

While most of ward 25 respondents are opposed to the potential landfill site in the area, they argue that people will start to see their area as a dumpsite and start to litter waste on the streets and inappropriate places. According to most of ward 27 respondents' perceptions, the presence of the landfill will be good because littering and illegal disposal will no longer be issues and their surroundings will be clean. Nefale's (2018), field observations conducted at the Thoyandou Block J landfill site, showed that there was extensive littering at the site. Most of the littering was seen during the operation period, maybe due to the wind. Additionally, Njoku et al. (2019), revealed that there is presence of littering in the neighbouring areas of the Thoyandou landfill site, which is an issue to the residents nearby. Sankoh et al. (2013) evaluated the effects of the SW landfill site on the environment and public well-being in Freetown Sierra Leone. The research revealed that the existence of the landfills raised the volume of waste and littering in the neighbourhood. These findings somehow agree with the opinions of the respondents in this study. The respondents in both areas reported that the potential landfill will put the safety of waste pickers and children living nearby at risk. They believe that this is because the waste pickers are not dressed appropriately, and the kids will be tempted to slip over and play in the landfill. They will be exposed to dangerous toxins there that might put their lives in jeopardy. Studies by Khumalo (2018) and Viljoen et al. (2021), have examined this perception. Most of the locals in both areas indicated that a neighbouring landfill site would increase traffic and noise pollution in their neighbourhood. Their tranquillity will be disturbed by the ins and outs of the truck vehicles transporting waste. The findings by Njoku et al. (2019), however, contradict this viewpoint. According to the authors, although most people residing far from the landfill site reported that noise pollution is a severe issue even though it does not directly come from the landfill site but rather from other sources, most people residing closer to the landfill site claimed that no type of noise pollution exists.

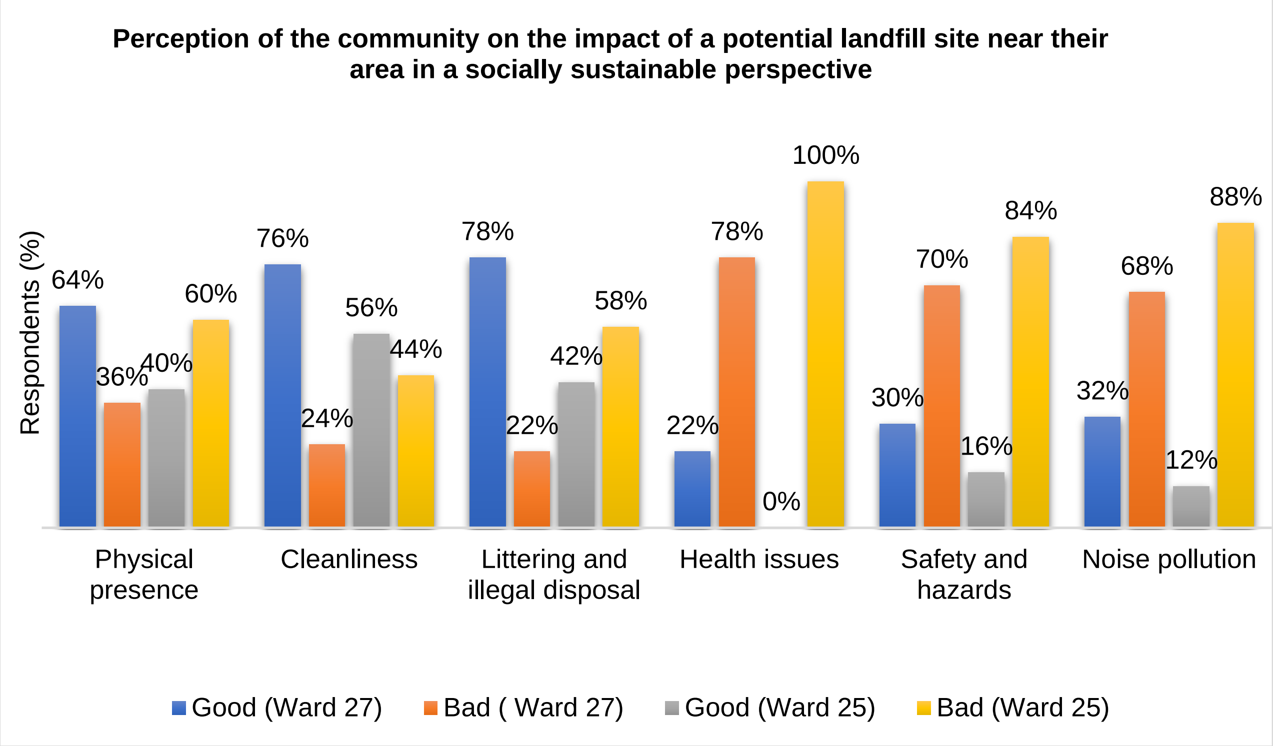


Figure 3.23: Perception of the community on the impact of a potential landfill site near their area in a socially sustainable perspective

Environmentally sustainable perspective

Environmental sustainability includes a complex component called SWM that, if handled incorrectly, can lead to numerous environmental problems. Disposing of MSW is getting more difficult, especially in developing nations. Most respondents from both the ward communities stated that they are worried about the landfill's potential to damage their local air with foul odours and dust. Consequently, having a dump nearby will have an impact on their health refer to 3.24. The opinions of the respondents support the conclusions of Khumalo's (2018) study that reported that when one enters Sobantu area, the smell is the first thing they notice. Njoku et al. (2019), added that 78% of the respondents who resided close to the landfill site reported substantial air quality contamination and the fact that they frequently smell something foul that they think is coming from the landfill site. As a result, it is undesirable to reside there or operate a business there.

In addition, the detrimental circumstances have had a disastrous effect on business. (Khumalo, 2018). As a result of the airborne emissions from landfills, such as carbon dioxide (CO2), methane (CH4), and volatile organic compounds (VOCs), landfill employees and others living nearby may have health effects (Njoku et al., 2019).

Water is a limited resource. Most respondents reported that water is a valued and limited resource. They claimed that the quality of the water they drink is threatened by the presence of a dump nearby. The TBJ dump site's ground water was found to be contaminated in terms of various metrics, bestowing to the results of the ground water quality study. Additionally, research has demonstrated that groundwater contamination from landfills is unavoidable due to leachate, which seeps into the ground through membrane defects in sanitary landfills and contaminates the water due to its high bacterial content (Njoku et al., 2019). If it is not properly constructed, maintained, and managed, even a tiny waste site has the potential to negatively affect the groundwater. Therefore, maintaining the groundwater system is crucial to prevent the contamination of groundwater resources (Njoku et al., 2019).

Most respondents in both wards are opposed to the landfill being built nearby. They indicated that it might be problematic since it could contaminate the soil of the nearby areas, leaving no suitable grass for grazing and the soil contaminated with toxic materials. According to Dickson (2012) and Khumalo (2018), employees stomping on the earth's surface and the usage of large machinery like trucks and bulldozers contribute to soil erosion in the vicinity, further degrading the land. The landfill is dangerous because it fosters the growth of dangerous insects, reptiles, bacteria, and viruses. Solid waste encourages the spread of disease among wildlife and humans (Aneseyee et al., 2020; Weldeyohanis et al., 2020). Most respondents in both areas believe that the potential landfill site nearby will be a source of fire outbreak. They believe that burning paper and plastic waste could start an unmanageable fire while minimising the quantity of disposed waste at landfills. The opinions of the respondents are valid because research from Nefale (2018), Khumalo (2018), and Njoku et al. (2019)

shows that waste is typically burned at landfill sites by waste pickers who are looking to recover valuable metals. The findings of Ayuba et al. (2013) differed from those of the authors in that they showed that insufficient compaction can sometimes trap methane from buried waste, which can then ignite fires continuously.

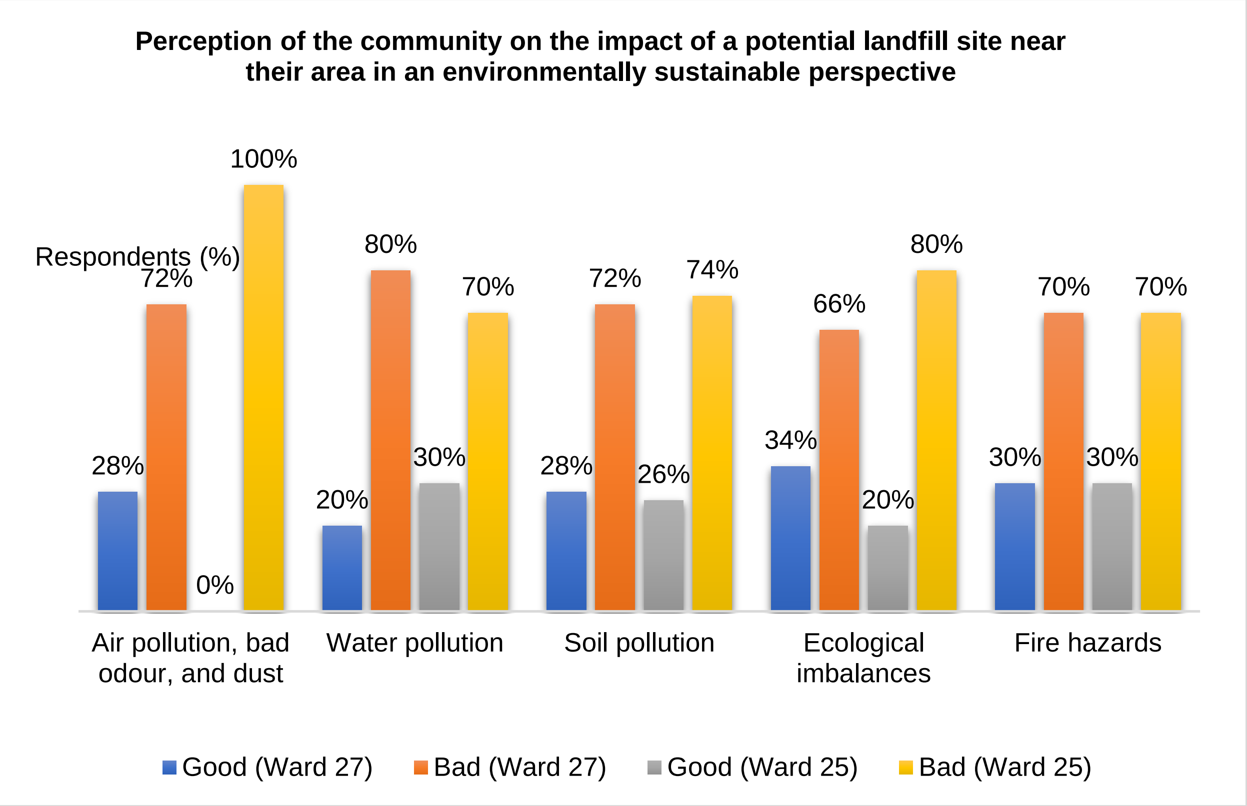


Figure 3.24: Perception of the community on the impact of a potential landfill site near their area in an environmentally sustainable perspective

Economically sustainable perspective

Most respondents indicated that they live at least 30 kilometres away from the landfill that is currently in operation (figure 3.25). According to the principles of agglomeration economies (theories of minimum-cost location), the need to reduce transportation costs also influences the choice of location (Capello, 2011; Khumalo, 2018). Most respondents are in favour of a prospective landfill site nearby. Most of them reported that, in comparison to the currently operational landfill, it would be less costly to transport waste to the potential disposal site by themselves. According to Khumalo (2018), people prefer to live in an area that is appropriate for both their jobs and other daily activities. Most of the time, economic factors cause spontaneous settlements, and many residents of the nearby municipalities depend on the dumpsite for work. Many waste pickers in the Sobantu area and neighbouring areas now have employment options thanks to the New England Landfill site. The New England landfill site has undoubtedly existed as a source of revenue for numerous underprivileged households, even though some neighbourhood members who are not waste pickers have expressed support for its demolition. Thus, there can be conflicting opinions about whether the site should be shut down. Naidoo (2009), reported that the NIMBY, or community disapproval to the location and MSW infrastructure operation adjacent to their vicinity, are generally established by the poor neighbourhoods in informal communities who fear that their areas are being aimed for landfill sites.

Landfilling as a method of SWM provides nearby towns with a variety of financial advantages. The establishment of private businesses for the operation of landfills, waste-to-energy production, recycling separation, and composting, among other activities that create jobs and stimulate local economies and improve income distribution, are among the indirect economic benefits (Tomaszewski, 2017). The tourism industry is impacted by this. The profitability of properties in the neighbourhood was evaluated. Most respondents in both the ward communities indicated that the development of a potential landfill site in their area could affect the land and housing value of their communities. The business has suffered because of the unfavourable effects of the dump site, which is foul-smelling and intolerable, on the number of customers and visitors (Khumalo, 2018). However, few of the respondents indicated that they do not think the potential landfill site could affect their housing value as they do not plan to move out. Njoku (2019) attempted to ask respondents about the influence of the proximity of the landfill site in their community. The study concluded that 54% of the respondents residing near to the landfill site noted that they face problems in the sales of their property.

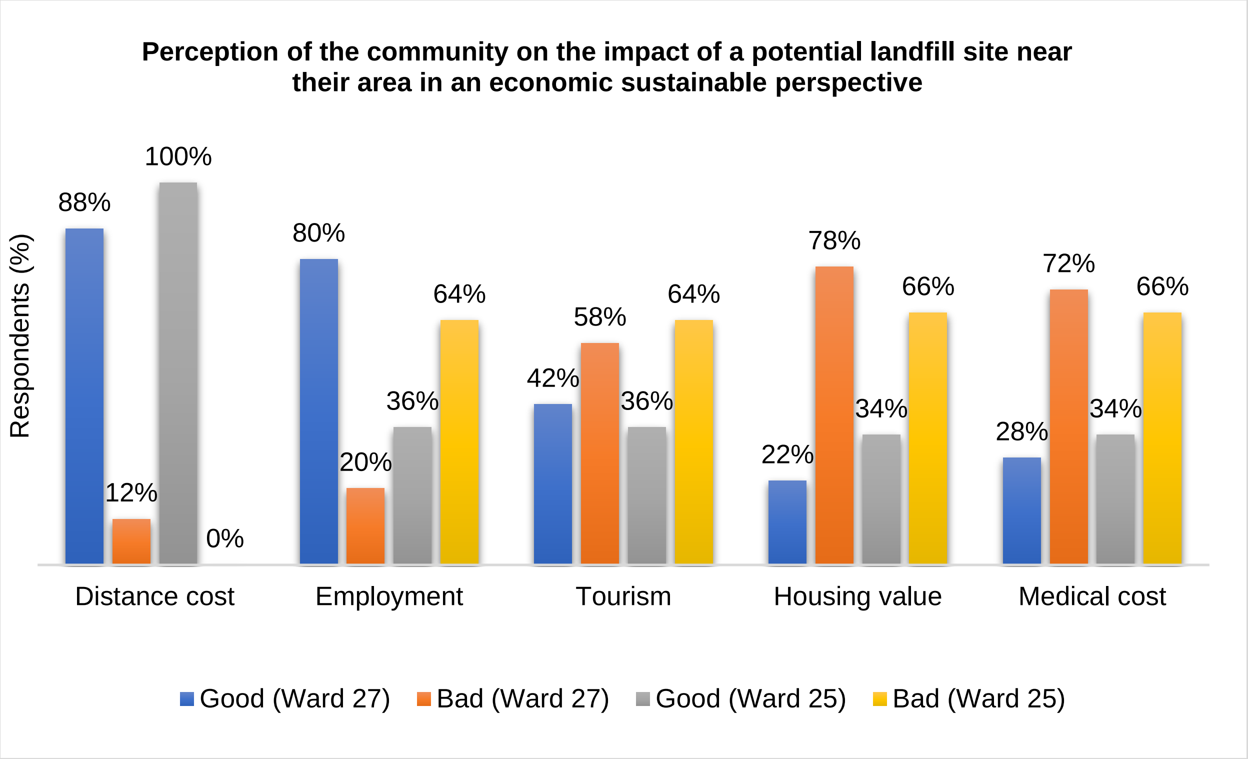


Figure 3.25: Perception of the community on the impact of a potential landfill site near their area in an economically sustainable perspective

3.4 Conclusion

This study's objective was to evaluate SWM practices and perceptions in the Mankweng cluster in Polokwane local municipality, South Africa. The study used mixed methods to collect data. Questionnaires were administered to sampled Mankweng residents and observations were conducted to add and validate what was said by the respondents. The results revealed that the practice and perception variation on HSWM in the communities (village and township) indicated that the difference in SWM service delivery has an influence on these communities. It is found that the waste generation per capita is different in the village and township. The township proved to have a higher waste generation per capita than the village. This might be due to household income differences, and lifestyle behaviour. Food waste contained the highest generation quantity among the other waste type. Although the income of both the village and township are within the low-income category, the slight difference between the household incomes in these two areas has been shown to have a substantial influence on the waste generation quantity. In general, as the results are not considerably different from what has previously been observed, comparing the composition and generation rates of wastes at varied income levels can produce results that can be used for SWM aims. Sorting and separation of waste at source is not highly practiced and respondents showed that they have difficulties in waste sorting and separation. In the village, dug pits are used to store their waste while in the township plastic bins and refuse plastic bags are used to store waste. Waste collection in the village is done when the communal bins are full, while in the township waste collection happens once a week. Waste missed from collection is illegally dumped in the village while, in the township, most households wait for the next collection service. Recycling is not highly practiced in both communities. There is variation in waste quantities between the two communities. There is illegal dumping at both the communities and the reason behind is that there is no waste collection service. The absence of bins, people's ignorance and poor SWM knowledge are also some of the reasons. This study emphasises the value of waste separation, recycling, and education awareness campaigns in achieving sustainable SWM. The study concludes that to attain sustainable SWM in households, the municipality, private business stakeholders, and community members need to unite and engage as they are the vital key stakeholders to achieving this goal. This study's outcome highly suggests that more recycling activities, and SWM educational awareness are fundamental basis towards zero-waste to landfill, circular economy and sustainable SWM. Additionally, the municipality needs to seek investments to promote SMMEs and improve its existing SWM services.

CHAPTER FOUR:

Forecasting Municipal Solid Waste Generation in Polokwane local municipality, South Africa.

Abstract

Solid waste (SW) is generated at an uncontrolled rate, primarily because of population increase, urbanisation, economic growth, and modern-day lifestyles. This result in poor management of solid waste. Therefore, waste generation projection is necessary to make proper planning and formulation of relevant policy measures towards sustainable solid waste management. Therefore, the goal of this study was to forecast the solid waste generation from 2022 to 2026 in the Polokwane local municipality. Correlation was used to determine the relationship, and multicollinearity between the solid waste generation, population, unemployment rate, literacy rate, and gross domestic product. Afterwards, multiple linear regression was used to forecast solid waste generation quantity. The results of the study have showed that multiple linear regression model used for forecasting waste generation in Polokwane Local Municipality yielded coefficient of determination (R^2) of 0.88, with RMSE of 50690.2 ton/year and $p<0.00$. The model was significant ($p \leq 0.05$) and was used to forecast future solid waste generation rate. The model showed that in future (2023 to 2026) the amount of municipal solid waste is set to increase leading to the need for construction of a new landfill site.

Keywords: solid waste generation; multilinear regression model; population; unemployment rate

4.1 Introduction

Projections are a crucial component of the waste management (WM) planning process. Making wise decisions requires decision-makers to have a clear understanding of the scope and dimensions of the problem. This is made possible by an accurate prediction of the production of various waste type. In order to explain the creation of specific waste regulation strategies as well as the development of waste recycling infrastructure and collection services, projections are frequently used. Utilizing socioeconomic and other explanatory variables, the multilinear regression approach uses these elements to explain and forecast increases in waste production. This strategy tries to show the possible casual links between those components for the forecast of waste generation in addition to making predictions about waste quantities. Among the explanatory parameters used to forecast the rate of MSW generation include household size, housing type, age range, occupation, energy usage, consumer price index (CPI), gross domestic product (GDP), education, religion, locality, and weather conditions (Johnima et al., 2022). However, for this study variables such as employment, education, household size and population are the focused ones. For instance, other studies have demonstrated that population and income are an influential factor in waste generation (Liu et al., 2019).

Waste generation increases as the population increases leading to villages expanding into towns and towns into cities (Ogola et al., 2011). According to Soni et al. (2019) planning is essential to have effective and positive management of SW generated. It is a critical element in management in a short-term and long-standing period. Kulisz and Kujawska (2020) has stressed out on the importance of developing effective planning strategies and implementing sustainable development, identifying relationships between factors influencing the MSW generation and forecasting waste demand play a key role. Soni et al. (2019), emphasised that it is a vital requirement for effective WM to compute a precise forecast of the amount of waste generated.

The forecast of the amount of MSW promotes efficient strategic planning and procedural of the waste collection system (Soni et al., 2019). Hence, forecasting of MSW generation has gained recognition (Al-Salem et al., 2018). SW predictions derived from predictive mathematical models are viewed as a critical tool for decision-makers, policymakers, and stakeholders to build effective and ISWM plans (Abbasi and El Hanandeh, 2016). Modeling MSW generation based on inducing factors is a critical challenge in SWM because it allows for more precise projections of future MSW generation (Bosire et al, 2017). Upon establishing MSWM plans, it is critical to have a comprehensive consideration of MSW status (Liu et al, 2019). According to Kulisz and Kujawska (2020), predicting the trends of waste generation in MSW production in fast-growing regions can be challenging, especially given the numerous factors involved, which includes population growth and migration, the magnitude, and the trend of municipalities' households, or variations in the labour market. Suthar and Singh (2015); Trang et al. (2017); and Hidalgo et al. (2019), elaborated that the amount of SW generated is mostly influenced by the sociodemographic and economic parameters. Moreover, these parameters are key players in defining the composition of waste of an area (Kulisz and Kujawska, 2020). Soni et al. (2019), advised that to develop an effective WM system, it is fundamental to make predictions about the amount of waste generated in that area. The advantage of making such a prediction leads to proper disposal in landfills, and recycling facilities, and the development of efficient operating waste collection infrastructure (Soni et al., 2019). An excessive or deficient collection of SWs and insufficient or more than treatment and disposal facilities availability are normally caused by the incompetency of Inaccurate waste generation predictions (Sonia et al., 2019).

According to Abbasi and El Hanandeh (2016), there are various forecasting methods with a wide variety of factors or variables used in SW generation. The mostly used methods are descriptive statistical models, regression analysis, time series analysis, and artificial intelligence methods. Additionally, more of the methods used for modeling the estimation of the current and the future SW generation rate is adaptive neuro-fuzzy inference system (ANFIS) (Soni et al., 2019), system dynamics (Popli et al., 2017), artificial neural networking (Soni et al., 2019), grey modeling technique (Intharathirat et al., 2015) and the multi-linear regression method (Al-Salem et al., 2018). These procedures are useful in estimating the quantitative relationship between dependent and independent variables. Although these techniques have been successfully explored in towns and villages of the developed countries, there are still few studies that has attempted to emulate this in the developing countries, mainly due to insufficient waste collection efforts. Consequently, there is inadequate information on the amount of waste produced in small towns and villages and this impedes efforts to forecast, develop policies, and make informed decisions on management of MSW. Thus, this study seeks to bridge the information gap by forecasting MSW generation using simple statistical modelling approach (correlation and regression) in Polokwane Local Municipality, South Africa. The objectives of the study include:

- to determine the relationship between solid waste generation in terms of GDP, unemployment, literacy, and population growth.
- To estimate how much solid waste will be generated from utilising the regression model from 2015 to 2026.

4.2 Methods and material

4.2.1 Polokwane local municipality’s solid waste management status quo.

The Polokwane local municipality currently have two landfill sites, namely sites namely Weltevreden (23^{0}56”50’S; 29029”37’E) and Aganang. Weltevreden is operational and the other is still under construction. It supplies WM services such as waste collection door to door, at communal skip bins, street sweeping, and from illegal waste disposal sites to all its wards. The collected waste is transported to the landfill site, then recycling is done by take place by informal waste reclaimers or pickers at the site. At the operating landfill (Weltevreden), there is a weighing bridge that is used to record the waste delivered at the landfill site. The delivered waste is not categorised by the origin source such as clusters but by the type of waste source such as households, commercial/business, garden, industrial, etc.

4.2.2 Data collection

The Polokwane local municipality landfill site started weighing and recording the quantity of waste they receive daily from March 2015 to date. Table 4.1 shows the historic data on waste generation yearly for Mankweng Cluster. This historic secondary data was provided by the Weltevreden landfill site under the Polokwane local municipality and other socio-economic (i.e., population, unemployment) parameters. Whereas the demographic and socio-economic data was provided by the office of tourism and economic development under the Polokwane local municipality

Table 4.1: Waste generation and socio-economic characteristics historical data (2015-2021)

Years	**Waste generation (tons)**	**Population (thousands)**	**Unemployment rate (%)**	**Literacy rate (%)**	**GDP (billions)**
2015	1027.51	789010	14.0%	85.4%	75.7
2016	893.77	801573	14.1%	85.7%	83.3
2017	155863.78	814036	14.2%	86.2%	89.4
2018	160379.21	826161	13.8%	86.8%	95.5
2019	175957.83	838161	14.9%	88.0%	99.1
2020	167786.95	849937	17.5%	89.4%	99.7
2021	194558.88	859671	20.7%	90.8%	115.1

*GDP denotes gross domestic product

4.2.3 Data analysis

4.2.3.1 Relationship between Solid waste generation and socio-economic factors

Firstly, before we can forecast solid waste generation in Polokwane local municipality, Pearson correlation (r) was used to establish the relationship between municipal waste solid waste generation and socio-economic variables such as population size, unemployment rate, literacy rate, and Gross Domestic Product (GDP). The correlation coefficient (r) was analysed at $\alpha = 0.05$ measuring the strength of the linear relationship between the waste generation and the socio-economic variables. Pearson correlation matrices were calculated to also to determine any multicollinearity in for independent and dependent variables. The calculation of the variance inflation factor (VIF) for each of the variables, which is defined as follows, allows for a more thorough investigation of multicollinearity. The values of VIF and tolerance determine how strongly the independent variables are correlated with one another and are inversely related (VIF = 1/Tolerance or Tolerance = 1/VIF). The problem of multi-collinearity in the model is shown by the high value of VIF. By inaccurately calculating the value of beta coefficients, multi-collinearity weakens the robustness of the quantitative link between the dependent and independent variables. A high degree of variable collinearity is indicated by a VIF value greater than 10.

4.2.3.2 Forecasting Solid Waste generation

In this study a simple multiple linear regression model (SMLR) was used to forecast the SW generation rate at the Polokwane local municipality. Multiple linear regression analysis uses at least two independent variables (Tabachnick and Fidell, 1996; Uyanık and Güler, 2013). In this study the waste generation rate was used as a dependent variable. Four independent variables including population size, unemployment rate, literacy rate, and Gross Domestic Product (GDP) were chosen for this study. The selection of the later variables to forecast the waste generation was informed by previous studies that has demonstrated that population size, education level, and unemployment rate have either direct or indirect effects on SW generation rates (Liu et al., 2019; Monavari et al., 2012; Popli et al., 2021; Popli et al., 2020; Sivakumar and Sugirtharan, 2010; Suthar and Singh, 2015). Therefore, the following sets of hypotheses were developed and evaluated in this study:

Null hypothesis - H_0: Population, unemployment rate, literacy rate, and GDP are not the contributing factors towards the quantity of solid waste generation.

Alternative hypothesis - H_1: Population, unemployment rate, literacy rate, and GDP are the contributing factors towards the quantity of solid waste generation.

Subsequently, H_0 will be rejected if the p-value is less or equal (≤) to the significance value (α) of 0.05. It demonstrates that the variable(s) significantly influence the SW generation. The multilinear regression model that was used in this study was denoted as follows:

$$Y = B_0 + B_1X_1 + B_2X_2, \ldots\ldots, B_nX_n .. + \varepsilon$$

In this study, Y signifies the dependent /response variable (in this study it is waste generation rate) then B_n denotes the parameters (i.e., determine the partial contributions of each of the X-variables), such that B_n measures the change in the Y per unit change in the X_1 while holding X_2 constant. Whereas X_n represent the selected independent/explanatory variables such as population rate, unemployment rate, literacy rate and GDP. Then ε is the random error term/ residual error.

The following assumptions were considered in this study to ensure the regression analysis is valid and accurate: (i) the residual values are normally distributed; (ii) multicollinearity is not present. To validate the forecast model developed in this study, standard statistical measures used to assess model performance which include the coefficient of determination (R^2), and the root mean square error (RMSE) were used.

4.3 Results and discussion

4.3.1 Descriptive statistics

The results in Table 4.2 to show the descriptive statistics shows that Solid Waste Generation (SWG/tons/year) data in Polokwane local municipality. About seven (7) SW observations were made annually from 2015 to 2021, the mean and the median values were 122352.56tons/year, and 160379.21 tons/year, respectively. The standard deviation and Sample variance were found to be 83857.61 and 7032098910487.44. In addition, a slight departure from normal distribution was observed with a kurtosis of -0.9 and the skewness of -1.13. Therefore, data analysed in this study portrays positive skewness or right skewness and was not normally distributed.

Table 4.2: Descriptive statistics of SWG

Variable	Mean	Median	SD	SV	Kurtosis	Skewness
SW	122352.56	160379.21	83857.61	7032098910487.44	-0.9	-1.13

SD = Standard Deviation, SV=sample variance

In addition, the Shapiro-Wilk test was used to determine the normality analysis in this study for the study variables at a 0.05 level of significance. The hypothesis of normality is rejected if the p-value of the variables is higher than 0.05. It may be deduced that all the selected dependent and independent variables followed a normal distribution. The difference between the dependent variable's observed and expected values is known as the regression residual. By using a normal probability plot (see figure 4.2) the results emphasises that the waste generation data used in this study is not normally distributed.

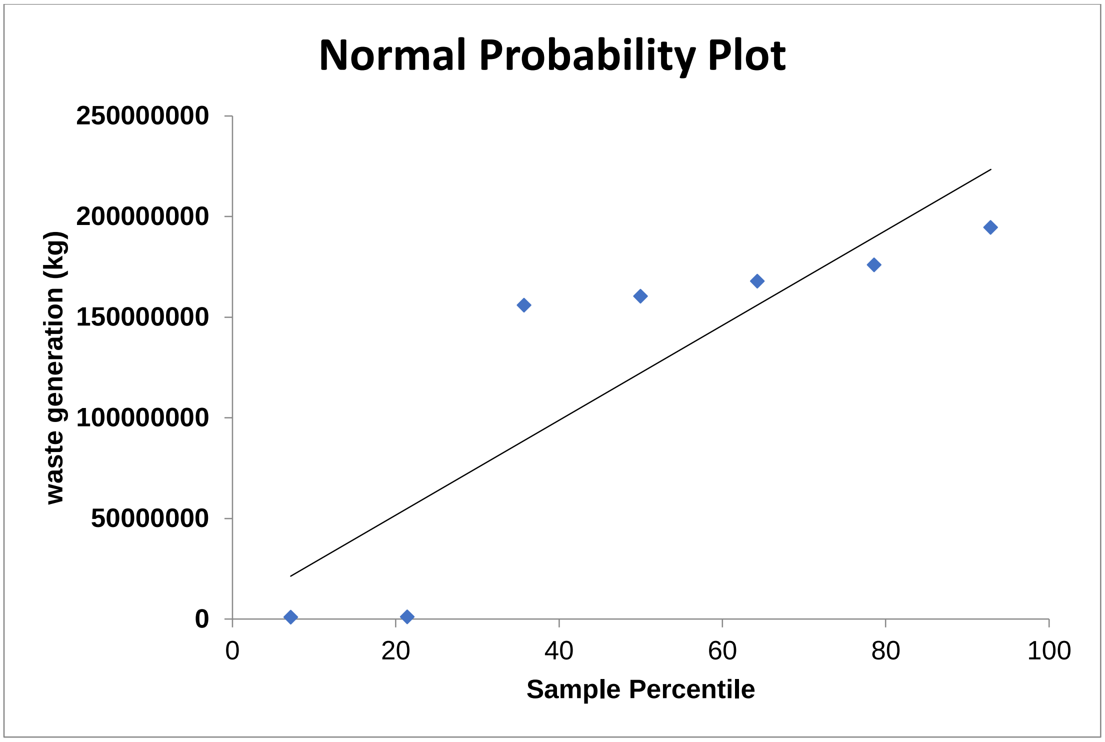


Figure 4.1: Normal probability plot of waste generation

4.3.2 Relationship between Solid waste generation and socio-economic factors

4.3.2.1 Correlations and Multicollinearity

The correlations between the independent variables are looked at to make sure that multicollinearity is not the cause of the independent variables' lack of statistical significance and illogical signs. The results of the study on Table 4.3 illustrates the relationship between solid waste generation, population size, unemployment rate, literacy rate, and Gross Domestic Product (GDP). The Pearson correlation coefficients (r) between SW generation, population size, unemployment rate, literacy rate, and GDP ranged from 0.52 to 0.87. Population has shown the very strong positive correlation (r =0.87) with SW quantity. This results agree with Popli et al. (2021) that reported that population and GDP have the greatest influence towards SW generation rate in Laos. On the other hand, Unemployment rate yield a moderate correlation (r =0.52) when related to SW generation quantity. Therefore, the result of this study shows that population increase can be used to estimate waste generation. Furthermore, it is apparent from the correlation matrix results that there is presence of multicollinearity among the population size, unemployment rate, literacy rate, and GDP. The correlation coefficient between population size and GDP is 0.97, which may be considered highest among the other independent variables.

Table 4.3: Correlation and multicollinearity matrix

	Population (thousands)	Unemployment rate (%)	Literacy rate (%)	GDP (billions)	Waste generation (kg)
Population (thousands)	**1**	0.81	0.96	0.97	0.89
unemployment rate (%)	0.805	**1**	0.93	0.83	0.52
literacy rate (%)	0.96	0.93	**1**	0.94	0.74
GDP (billions)	0.97	0.83	0.94	**1**	0.85
waste generation (tons/year)	0.87	0.52	0.74	0.85	**1**

Table 4.4 provides a summary of the variance inflation factor results for all of the independent variables. A large VIF indicates that the variance (and, consequently, standard error) of the regression coefficient is overestimated, resulting in a smaller-than-expected t-value. A value greater than 5 or 10 is likely unacceptable. Collinearity is present if VIF > 5, according to a handy rule of thumb. The literacy rate variable is only 212 times what it should be if collinearity did not exist, as indicated by the table's highest VIF of 212. This VIF is too high to warrant worry at this level. With this discovery, it is possible to conclude that collinearity is the model's primary flaw. Therefore, given that some of the VIF values are greater than 10, there is a significant multicollinearity problem.

Table 4.4: Variance Inflation Factors (VIF)

	Population (thousands)	**unemployment rate (%)**	**literacy rate (%)**	**GDP (billions)**
Tolerance	0.01	0.02	0.01	0.04
VIF	140.02	51.13	212.22	25.44

4.3.3 Forecasting Municipal Solid Waste Generation

4.3.3.1 Modelling solid waste generation

The table 4.5 provides a summary of the regression results. Popular key performance indicators (KPI) including P-value, R^2, and root mean square error (RMSE) are analysed to verify the veracity and correctness of the generated model. The results of the study presented that regression model is statistically significant, with F statistic of 3.61 and p-value = 0.000. Looking at the coefficient of the determinant (R^2 =0.88) of the model, the four explanatory variables (population size, unemployment rate, literacy rate, and GDP) work together to explain around 88% of the variation in the waste generation. Therefore, the amount of SW produced in this study can be meaningfully described by the independent variables. As a result, a null hypothesis, which states that the population, GDP, unemployment rate, and literacy rate are not influencing factors in the quantity of SW generation, is rejected. Consequently, the regression model in Table 4.5 was then used to forecast future SW Generation. Thus, this study is similar to Popli et al. (2021) that reported that model 2 of scenario 4 is regarded as the most accurate model with the R^2 value of 0.99.

Table 4.5: Summary of the regression statistics

Model	**R^2**	**RMSE**	**F**	**P-value**
Waste generation (kg) = -70138. 75 +(5.47) *population-(511.75) *unemployment rate – (5237108.91) *literacy rate+(2770.43) *GDP	0.88	50690.20	3.61	0.00

4.3.3.2 Waste generation forecast

The graph in figure 4.4 shows a sharp increase in SW generation quantity from baseline year 2017 reaching as high as 155863.78 tons/year, then stabilized slightly until 2020 (167786.95 tons/year. Furthermore, our regression model computed in this study demonstrates that the generation of waste is expected rise in the future (2022 -2026). The trend is anticipated to get worse every year. For instance, waste generation quantity will reach an all-time high of 379800.27 ton/year mainly due to expected rise in population and standard of living in Polokwane local municipality.

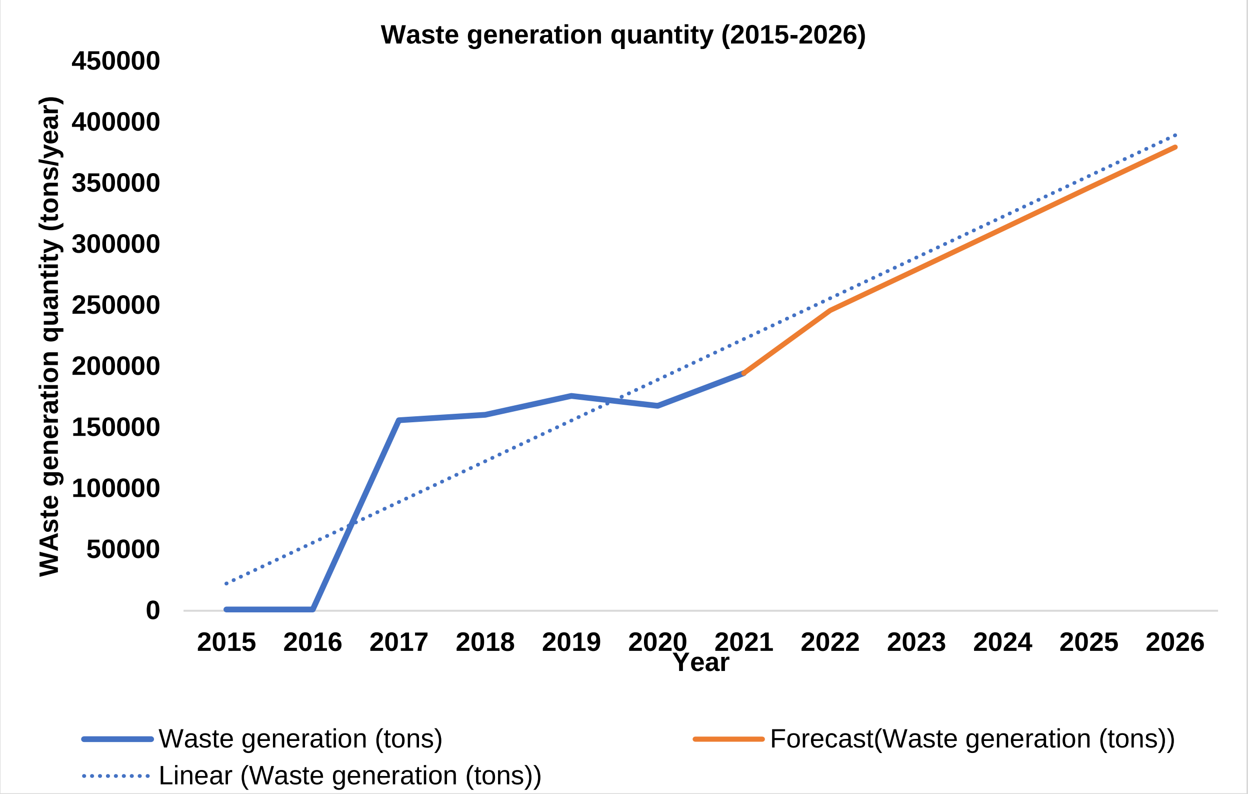


Figure 4.2: Municipal Solid Waste Generation and forecast for period (2015-2026)

4.4 Conclusion

To predict how much waste a municipality will produce is a vital step in developing an efficient SWM system. By calculating the amount of waste in advance, landfill locations, recycling facilities, and the development and management of waste collection facilities may all be planned appropriately. Hence, this encourages making accurate and appropriate planning measures and decisions by the stakeholders. The SWM system in Polokwane local municipality has improved over the years. The local municipality has most of basic waste generation facilities and machineries. For instance, the municipality has a waste weighing bridge at the Weltevreden landfill site. The recorded daily waste data allowed the retrieval of the data and was used in this study to forecast waste generation quantity for the municipality. This is unlike most municipalities in other provinces that do not weigh their waste because of lack of weighing bridge at the disposal site (Mathema et al., 2017; Nefale, 2018). As such, this poses a challenge in recording reliable waste data and making accurate forecasting and decisions towards sustainable SWM (Abbasi and El Hanandeh, 2016; Popli et al., 2021). The present study developed a prediction model to forecast waste generation quantity for the future using multiple linear regression. The SW generation is correlated to the four socio-economic factors (population size, unemployment rate, literacy rate, and GDP). The population size was found to be the most correlated to the waste generation quantity, followed by the GDP. The study's findings also demonstrated the statistical significance and dependability of the regression model for projecting future waste generation. Looking at the coefficient of the determinant (R^2 =0.88) of the model. Finally, the model demonstrated that in future the quantity of MSW is set to increase. The waste generation quantity will reach an all-time high of 379800.27 ton/year mainly due to expected rise in population and standard of living in Polokwane local municipality. drawback from this study is the lack of sufficient data for the model’s development. The scope of the methodology and the developed model can be expanded in the future by considering a huge database and a variety of socio-economic aspects.

CHAPTER FIVE:

Integrating GIS And Multi‑ Criteria Decision Analysis for Landfill Site Selection: A Case Study Mankweng Cluster, South Africa

Abstract

The rapid fill-up of landfill sites and lack of suitable land areas to construct disposal site for the disposal of municipal solid waste (MSW) are some of the problems facing semi-urban areas in developing countries. This has negative effect on the environment, society, and the economy. Therefore, a selection of a disposal site is required to enable proper planning of land use that will promote sustainable solid waste management disposal. Consequently, the aim of this study was to identify a potentially suitable landfill site using a Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) in Mankweng Cluster of Polokwane Local Municipality. About ten layers including land use, elevation, slope, aspect, soil type, powerlines, protected areas, village, roads, and rivers were processed based on their importance and weighting using GIS-based AHP. Five categories such as: not suitable, less suitable, moderately suitable, suitable, and very suitable were used to classify site suitability map. The results of the study showed that roughly 67% of the Mankweng cluster was classified as suitable for construction of a disposal site. The remaining 33% of the area ranged from less suitable to moderately suitable. Finally, the study demonstrated the effectiveness of integrating GIS and multicriteria decision analysis (AHP) in the selection of suitable landfill site in Mankweng Cluster.

Keywords: Municipal Solid Waste, GIS, MCDA, Weighted Overlay, Landfill site

5.1 Introduction

Rapid growth economic, urbanisation, population, and rise in waste types (Şener and Şener, 2020; Weldeyohanis et al., 2020; Xiao et al., 2020) necessitate a sustainable integrated method that incorporates all waste, instead of founding a separate WM system for each waste type (Nadiri et al., 2018; Şener and Şener, 2020). The management of municipal solid waste (MSW) is experiencing a grave segment owing to the lack of appropriate amenities for treatment and disposal of the rising quantity of MSW produced in cities (Sener et al., 2010). Waste management (WM) operations identify the locations of landfills for solid waste (SW) depending on a variety of variables, including the geographic nature of an area. Location selection for SW landfills is vital for any area because of the cost inferences, reversal complications and long-term obligation required. While choosing a landfill site, a number of issues, including social, economic, and environmental considerations should be recognised. Selecting a landfill location is a tremendously complicated procedure (Şener and Şener, 2020; Weldeyohanis et al., 2020) and the critical stage for perfect site selection is the reliable discovery of the importance of each criterion (Sener and Sener, 2020; Senkiio et al., 2022). Due to a number of variables, including rising waste levels, population growth, environmental and societal well-being risks, and declining land availability for waste disposal, finding an appropriate location for landfills is also quite difficult. It can be difficult to choose landfill locations for SW disposal that are both economically viable and environmentally friendly. Well-known techniques for multi-criteria decision-making (MCDM) is the analytical hierarchy process (AHP) method. In many different disciplines, it may resolve complex decision-making issues. By breaking the problem down into a hierarchy of smaller issues, it can be more readily understood and analysed from a variety of perspectives (Elhamdouni et al., 2017). Using this method, big issues are broken down into hierarchies of smaller issues, allowing for more precise and individualised evaluations. It is also used to create a matrix for pairwise comparisons in order to assess the consistency of weightings for criterion. With this combination, imprecision criteria may be managed, and qualitative and quantitative aspects can be included (Abdulhasan et al. 2019). For the purpose of choosing landfill areas in Al-Hashimiyah Qadhaa, Babylon, Iraq, Chabuk et al. (2017) used MCDM and GIS analysis.

The objective of this study is to find an appropriate disposal site using a GIS-based strategy and to support the method by contrasting it with the conventional AHP methodology, which is utilised to find suitable disposal sites for waste in South Africa's Limpopo province's Mankweng cluster. Currently, there is one operating landfill and one that is still under construction. The results of this study will aid city planners, decision-makers, and interested parties in strengthening SWM procedures. **Methods and materials**

5.1.1 Data collection and processing

The purpose of the study is to adopt GIS-based MCDA to locate acceptable landfill sites for the Mankweng cluster's proper solid waste management. Numerous criteria were devised in order to overcome the cluster's spatial challenge.

The South African regulatory context of landfill site selection.

As mentioned in chapter 2 that the landfill site selection is guided by the section 4 in the Minimum Requirements of waste disposal by landfill document. The Polokwane local municipality has two existing operating landfill site both classified as landfill site that receives General waste stream, and its sizes are Medium with no significant leachate produced (B) meaning it does not require a leachate management system. However, the buffer zones towards the critical factors and the fatal flaws of a G:M:B- are recognised special consideration to be given by the specialist or departmental relevant officer (DWAF, 1998). Therefore, the Polokwane local municipality’s relevant departmental officer is responsible to set out the buffer zones of a proposed landfill site. With the following flaws not ruled out: Airports, floodplains, wetlands, unstable regions (such as fault zones, seismic zones, and sinkhole-prone regions), areas near significant surface water resource, areas of ground water recharge because of topography and/or highly permeable soils, catchment areas for important water resources, sensitive ecological and/or historical areas, areas with steep gradients, where slope stability may be a problem, and areas immediately upwind (DWAF, 1998).

Data for the influencing factors as well as the map layers were gathered from a variety of sources (see table 5.1). The ArcMap environment standardised the layers. Utilizing AHP and the weighted overlay technique, spatial decision analysis and criteria evaluation was performed. The Digital Elevation Model (DEM) data was download from United States Geological Survey (USGS) website and used to create a slope, elevation, and aspect map layers. The soil data layer was extracted from the SOTER website for soil type and clipped to the borders of the study area. All this input criteria datasets were georeferenced to WGS 84 datum in ArcMap environment. these criteria datasets were processed and analysed using ArcGIS version 10.6 and the MCDA (AHP). Table 5.2 shows the results from the literature and scholar's views regarding the buffer zone distances of the selected criteria of the study. These results guided the researcher in determining the proximity and suitability description for the criteria.

Table 5.1: Data types and sources

Variable	**Data source**	**Format**
Rivers	SANBI website	Vector
DEM (elevation, slope, and aspect)	USGS website	Raster
Soil type	SOTER	Vector
Roads	SANRAL	Vector
Powerlines	ESKOM	Vector
Protected sites	SANBI website	Vector
Landuse	SANBI website	Raster
Village	SA Municipal Demarcation Board	Vector

Table 5.2: Literature results about the criteria buffer zone distances

Criteria	Restricted criteria (Buffer zone values)	Researcher
Rivers (km)	>1 km from rivers and dams	Balew et al., 2020; Kareem et al., 2021; Makonyo and Msabi, 2021; Moon, 2020; Sisay et al., 2021

Land elevation (a.m.s.l)	1350 - 2100 m	Moon, 2020; Torabi-Kaveh et al., 2016
Landuse	Agriculture, water body, build-up, and industrial area are restricted	Balew et al., 2020; Chabok et al., 2020; Khan and Samadder, 2015; Makonyo and Msabi, 2021; Moon, 2020; Sener and Sener, 2020; Sisay et al., 2021
Soil type	Clay soil	Makonyo and Msabi, 2021; Moon, 2020
Road (km)	>2 km distance from the roads	Ayiam et al., 2019; Chabok et al., 2020; Elhamdouni et al., 2017; Makonyo and Msadi, 2021; Pasalari et al., 2019; Rahimi et al., 2020; Randazzo, et al., 2018; Sener et al., 2010
Slope (%)	5 – 10 % or 15 – 50 degrees	Kareem et al., 2021; Kamdar, 2019; Khan and Samadder., 2015; Makonyo and Msadi, 2021; Sisay et al., 2021
Powerlines	300m distance from powerlines	
Villages	>1 km distance from human settlement	Chabok et al., 2020; Elhamdouni et al., 2017; Kareem et al., 2021; Makonyo and Msabi, 2021; Moon, 2020; Sener and Sener, 2020
Archaeological sites (km)	1-3 km distance from archaeological sites	Elhamdouni et al., 2017; Kamdar et al., 2019; Moon, 2020; Sisay et al., 2021
Protected sites (km)	5-10 km distance protected sites	Elhamdouni et al., 2017; Pasalari et al., 2019; Rahimi et al., 2020; Sener et al., 2010

5.1.2 Geospatial data preparation and presentation

5.1.2.1 The Analytical Hierarchy Process method: Criteria weights

The pairwise comparison matrix is the key to the AHP method. It serves as the input while the relative weights are produced to serve as outputs. The matrix was computed for pairwise comparison using a scale with values from 1 to 9 to measure the alternatives against each other (Table 5.3). The site selection process included eleven factors. As a result, the AHP method was employed to compute their weights.

Table 5.3: The pairwise comparison scale (Saaty, 1980)

Intensity of importance	Definition

1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

The matrix is used to determine the importance of one criterion against the other. Furthermore, by measuring the consistency ratios, the AHP approach helps in evaluating inconsistency in datasets (Sisay et al., 2021). The typical pairwise comparison matrix for n objectives (Eq. 1).

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & \cdots & a_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & \cdots & a_{nn} \end{bmatrix} \qquad (1)$$

Eq. 2 is the pairwise comparison matrix with the relative weights of the objectives. The greater a factor's influencing weight, the more significant it is (Makonyo and Msabi, 2021).

$$AW = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & \cdots & a_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & \cdots & a_{nn} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \cdots \\ \cdots \\ w_j \end{bmatrix} \qquad (2)$$

$$a_{ij} = \frac{1}{a_{ij}}, a_{ij} \neq 0$$

Table 5.4 present the pairwise comparison matrix of the study criteria. The criteria were compared against each other using the 1-9 significance scale in table 5.3.

Table 5.4: Pairwise comparison matrix of the study criteria

	River	Village	Landuse	Land elevation	Slope	Soil type	Road	Powerline	Protected site	Aspect
River	1	1	1	3	3	3	5	9	7	7
Village	1	1	1	3	3	1	5	9	5	7
Landuse	1	1	1	5	5	3	1	5	5	9
Land elevation	0.33	0.33	0.2	1	1	1	3	5	7	5
Slope	0.33	0.33	0.2	1	1	1	1	7	3	5
Soil type	0.33	1	0.33	1	1	1	5	5	3	5
Road	0.2	0.2	1	0.33	1	0.2	1	5	3	3
Powerline	0.11	0.11	0.2	0.2	0.14	0.2	0.2	1	1	3
Protected site	0.14	0.2	0.2	0.14	0.33	0.33	0.33	1	1	1
Aspect	0.14	0.14	0.11	0.2	0.2	0.2	0.33	0.33	1	1

The consistency ratio is very important as it confirms if the comparison is consistent or not. Therefore, after the weights are given and criteria are compared to one another, a consistency ratio is carried out to validate the comparison. That is acquired through a step by step that involves calculations of several equations as follows:

The Eigenvector calculations

The pairwise comparison matrix's output value is multiplied by the value for each criterion in each column of the same row to determine the eigenvectors (Egi) for each row. The output value is then subtracted from the root for the number of elements in each row and applied to each row in turn. (Eq.3).

The eigenvalue of a row is determined using the following equation:

$$Eg_i = \sqrt[n]{a_{11} \times a_{12} \times a_{13} \times a_{14} \times \dots \dots \times a_{1n}} \qquad (3)$$

Where Egi is the eigenvalue for row I and n denote the number of elements in row i.

The priority vector is computed by normalizing the eigenvalue to 1 (the sum of the eigenvalues).

$$Pr_i = \frac{Eg_i}{(\sum_{k=1}^{n} Eg_k)} \qquad (4)$$

Where Eg_k is the sum of the Eg_i

Table 5.5 represent the normalized pairwise comparison matrix of the study criteria. The normalized matrix is the first step that allows the performance of the consistency analysis to obtain the criteria weights and validate them.

Table 5.5: The normalized pairwise comparison matrix of the criteria

River	Village	Landuse	Elevation	Slope	Soil type	Road	Powerlines	Protected sites	Aspect	CW
0.22	0.18	0.19	0.20	0.19	0.27	0.23	0.19	0.19	0.15	0.20
0.22	0.18	0.19	0.20	0.19	0.09	0.23	0.19	0.14	0.15	0.18
0.22	0.18	0.19	0.33	0.32	0.27	0.05	0.11	0.14	0.20	0.20
0.07	0.06	0.03	0.06	0.06	0.09	0.14	0.11	0.19	0.11	0.09
0.07	0.06	0.04	0.07	0.06	0.09	0.05	0.15	0.08	0.11	0.08
0.07	0.19	0.06	0.07	0.06	0.09	0.23	0.11	0.08	0.11	0.11
0.04	0.038	0.19	0.02	0.06	0.02	0.05	0.11	0.08	0.07	0.07
0.02	0.02	0.04	0.01	0.01	0.02	0.01	0.02	0.03	0.07	0.02
0.03	0.04	0.04	0.01	0.02	0.03	0.02	0.02	0.03	0.02	0.03
0.03	0.06	0.02	0.01	0.01	0.02	0.02	0.01	0.03	0.02	0.02

The weighted sum vector is divided by the predetermined criterion weights to get the consistency vector. The first criterion's weight is multiplied by the first column of the original comparison matrix in pairs, the second criterion's weight is multiplied by the second column, the third criterion's weight is multiplied by the third column of the original multiply, and then these values are added to produce the weighted sum vector.

After determining the eigenvalue and the priority vector, the lambda max (max) is produced from the summation of products by multiplying the sum of each matrix column by the corresponding value of the priority vector. By multiplying each priority vector component by the sum of the columns of the reciprocal matrix, the lambda max (max) was obtained., as given in the formula below.

$$\lambda_{max} = \frac{1}{n}\sum_{\mathrm{wi}}^{n}\frac{(AW)i}{\mathrm{wi}} \tag{4}$$

Where aij is the sum of criteria in each column of the matrix; Wi is the weight value for each criterion that corresponds to the priority vector in the decision matrix, with values (i=1, 2... n).

The right eigenvector, which is obtained from the maximum absolute eigenvalue (max, 1,2), is used to determine the weight coefficients of the ranking criterion and decision sub-criteria. All the criteria's grade values have been normalized to 1. The corresponding eigenvector of max is W, and the weight value for ranking is wi I = 1, 2..., n).

W is the associated primary eigenvector, Wi is the weight of criteria value, and I = 1, 2... n is the number of criteria involved.

The Consistency Ratio (CR)

In AHP, the consistency index (CR) of a matrix is computed to access the Consistency Index (CI) of the utilised judgment during the weighing of the criteria (Saaty, 1980). Consistency is measured by the Consistency Index (CI), which is a measure of deviance. The Consistency Index formula (Eq. 7).

$$CI = \frac{(\lambda_{max} - 1)}{(n - 1)}$$

where, n is the size or order of the matrix, and CI is the equivalent of the mean deviation of each comparison element and the standard deviation of the evaluation error from the actual ones.

According to (Saaty, 1980), the consistency ratio (CR) was calculated by dividing the consistency index (CI) value by the Random index value (Eq. 8). The Random index value RI for matrices of various sizes (Saaty, 1980) for this study is displayed in table 3.6.

$$CR = \frac{CI}{RI}$$

The RI is determined by the number of elements being evaluated (see table 5.6). The conditions are: If $CR < 0.1$, this means there is consistency in the ratio values of the pairwise comparison, however, $CR \geq 0.10$, means there is no consistency in the ratio values of the pairwise comparison.

Table 5.6: The "n" numbers of the Random Inconsistency Indices (Saaty, 1980).

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

5.1.2.2 The Geographical Information System

A computerised tool and framework known as GIS is used to record, save, retrieve, update, manipulate, display, map, and analyse the spatial relationship between mapped geographical features on the surface of the planet (Rikalovic et al., 2014). Planning and maintaining environmental and socioeconomic settings can be done using spatial datasets that have undergone GIS analysis (Balew et al., 2020). Geographic Information System (GIS) was used for the preparation of 10 thematic maps and ArcGIS 10.6 software, various tools spatial analysis from arc toolbox were used. Furthermore, the 10 thematic maps were overlayed was used using the weighted overlay tool in the GIS to produce the suitability map.

Once the criteria shapefiles are prepared and available, the next step is to specify the working environment. This is where all the criteria maps will be stored. A new geodatabase was created to store all the resulting maps. A boundary map of the Mankweng cluster was digitized from the Polokwane local municipality. Additionally, the border map was used as the processing extent. The following tools were used to achieve site suitability analysis of a landfill.

(a) Buffering

A buffering tool is one of the geoprocessing tools in the ArcMap software used in the initial stages of data preparation and analysis of this study. It is used to create a demarcation between two or more features at a specified distance. There are two types of buffering. A single-ring buffer and a multi-ring buffer. In this study, a multi-ring buffering was used at different distances apart. This is because the several distances specified have their on-suitability classes for the criteria that are significant in this analysis. The criteria maps buffered include the roads, powerlines, rivers, protected sites, and villages.

(b) Clipping

Clipping is vital I this analysis. This is because normally these criteria maps cover more than the study area. Therefore, this causes the extraction of the study from the other regions. Clipping can be referred to as cutting. The criteria maps like roads, rivers, soil type, protected sites, powerlines, and villages were clipped to the processing extend of the boundary map since they are in vector format. While criteria maps such as landuse, slope, aspect, and elevation were extracted by mask tool to the processing extend of the boundary map since the maps are in raster format.

(c) Rasterization

Rasterization is a tool in ArcMap Toolbox that converts all vector-type data formats to a raster format. This is because, suitability analysis works best with raster data. Hence, the conversion. The rasterized vector included the roads, rivers, protected sites, powerlines, villages, and soil type criteria map data.

(d) Reclassification

This is a procedure of conversion of fluctuating, continuous datasets into distinct and integer values. Following the derivation of datasets from the input maps, such as slope, distance to the road, rivers, protected sites, powerlines, villages, soil type, slope, aspect, elevation and the land use map, the datasets were reclassified into a common number of classes. Considering the definition, it is reasonable to interpret the task of assigning appropriate scales to each class value in each factor map as reclassification of the factor map. Various appropriateness grading scales are now in use. The most widely used suitability scales in land use classification are either three (varying from highly suitable, moderately acceptable, and not suitable) or five suitability groups.

However, in this study, five suitability classes were used. This includes (1) not suitable, (2) less suitable (3) moderately suitable (4) suitable, and (5) highly suitable. The numbers correspond with the classes respectively. Table 5.7 presents the detailed buffer distances, suitability scale used, the suitability description, and weights of the criteria used in this study.

Table 5.7: The buffer zones, suitability scales and descriptions, and weights of the criteria.

Criteria	***Proximity (m)***	***Suitability***	***Suitability description***	***Weight (%)***
River	0-500	1	Unsuitable	20%
	500-1000	2	Less suitable	
	1000-1500	3	Moderately suitable	
	1500-2000	4	Suitable	
	>2500	5	Highly suitable	
Road	0-500	1	Unsuitable	7%
	500-1000	5	Less suitable	
	1000-1500	4	Moderately suitable	
	1500-2000	3	Suitable	
	>2000	2	Highly suitable	
Villages	0-500	1	Unsuitable	18%
	500-1000	5	Less suitable	
	1000-1500	4	Moderately suitable	
	1500-2000	3	Suitable	
	>2000	2	Highly suitable	
Powerlines	0-500	1	Unsuitable	2%
	500-1000	2	Less suitable	
	1000-1500	3	Moderately suitable	
	1500-2000	4	Suitable	
	>2000	5	Highly suitable	
Protected sites	0-500	1	Unsuitable	3%
	500-1000	2	Less suitable	
	1000-1500	3	Moderately suitable	
	1500-2000	4	Suitable	
	>2000	5	Highly suitable	
Landuse	Barren land	5	Very suitable	20%
	Built-up	2	Less suitable	
	Cultivated	5	V suitable	
	Forested land	3	Moderately suitable	
	Grassland	4	Suitable	
	Mine quarries	1	Unsuitable	
	Waterbodies	1	Unsuitable	
	Wetlands	1	Unsuitable	
Soil	Ach (loam to clay)	5	Highly suitable	11%
	Arh (sandy)	1	Unsuitable	
	Cme (clay/sandy loam)	3	Moderately suitable	
	Lpe (sandy loam to clay)	3	Moderately suitable	
	Lpq (sandy loam to clay)	3	Moderately suitable	

	Lvf (clay)	5	Highly suitable	
	Lvx (clay)	5	Highly suitable	
	Lxh (clay)	5	Highly suitable	
	Rge (sandy clay loam/ sandy)	1	Unsuitable	
Slope (degrees)	20.50-42.53	1	Unsuitable	8%
	12.12-20.50	2	Less suitable	
	6.34-12.12	3	Moderately suitable	
	2.80-6.34	4	Suitable	
	0-2.80	5	Highly suitable	
Elevation (m)	1013-1293	1	Unsuitable	9%
	1293-1364	2	Less suitable	
	1364-1446	3	Moderately suitable	
	1446-1575	4	Suitable	
	1575-1876	5	Highly suitable	
Aspect	NW	1	Unsuitable	2%
	W, SW	2	Less suitable	
	SE, S	3	Moderately suitable	
	NE, E	4	Suitable	
	F, N	5	Highly suitable	

Figure 5.1 shows the workflow of the methodology adopted to identify suitable area for municipal site in Mankweng Cluster. The methodology included four stages to determine the potential disposal site. The first stage was to identify the criteria to use assessing the suitable area for disposal site. In this stage the criteria were categorised in terms of environmental, social, and economical. In the second stage the criteria data were manipulated using the GIS techniques and MCDA though the analytical hierarchy process (AHP). In the third stage, the criteria were weighted using AHP. The last stage included the overlaying of the criteria to produce the final suitability map for the potential disposal site.

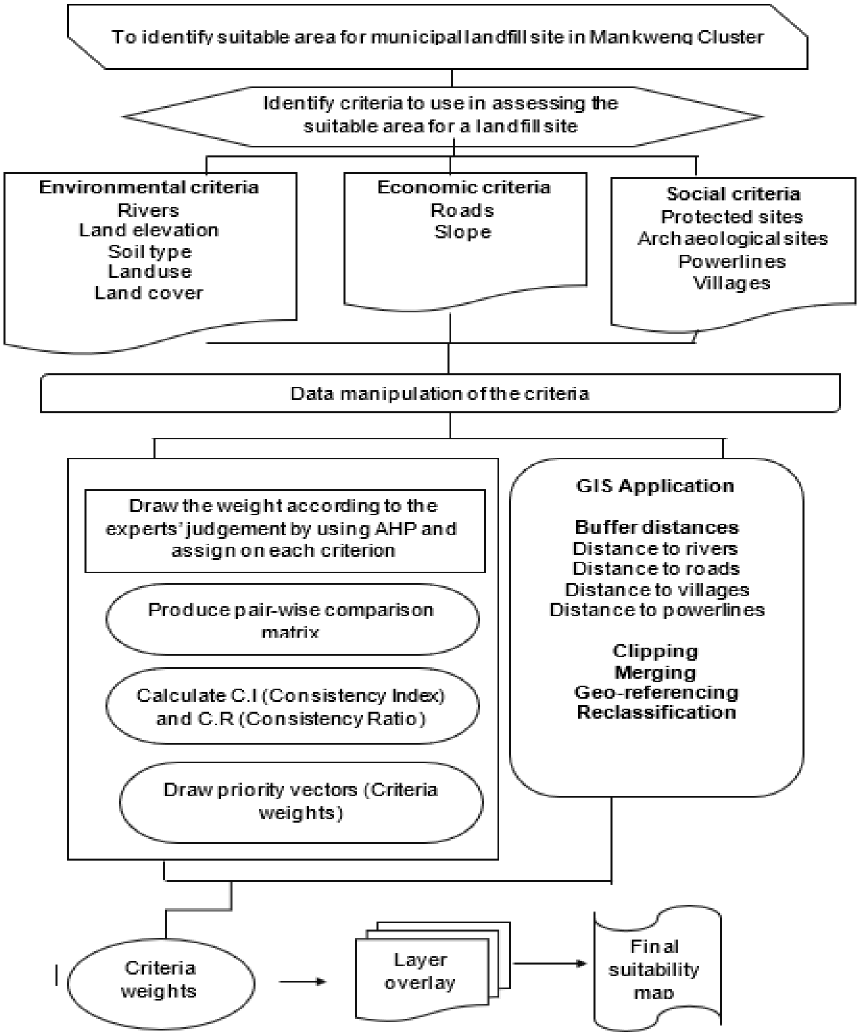


Figure 5.1: the flowchart diagram summarizing the methodology of the study.

5.2 Results and Discussion

The results of this study have been summarized and described using thematic maps (figure 5.2 to 5.7) according to evaluation criteria complying with the regulations of the South Africa's Department of Water Affairs and Forestry (1998) and the literature review for landfill site selection. The characteristics of the study were represented using maps of the following criteria: (a) roads, (b) rivers, (b) elevation, (c) slope, (d) soil, (e) land use/cover (f) protected sites, (g) powerlines, (h) villages, and (i) aspect. These maps were then overlayed to create a landfill suitability map presented in figure 5.7.

a) Roads

Figure 5.2 (a) shows road buffers or distance from the road. Distances from the road must be considered while transporting solid waste vehicles. As a result, time should be reduced and access to a landfill site should be achieved so that regional aesthetics are not harmed (Kareem et al., 2021). Due to the higher or lesser accessibility to the place, the distance from the road network should be factored in while locating a landfill. (Ayiam et al., 2019; Pasalari et al., 2019; Randazzo, et al., 2018If the proposed sites are too far from the current road network, it will inevitably result in high building expenditures for linking the roads (Moon, 2020; Sisay et al., 2021). However, this does not imply that a landfill should be located near a road as this will cause congestion of waste vehicles to and from landfills (Balew et al., 2020; Sisay et al., 2021).The following classes were created; 0-500m was considered unsuitable, (500—1000 m) suitable, (1000—2000 m) highly suitable, and (greater than 2000m) was considered extremely suitable (Chabok et al., 2020; Elhamdouni et al., 2017; Makonyo and Msadi, 2021; Rahimi et al., 2020; Sener et al., 2010. On the other hand Figure 5.2 (b) shows road suitability map.

b) River

Figure 5.2 (c) shows river proximity map. The river criteria is necessary to stop surface water contamination brought on by various pollutants present in landfill leachate that may end up in the river (Kareem et al., 2021). According to Moon (2020), around vital water bodies (i.e. such as ponds, lakes, rivers, and streams), a buffer zone should be maintained at a particular distance. The literature revealed that the proximity distance of a landfill to waterbodies is suggested as follows: less than 500m distance is unsuitable, 500m-1000m is less suitable while greater than 1000m is suitable greater than 2500m is highly suitable (Balew et al., 2020; Makonyo and Msabi, 2021; Sisay et al., 2021)

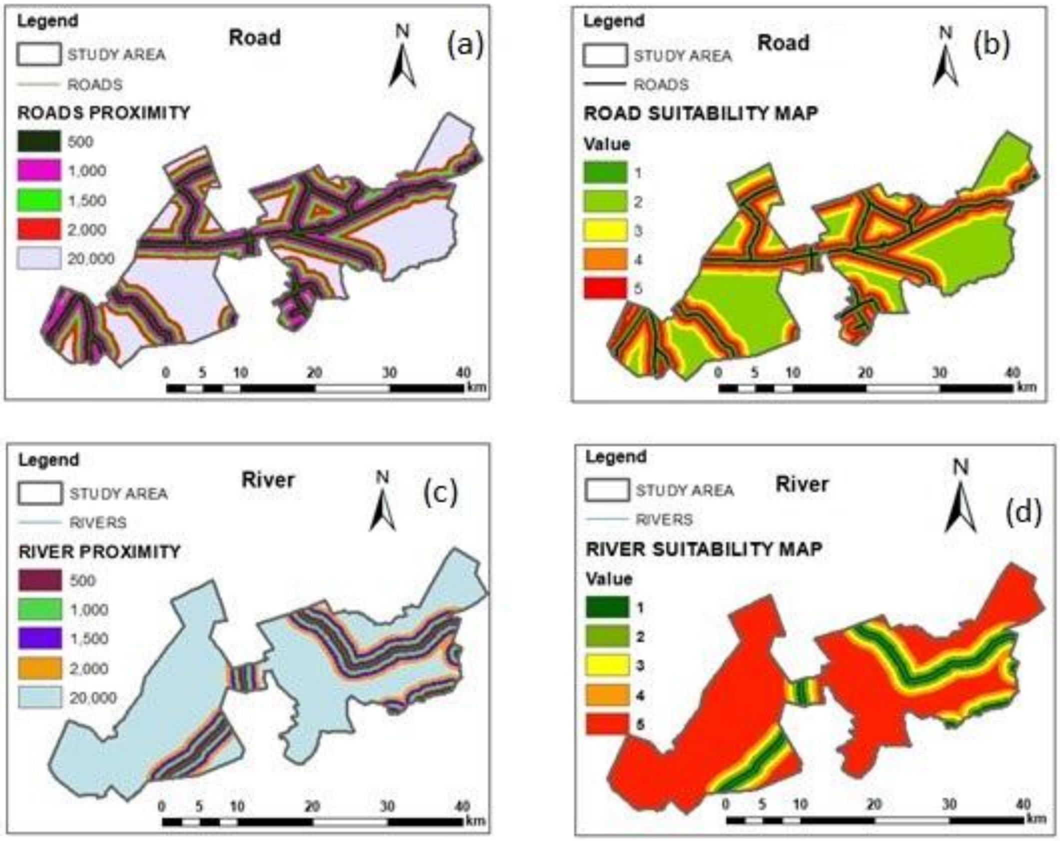


Figure 5.2: Criteria road and rivers' proximity and reclassification

c) Slope

Flat slopes may affect runoff drainage, while steep "slopes" are difficult to construct and maintain, make waste transportation problematic, and cause water contamination owing to leachate drainage (Kareem et al., 2021; Kamdar, 2019; Makonyo and Msadi, 2021). According to Khan and Samadder (2015), when the slope is greater than 12 percent, there is a high rate of precipitation runoff. If the runoff rate is higher and infiltration is lower, contaminants may escape the containment area furtherThe criterion for slope was devised by Kamdar (2019) and Sisay et al. (2021), who stated that places with a slope of more than 15 degrees were unsuitable while those with a slope of less than 5 degrees were highly suited. Figure 5.3 (a) illustrate the slope of the study categorised into five classes, whereas figure 5.3 (b) shows the slope of the study classified into five siutability classes.

d) Elevation

Figure 5.3 (c) present the elevation of the study. “Elevation (Topography)” criteria were adopted to avoid flooding risk (Chabuk et al., 2016; Kareem et al., 2021). Moreover, landfill sites must not be located at high elevations because doing so would be challenging during construction, while being too low would affect runoff drainage (Moon, 2020; Torabi-Kaveh et al., 2016). On the other hand figure 5.3 (d) present the classified the elevation into five suitability classes.

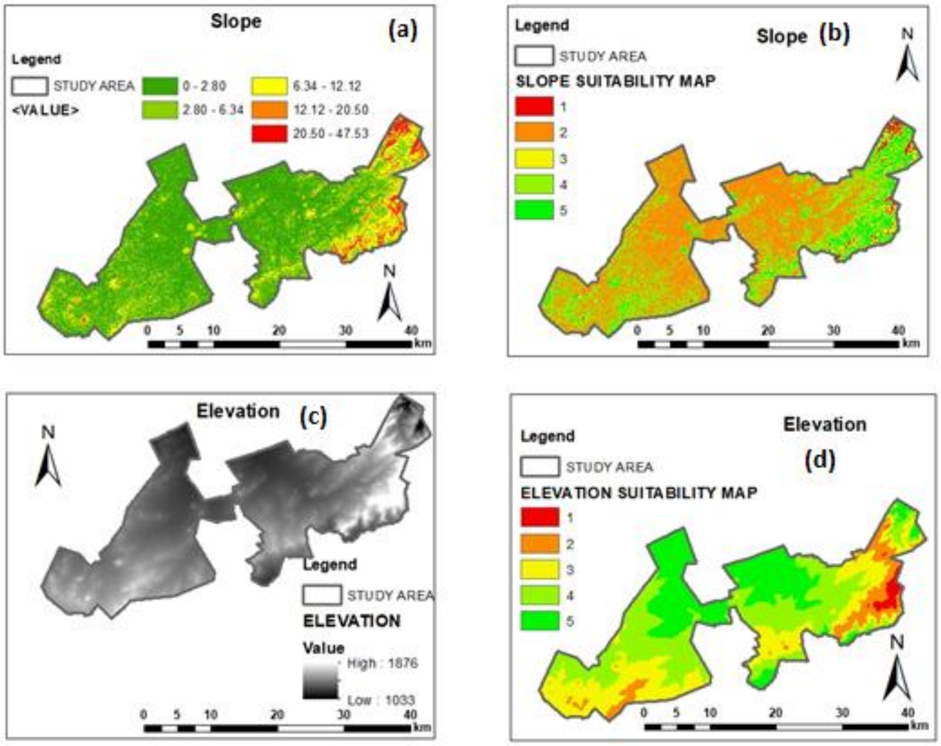


Figure 5.3: Criteria slope and elevations' proximity and reclassification

e) The soil

Figure 5.4 (a) shows the soil types found on the study. To reduce soil pollution caused by leachate infiltration through soil horizon, the soil requirement was crucial. The state of the soil can be useful in determining the best location for a landfill. The permeability and coarseness of the soil were utilised to determine its appropriateness. Soil having a high percentage of unconsolidated elements is thought to be ideal for examination

(Makonyo and Msabi, 2021). Permeable soils, for example, will provide less protection and may necessitate the installation of extra controls within the landfill. Because of the possibility of pollutants, can have a significant influence on groundwater, surface water resources, and plants. (Moon, 2020). Whearas, figure 5.4 (b) demonstrate the reclassification of the soil type in the study area.

f) Landuse-Landcover

Figure 5.4 (c) shows the landuse-landcover found in the study area, whereas figure 5.4 (d) shows the landuse-landcover of the study area classified into five classes of suitability. Using the landscape for development, conservation, or a combination of the two is referred to as landuse. Urban sprawl, the preservation of farmland, and population growth all have an impact on landfill location today. Hence, the siting process should not include inappropriate locations or proposed future development (Moon, 2020). The landuse map has classes of industrial areas, villages, townships, Agricultural lands, Unused land, Archaeological, and orchards. To avoid human and environmental consequences as well as future developments, landfills should be located at least 1km away from human settlements. (Chabok et al., 2020; Sener and Sener, 2020; Sisay et al., 2021, however, Open fields and bare terrain, on the other hand, are ideal locations for landfills (Balew et al., 2020; Khan and Samadder, 2015; Makonyo and Msabi, 2021.

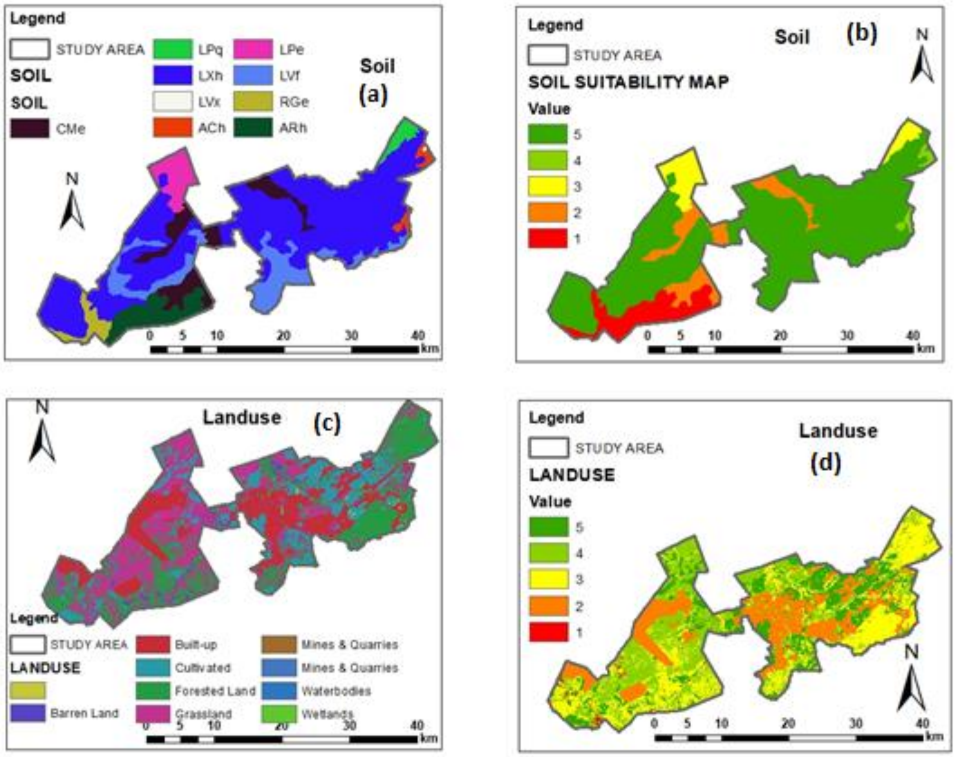


Figure 5.4: Criteria soil type and land use's proximity and reclassification

g) Powerlines

The powerlines buffer distance is shown by figure 5.5 (a). On the other hand figure 5.5 (b) shows the five classes of the classifed powerlines. Powerlines used to transmit power are important to consider when conducting site selection of a landfill site. That is because landfill sites attract birds as such birds will be shocked and killed by the high power transmitting powerlines if the landfill is constructed close. As such, in this study, the powerline criteria are buffered with distances of 0-500m is considered unsuitable, 500-1000m less suitable, 1000-1500m moderately suitable, 1500-2000m suitable, and >2000 considered highly suitable.

h) Protected sites

Figure 5.5 (c) present the buffer distances of the protected sites, while figure 5.6 (d) present the five suitability classes of the protected sites in the study. The literature proximity distance (Elhamdouni et al., 2017; Pasalari et al., 2019; Rahimi et al., 2020;

Sener et al., 2010). Less than 500m is considered very unsuitable to unsuitable, and 500-1000m is considered suitable to highly suitable by >2000m.

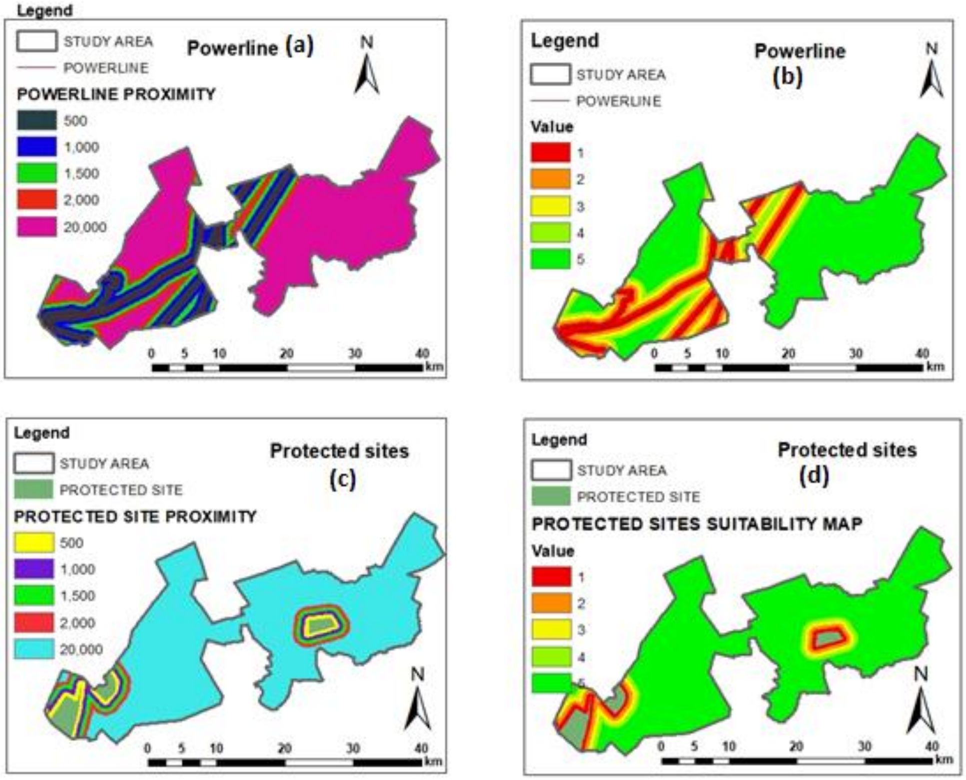


Figure 5.5:Criteria powerline and protected site's proximity and reclassification

i) Villages

Figure 5.6 (a) shows the buffer distance of village settlements in the study. On the other hand figure 5.6 (b) shows the village settlements classified into five suitsbility classes. According to Makonyo and Msabi (2021), to reduce odours and contamination from waste, landfills should be located away from residential areas. The villages criterion is necessary for this study because there must be an appropriate distance between landfill sites and villages and other residential areas, as well as the possibility of future expansion. (Kareem et al, 2021). Public concerns are raised when MSW landfills are located close to populated areas in addition to several environmental issues. A suitable distance of proposed dump sites from residential areas should be heavily taken into consideration because it involves a number of factors, including the health risk to inhabitants, property values, and residents' quality of life (Moon, 2020). As such, in the literature studies (Chabok et al., 2020; Elhamdouni et al., 2017; Makonyo and Msabi, 2021; Sener and Sener, 2020) used buffering for proximity distance for villages criteria. In this study, a proximity distance of fewer than 500m was considered unsuitable, the 500m-1000m was considered moderately suitable while a greater than 1000m proximity was considered highly suitable.

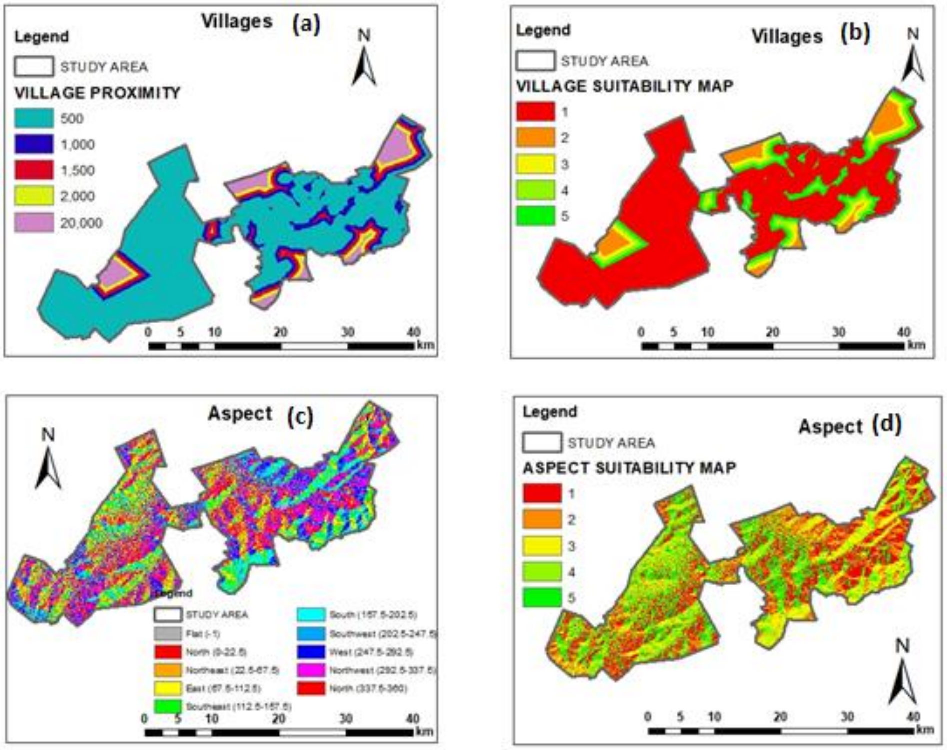


Figure 5.6: Criteria village and aspect's proximity and reclassification

j) Weighted Overlay Analysis

Weighted Overlay, according to Giap et al. (2003), is a method for integrating and combining various factor maps with data from a common measurement scale to create a single integrated result. We can assign weights for as many different elements as we want to investigate using the weighted overlay process. The weight identifies the proportional significance of the factor being taken into account. The weights' total combined value must be 100%. The Weighted Overlay tool in the spatial analysis tools allows for simultaneous weighting and blending of the values of each criteria (Giap et al.2003).

The value of an area of the land influences how suitable it is. The explanations for the value scales are as follows: 2 (less suitable), 3 (moderately suitable), 4 (suitable), and 5 (highly suitable). Therefore, the suitability for landfill construction increases with increasing value. Additionally, the value scale 1 and 2 (areas that are not suitable) are coloured in red, while the value scales 4 and 5 (areas that are suitable and highly suitable) are shaded in orange and green, respectively. On a final suitability map, very appropriate places for landfill construction are sparsely distributed throughout the second small region of the Mankweng cluster (see figure 5.7).

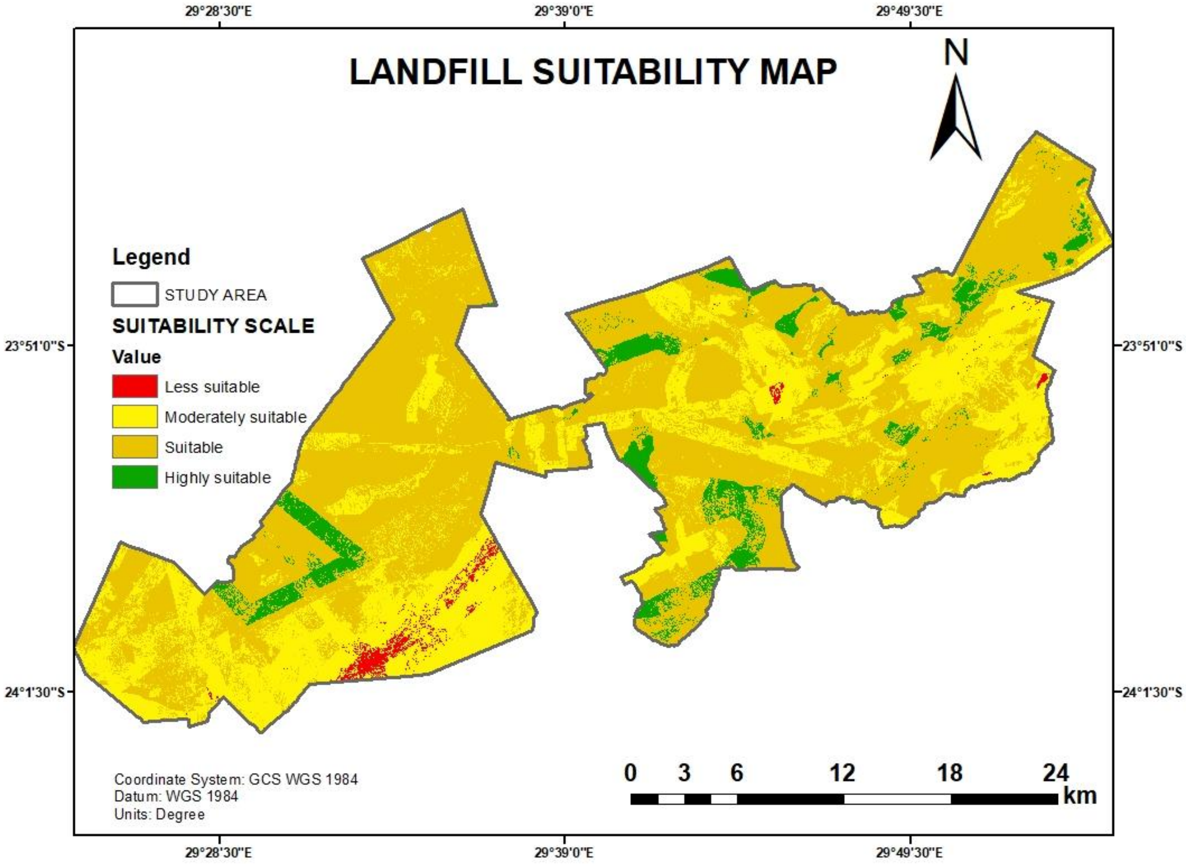


Figure 5.7: The landfill suitability map

The proportion by counts of suitable sites

The table 5.8 below shows that the selection of a waste disposal site in the Mankweng cluster is suitable for suitability scale values 5 and 4, respectively. A suggested landfill site location is found to be generally acceptable for around 67% of the area, while the other 33% is both permanently and currently unsuitable for landfill construction.

Table 5.8: The proportions of the suitability observed in the landfill site suitability map.

Factor	Suitability scale	Count	Proportion
Weighted overlay map	2 less suitable	8134	1%
	3 moderately suitable	243740	32%
	4 suitable	473948	61%
	5 highly suitable	45912	6%

5.3 Conclusion

The lack of suitable bareland to develop a landfill site in most cities is a serious concern. This has a severe environmental and social repecursion if not properly handled. This is due to the complexity of the process to select MSW disposal sites that requires taking consideration of factors such as environmental, social, economical, technical, and political. This study used GIS and MCDM (AHP) methods to select a suitable SW disposal site in Mankweng cluster. The criteria used in this study were drawn from the South Africa’s Department of Water Affairs and Forestry (1998) and literature review. At the beginning of the study, ten criteria including roads, rivers, elevation, slope, aspect, soil type, landuse-landcover, protected sites, powerlines, and villages were selected for evaluation. The AHP was used to compute the weights of the criteria. All the criteria were reclassified into five suitability classes (i.e not suitable, less suitable, moderately suitable, suitable and not suitable) and overlayed together using a GIS spatial analyst tool ‚Wieghted overlay‘. The suitability map produced indicate that 33% is not suitable to moderately suitable whereas 67% is suitable to very suitable. Therefore Mankweng cluster has suitable space for the construction of a disposal site.

CHAPTER SIX: SYNTHESIS

6.1 Introduction

Solid waste management (SWM) is a global pandemic. The increase in solid waste (SW) generation due to a rapid rise in economic growth, urbanisation, and population growth is a challenge. Instead of creating a separate management system for each form of waste, this increase necessitates an integrated sustainable strategy that covers all waste streams. (Nadiri et al., 2018; Şener and Şener, 2020; Weldeyohanis et al., 2020; Xiao et al., 2020). The management of municipal solid waste (MSW) is going through a grave stage owing to the lack of suitable facilities for treatment and disposal of the rising quantity of MSW generated in cities (Sener et al., 2010). Understanding the nature of SWM generation, including its quantity, and composition is essential towards the sustainable SWM. This results in the design, implementation, and improvement of WM systems as they require appropriate alternative methods of handling and treatment (Abdel-Shafy and Mansour, 2018; Johnima et al., 2022; Papachristou, 2009). In addition, waste generation forecasting is necessary to make proper planning and formulation of relevant policy measures towards sustainable SWM. Furthermore, this information will assist in the selection of a suitable waste disposal site, which will enable proper planning of land use that will promote sustainable SWM disposal. Consequently, this current study aimed to investigate the management of SW in the Mankweng cluster and find a potentially suitable area for a SW disposal site. The objectives of the study were to:

i. Evaluate household solid waste management practices and perceptions in the Mankweng Cluster.
ii. Forecast the municipal solid waste generation in the in Polokwane Local Municipality, South Africa.
iii. Identify a potential suitable landfill site through site suitability analysis using Geographic Information System (GIS) and Analytical Hierarchy Process (AHP).

6.2 Summary of the results

6.2.1 Evaluating household solid waste management practices and perceptions.

The results revealed that the practices and perceptions variation on household solid waste management in the wards under study is influenced by the difference in SWM service delivery. The study has discovered that food waste was the highly generated waste in both wards. The estimated SW generation rate for ward 25 was 0.27kg/cap/day whereas in ward 27 is 0.13kg/cap/day. This might be due to household income differences, and lifestyle behaviour since ward 25 is semi-urban, while ward 27 is mainly rural settlement. Additionally, the household income difference in both wards has been shown to have a significant impact on the waste generation quantity. According to Tsheleza et al. (2019), South Africa generated an average of 0.94 kg of MSW per day, ranging from 0.09 kg per day to 5.50 kg per capita per day. Additionally, World Bank, 2012 reported that the average daily generation of SW per capita in Sub-Saharan Africa is 0.65 kg, with a range of 0.09 to 3.0 kg. Sorting and separation of waste at source is not highly practiced (Strydom, 2018) and respondents indicated that their difficulties in waste sorting and separation is lack of available space for different waste type bins for storage. Waste collection in ward 27 is done when the communal bins are full, whereas in ward 25 is collected once a week. Both wards indicated that improper waste management practices lead to, amongst to other things, illegal dumping. Furthermore, the respondents stated that illegal dumping occurs because of ignorance, lack of knowledge and unavailable waste collection services. Niyobuhungiro and Schenck (2022), reported similar results. They recommended that the municipality should build recycling facilities, install disposal bins on hotspots for illegal dumping, and promote good SWM practices.

6.2.2 Forecasting of Municipal Solid Waste Generation.

The results of the study further showed that the multiple linear regression model that was used for forecasting waste generation rate in Polokwane Local Municipality yielded coefficient of determination (R^2) of 0.88, with RMSE of 50690.2 ton/year and $p<0.000$. The model was significant at $p \leq 0.05$ and was therefore used to forecast future SW generation rate from 2022 to 2026. The model showed that in the future the quantity of MSW is set to increase leading to the need for construction of a new landfill. These results will help SWM authorities to plan and make informed decisions on the quantity of waste that is likely to be generated in the future and subsequently, to decide on the possible need for a new landfill site. The significancy demonstrated by the independent variables regarding the dependent variable (Waste generation) in the study reveals similarity observed in the studies of Popli et al. (2021).

6.2.3 Integrating GIS and multi‐criteria decision analysis for landfill site selection.

The results for site selection for a new landfill estimated that roughly 67% of the area in Mankweng cluster is suitable for the construction of a disposal site. However, in future the land available might shrink due to rapid urban expansion. This study has demonstrated the effectiveness of the use of GIS-based MCDA in finding a suitable location for landfill site that correlates with other studies such as Chabok et al., 2020; Makonyo and Msabi, 2021; Moon, 2020; Sener and Sener, 2020. This literature studies further show the similarity of the literature from various regions and the South African Regulations regarding criteria used of site selection of a landfill.

6.3 Conclusion

The study aimed to investigate the management of SW in the Mankweng cluster and find a potentially suitable area for a solid waste disposal site. The outcome of the study has shown that waste management practices and perceptions of households in Mankweng cluster has an influence on waste generation as well as its composition. For instance, waste generation rate and composition differed across the two wards (i.e., rural vs urban) due to income differences and lifestyle behaviour. Another observation that was made involved the differences in waste collection between the rural-based ward 27 and urban-based ward 25. In rural-based ward where there is no municipal waste collection, households' resort to burning and burying of solid waste. In some instances, the problem of illegal dumping was observed. On the other hand, in the urban-based ward there was a proper waste collection service, and the waste is then disposed of at the Mankweng transfer station in transit to the main landfill in Polokwane. Further, more the results of the study have shown that simple multiple linear regression model can be used to forecast waste generation rate in Polokwane Local Municipality. The model has shown a high significance level and was able to explain about (R^2) 88% of the data variation in the study and it was then deemed as a robust model to forecast SW generation from 2022 to 2026. This non-complex modelling can be used by waste management authorities who have minimal expertise in statistics to forecast solid waste generation and make informed decisions. However, in the future big datasets and complex statistical modelling approach such as machine learning and artificial intelligence will be explored to forecast solid waste generation. Finally, the outcome of the study has demonstrated the effectiveness of integrating GIS-based multicriteria decision analysis (AHP) and community perceptions in finding a suitable place for locating a landfill site.

6.4 Recommendations

- ✓ The policy and decision makers in the research area and other clusters in the nearby municipality can use the results of the waste generation in this study region to plan for SWM. This is also applicable to other localities, cities, and villages that share the study area's features. Especially those without any engineered SW disposal sites or SWM characteristics, content, quantities, or results that could aid as a preliminary point for such planning. Moreover, there is an opportunity of waste recycling activities on different waste.
- ✓ The municipality should promote sponsored recycling facilities, instructional programmes, awareness campaigns about sustainability, and lessons on creative ways to reuse recyclables producers of several recyclable product sources ought also to spread to rural and distant societies.
- ✓ It is acknowledged that, like many rural and distant areas, the municipality's efforts to provide the amenities and services required to progress toward sustainable WM may be hampered by financial limitations. Consequently, the municipality should seek more investments from private companies.

- ✓ The municipality should investigate alternate HSW approaches and organisation with surrounding communities as the villages and towns are normally far from markets for recyclables.
- ✓ It is recommended that more research studies be conducted on this topic of waste generation and composition with an increased data collection period as waste quantity variation can be influenced by several factors.
- ✓ Waste forecasting needs a long historic period data to produce accurate and reliable results. As such, municipalities are encouraged to weigh their waste as this will assist them in the future to make feasible decisions based on facts and reliable data.
- ✓ The municipal waste disposal site should install weighing bridges to record the incoming daily waste to enable accurate solid waste forecasting.
- ✓ To avoid the local municipality in lacking suitable land to dispose of its waste amidst high population grow and rapid urban expansion, vacant land for future waste disposal facilities should be reserved.

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Appendix 1

Faculty of Science and Agriculture

Department of Geography and Environmental Sciences

Solid waste management and selection of a solid waste disposal site in Mankweng cluster

Research questionnaire cover letter

Dear participant

I am Tsakani Germina Selomo, a master's student in the department of Geography and Environmental Science at University of Limpopo. I cordially invite you in participating in a research study titled **"Solid waste management and selection of a**

solid waste disposal site in Mankweng cluster" that is supervised by Dr Letsoalo and Mr. Mashao.

<u>Consent to take part in the research study.</u>

I……………………………………. (Respondent's name) willingly decide to take part in this research study. I am fully aware that even if I decide to participate now, I can retreat at any time or refuse to answer any question that brings discomfort. I understand and agree to give information that is reliable and accurate to my best knowledge. I comprehend that all information I provide for this study will be treated confidentially. I understand that I am free to contact any of the people involved in this research study to seek further clarification and information.

Signature…………………….

Questionnaire: Residents of Mankweng cluster

Section A: Socio-economic characteristics data

1. Gender

Female	
Male	

2. Age

18-28	
29-38	
39-49	
50+	

3. Highest qualification

No schooling	
Primary education	
Secondary education	
Tertiary/ Post matric	

4. Employment status

Unemployed	
Employed	
Self-employed	
Student	
Pensioner	

5. How many family members do you reside with?

6. Monthly household income

< R1000	
R1000 – R3000	

R3000 – R5000	
R5000 – R7000	
R7000 – R9000	
> R9000	

Section B: Waste management related question.

7. What is waste in your view?

………...

8. What type of waste do you generate at home?

Food/ organic waste	
Builders' rubbles	
Paper	
Garden waste	
Plastic and rubber	
Others, specify	

9. Do you separate and sort waste prior collection or disposal?

Yes	No

if yes, what do you do with the sorted waste?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

……………………………………………………………………………………

10. Do you find waste separation at source difficult?

Yes	No

Please explain,

………………………………………………………………………………………..……………

…………………………………………………………………………………………………

……………………………………………………………………………………

11. What type of container do you use to store waste?

Plastic bag	
Plastic bin	
Metal bin	
Communal bin	
Other, specify	

12. How many times is waste collected in your area?

No collection service	
Once a week	
2-3 a week	
5 working days	

13. Is the frequency of collection of waste sufficient?

Yes	No

Please explain why,

…………………………………………………………………………………………………

…………………………………………………………………………………………………

……………………………………………………………………………………

14. How do you handle the waste generated if you missed the waste collection day or when you do not receive waste collection service?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

……..

15. Do you recycle waste?

Yes	No

16. If yes, what type of waste do you recycle?

Plastic	
Papers	
Metal	
Glass	
Food refuse	
Other, specify.	

17. How many bags of waste do you dispose of each week?

1-2 bags per week	
3-4 bags per week	
5-6 bags per week	
7+ bags per week	

18. What type of disposal method do you use?

Burn the waste inside the yard.	
Bury the waste inside the yard.	
Dispose waste on illegal spot areas like near rivers, bushes, canals etc.	
Haul the waste to a nearby waste facility such as transfer station, community dumpsite, communal bins.	
The waste is collected and taken to the landfill.	

19. Is there illegal dumping of solid waste in your area?

Yes	No

If yes, who collect that waste?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………………………………………

20. In your opinion, what causes illegal dumping of solid waste in your area?

Lack of knowledge about proper solid waste management	
No waste collection service	
Long distance to the landfill or transfer station	
Ignorance of people by littering, illegal dumping	
Insufficient waste collection days, lack of communal bins	
Other, specify	

21. What do you think the municipality could do to reduce the illegal dumping?

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

22. What do you think can be done to improve solid waste management in your area?

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

23. What do you think about the landfill site next to you?

Good	Bad

24. How do you think having a landfill site close will impact your community?

Good	Bad

25. How do you think having a landfill site close to you will affect you in the following themes?

Socially	
Environmentally	
Economically	

Appendix 2

Faculty of Science and Agriculture

Department of Geography and Environmental Sciences

Solid waste management and selection of a solid waste disposal site in Mankweng cluster

Research interview guide cover letter

Dear participant

I am Tsakani Germina Selomo, a master’s student in the department of Geography and Environmental Science at University of Limpopo. I cordially invite you in participating in a research study titled **“Solid waste management and selection of a**

solid waste disposal site in Mankweng cluster" that is supervised by Dr Letsoalo and Mr. Mashao.

<u>Consent to take part in the research study.</u>

I…………………………………… (Respondent's name) willingly decide to take part in this research study. I am fully aware that even if I decide to participate now, I can retreat at any time or refuse to answer any question that brings discomfort. I understand and agree to give information that is reliable and accurate to my best knowledge. I comprehend that all information I provide for this study will be treated confidentially. I understand that I am free to contact any of the people involved in this research study to seek further clarification and information.

Signature…………………….

INTERVIEW GUIDE: KEY INFORMANTS

A. PERSONAL INFORMATION

1. What is your age?
2. What is your gender (sex)?
3. Do you live within the Polokwane local municipality?

B. WORK ENVIRONMENT INFORMATION

1. What is your position in the Polokwane local municipality?
2. How long have you been working in this municipality?
3. Which department are you working under?

C. CAN YOU PLEASE GIVE SCALE WEIGHTING OF THE FOLLOWING CRITERIA AGAINST EACH OTHER FOR THE POTENTIAL LANDFILL SITE USING THE KEY SCALE BELOW?

WEIGHTING THE CRITERIA TABLE

	River	**Soil type**	**Land use**	**Slope**	**Elevation**	**Power lines**	**Roads**	**Villages**	**Archaeological site**	**Protected site**

Rivers										
Soil type										
Landuse										
Slope										
Elevation										
Power lines										
Roads										
Villages										
Archaeological sites										
Protected sites										

Key table for Scale of preference between two criteria in AHP method.

Number scale	**Degree of preference**	**Explanation**
1	Equal importance	Two criterions contribute equally to the objective.
3	Moderate importance	Experience and judgement slightly favour one criterion over another.
5	Strong importance	Experience and judgement strongly preferred one criterion over another.
7	Very strong importance	One criterion is preferred very strongly over another.
9	Extreme importance	The evidence prefers one criterion over another is of the highest possible order of assertion.
2, 4, 6, 8	intermediate	Used to present concessions between the preference in weights 1, 3, 5, 7 and 9.

D. SELECT ONE OF THE PROPOSED ATTRIBUTE VALUES IN EACH CRITERION FOR SUITABILITY RATING FOR A POTENTIAL LANDFILL SITE.

Criterion (unit of measure)	**Attribute values**	**The selected attribute value**

Rivers (km)	0-1	>1			
Groundwater depth (m)	0-2	2-4	4-6	>6	
Soil type	Soil A (loam sand) Soil B (sand) Soil C (sandy clay) Soil D (sandy clay loam) Soil E (sandy loam)				
Landuse	Industrial area Archaeological Orchards	Villages Agricultural lands Unused land	Township		
Slope (degree)	<5	5-10	>10		
Elevation (a.m.s.l)	16-22	22-28	28-34	>34	
Powerlines (m)	<30	>30			
Roads (m)	0-500 2000-3000	500-1000 >3000	1000-2000		
Villages (m)	<5	5-10	>10		
Archaeological sites (km)	0-1	1-3	>3		
Protected sites (km)	<5	5-10	>10		

Thank you!!!!!!