DEVELOPMENT OF A GIS DATABASE PROTOTYPE FOR EFFECTIVE SOLID WASTE MANAGEMENT IN THOHOYANDOU CBD AND ITS ENVIRONS, LIMPOPO PROVINCE

BY

MURENDENI NETSHAULU

University of Venda

February, 2020

DEVELOPMENT OF A GIS DATABASE PROTOTYPE FOR EFFECTIVE SOLID WASTE MANAGEMENT IN THOHOYANDOU CBD AND ITS ENVIRONS, LIMPOPO PROVINCE

BY

Murendeni Netshaulu
Student Number: 14014230

Supervisor: Dr N.S Nethengwe

Co Supervisor: Dr N. V Mudau

A Masters Research Dissertation submitted to the School of Environmental Sciences, Department of Geography and Geo-Information Sciences, University of Venda

University of Venda

February, 2020

DECLARATION

I, Murendeni Netshaulu, hereby declare that the dissertation for Masters degree in the Department of Geography and Geo-Information Sciences, School of Environmental Sciences at the University of Venda, hereby submitted by me, has not been submitted previously for a degree at this or any other University, that is my own work and that reference materials contained herein have been duly acknowledged.

Student: Murendeni Netshaulu

Signature...M.Netshaulu..... Date: .....16/07/2020.....

DEDICATION

I dedicate this research to my loving siblings Thendo and Makondelele Netshaulu. May this research motivate and inspire you to achieve remarkable things. May this research also serve as a reminder that with hard work and dedication anything is possible.

ACKNOWLEDGEMENTS

I would like to thank God for strength, love and wisdom.

I would also like to thank the following people:

- My supervisor Dr N.S Nethengwe and my co- supervisor Dr N.V Mudau for their invaluable assistance in this research for their comments and support really helped me a lot.
- My loving dad (Alfred Netshaulu), and mother (Sarah Kwinda) for motivating and supporting me throughout my studies.
- Mr P.E Ratshiedana for helping me construct the budget for the research
- National Student Financial Aid Scheme (NSFAS) for paying for my first-year fees and for paying for my second-year registration fees.
- Dr H. Motlhaka for proof-reading my masters research proposal
- Dr B. Maposa for editing my research dissertation

ABSTRACT

The biggest environmental challenge affecting developing countries is the rapid growth of solid waste and its consequent poor management. Management of waste requires data from different entities associated with solid waste, and Geographic Information Systems (GIS) has the capability to integrate data from different sources. The lack of knowledge and data concerning waste attributes due to the inability of municipalities to manage data from different sources contributes to poor management of waste. Therefore, this study aimed to develop a GIS database prototype for efficient solid waste management in Thohoyandou Central Business District (CBD) and its environs. Previous studies have never tried to create a database which contains data on the nature, and the handling of solid waste generated by households, business establishments, and institutions; there is also lack of information on the locational suitability of landfill; and the compliance of landfill with the environmental, health and safety regulations in Thohoyandou. The study adopted qualitative and quantitative methods of data collection. Field observation, questionnaires, and Global Positioning Systems (GPS) were used to elicit data on the nature and handling of waste generated from households, institutions and business establishments. Descriptive statistics was used to analyse the data, and the results were presented in the form of graphs. To establish the extent to which Thohoyandou Landfill complies with the environmental, health and safety regulations, a checklist was derived from the minimum requirements for the disposal of waste by landfill and the Occupational Health and Safety Act 85 of 1993. Descriptive statistics was used to analyse the data, and the results were presented as narrative and graphs. GIS and Analytical Hierarchy Process (AHP) were used to evaluate the locational suitability of the Thohoyandou Landfill. The criteria used were slope and proximity to residential areas, cultivated areas, fragile ecosystems, rivers, and town. Euclidian distance, Reclassify and Majority filter tools were used for data analysis, and the results were presented as a suitability map. The study found that organic waste was dominant in households, while, paper/ cardboard was dominant in business establishments and institutions. There was lack of segregation of waste from the households. The study found that the landfill complied with the health and safety regulations. However, the study also found that with respect to the environmental regulations, Thohoyandou Landfill was partially compliant due to inadequate equipment, fencing, and waste acceptance procedures. The financial challenges contributed to the lack of compliance with some of the environmental regulations. Thohoyandou Landfill was in an unsuitable location due to slope and its proximity to rivers, residential area and road. The location of the landfill poses a threat to the environment. The results were uploaded onto a relational database with the use of Microsoft Access. The data from Microsoft Access was exported to Caspio cloud. Query of data is possible.

Keywords: Database, Solid Waste, Waste management, Geographic Information Systems (GIS), Urbanisation, Solid waste treatment facilities

TABLE OF CONTENTS

Contents

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

LIST OF ACRONYMS AND SYMBOLS

TIN	Triangulated Irregular Networks
GIS	Geographical Information Systems
°C	Degrees Celsius
GPS	Global Positional Systems
DBMS	Database Management Systems
RDBMS	Relational Database Management System
ODBMS	Object Database Management System
ORDBMS	Object- relational Database Management Systems
AHP	Analytical hierarchy process
MCDM	Multi-Criteria Decision Making
MSW	Municipal Solid waste
LFGRS	Landfill Recovery System
%	Percent
CBD	Central Business District
PPE	Personal Protective equipment
Km	Kilometre
m	metre
NEMWA	National environmental Management: waste act
GHG	Green House Gases
WHO	World Health Organisation
DWAF	Department of Water and Sanitation
EPR	Extended Producer Responsibility
TPB	Theory of Planned Behaviour
IT	Information technology
SLC	System Life Cycle
ER	Entity relationship
ESRI	Environmental Systems Research Institute
StatsSA)	Statistics South Africa
USGS	United States Geological Survey
TBJ	Thohoyandou Block J

CHAPTER 1: INTRODUCTION

1.1 Background to the study

According to Soroudi *et al.*, (2018) the biggest environmental challenge affecting both developed and developing countries is the rapid growth of solid waste. Human activities create or produce waste and the way the solid waste is collected, stored, handled and disposed of may pose a risk to the environment and public health (Reddy, 2016; and Batool and Ch, 2009). According to Mohee and Simelane (2015: 6), Minghua *et al*., (2009), Al-Khatib *et al*., 2010), and Khan *et al*., (2018) waste generation is increasing every day, and this is attributed to the rapid economic growth and improving lifestyles, population growth and the uncontrolled urbanisation which characterise population dynamics in the developing countries. Furthermore, this is due to the continued availability of raw materials (Mohee and Simelane, 2015: Reddy, 2016). The generation of waste and the quantity vary from one country to another. According to Mohee and Simelane (2015: 6) approximately 1.3 billion tons of municipal solid waste (MSW) are currently generated worldwide every day.

Mohee and Simelane (2015:3) stated that "In urban centres throughout Africa, less than half of the solid waste generated is collected, and 95 percent of this waste is either contained or recycled". South Africa generates over 42 million cubic metres of solid waste every year (Mohee and Simelane, 2015: 2). In South Africa, the majority of the waste (90.7%) is disposed in landfill sites which are often improperly designed and operated or the waste is disposed of at an open dump. Less than 10% of all waste generated in South Africa is recycled (Republic of South Africa, 2000). According to Visser and Theron (2009) waste generated in most urban areas are expected to quadruple by 2025. Solid waste is an inevitable consequence of production and consumption activities in any economy (Sasikumar and Krishna 2009). According to Sasikumar and Krishna (2009) in developing countries, solid waste management consists of activities such as collection, transportation and the disposal of waste. According to Batool and Ch (2009) the improper handling of the solid waste may lead to the contamination of soil, water, atmosphere and have an impact on public health.

1.2 Problem statement

According to Soroudi *et al.,* (2018) the biggest environmental challenge affecting developing countries is the rapid growth of solid waste and its consequent poor management. This is attributed to rapid population growth due to the uncontrolled and unplanned urbanisation that characterises population dynamics of developing countries. More importantly, it is attributed to the individual attitudes and value systems as they relate to waste management. In addition, the rapid economic growth is also responsible for the increase in the solid waste generated (Guerrero *et al.,* 2013). Poor management is attributed to the capitalist economy which promotes mass consumerism. Management of waste requires data from different entities associated with solid waste and GIS has the capability of integrating data from different sources. There is a lack of knowledge and data concerning waste attributes due to the inability of municipalities to manage data from different sources. This often contributes to the poor management of solid waste. Therefore, this study aimed to develop a GIS database prototype for the effective management of solid waste.

1.3 Research aim and specific objectives

1.3.1 Research aim

The main aim of the study was to develop a GIS database prototype for effective solid waste management in Thohoyandou CBD and its environs.

1.3.2 Specific objectives

The specific objectives were to:

- Identify the solid waste generators/sources; and determine nature and estimate amount of waste generated;
- Identify and assess the type of solid waste that were accepted at the solid waste facilities;
- Establish the extent to which the Thohoyandou landfill complies with the environmental, health and safety regulations;
- Evaluate the locational suitability of the Thohoyandou landfill using Geographical Information Systems (GIS) and the Analytical Hierarchy Process (AHP); and
- Develop a GIS database prototype for effective solid waste management.

1.4 Research questions

- Who are the solid waste generators/ sources and what is the nature and the estimated quantity of waste produced?
- What are the types of waste disposed at the identified waste treatment facilities?
- To what extent does the Thohoyandou landfill comply with the environmental, health and safety regulations?
- How suitable is the location of the Thohoyandou landfill when evaluated using Geographical Information Systems (GIS) and the Analytical Hierarchy Process (AHP)?
- How can a GIS database prototype for effective solid waste management be developed?

1.5 Delimitation of study and description of the study area

1.5.1 Delimitation of the study

The study was conducted in Thohoyandou and it focused on solid waste. The study identified the solid waste generators/sources; determined the nature and estimated amount of waste generated; identified the solid waste facilities and the type of waste that was disposed of in the solid waste facilities; evaluated the extent to which the Thohoyandou landfill complied with the environmental, health and safety regulations; evaluated the locational suitability of the Thohoyandou landfill using GIS and AHP; and developed a GIS database for the management of the solid waste. The study, however, did not focus on the solid waste generators such as hospitals, clinics, mortuary and the pharmacy stores because of the nature of the waste and the protocols that are associated with its handling.

1.5.2 Description of the study area

- ***Location***

Thohoyandou is a town which is situated in Limpopo Province, South Africa. Thohoyandou falls in the Vhembe District and the Thulamela Municipality. The geographic co-ordinates of Thohoyandou town are: 22^0 57' S, 30^0 29'E.

- ***Population***

There has been population growth in the area since the year 2001. The population increased from 280 829 in 2001 to 602 819 in 2010, the population difference was 21 990. The population increase is 0.62%, (TLM IWMP, 2011). Population growth has a huge influence on

the amount of waste that is generated in an area. As the population growth increases the amount of solid waste generated also increases.

- ***Climate***

The rainfall peaks are evident from December to February. The temperature ranges from 16 °C and 40 °C in summer. In winter, the temperature ranges from 12 and 22 °C. Climate is very vital in the study because climate is one of the parameters that needs to be considered in evaluating the locational suitability of the solid waste landfill. In addition, climate is also vital in solid waste treatment processes. For example, the incineration of solid waste would be challenging if the waste would be wet.

- ***Fragile ecosystems***

There are three wetlands that are in Thohoyandou. One wetland is found in Thohoyandou next to Golgotha. The geographical co-ordinates are: 30° 27' 00" E - 30° 27' 04" E and 22° 58' 10" S - 22°58' 14" S. The second wetland is located at Thohoyandou block F. The geographical co-ordinates are: 30° 27' 55" E- 30° 28' 04 E and 22° 58' 04 S- 22° 58' 45" S. The third wetland is located at Thohoyandou West of Liivha secondary school. The geographical co-ordinates are: 30° 27' 50" E- 30° 27' 60" E and 22° 57'28" S -22° 57' 57" S.

- ***Socio-economic characteristics***

The household income level of Thohoyandou is low, medium and high. According to Ogola *et al*., (2011) there is a significant relationship between the household income and the amount of waste generated. On one hand areas with high household income generate more waste while on the other hand areas with low household income tend to have less waste generated. Regions that are characterised by high income are known for 'use and throw' habit generating huge quantity of waste. On the other hand, regions that have a lower income use and reuse the resources available to the maximum extent, therefore, generating lower quantity of waste.

- ***Land-uses***

Thohoyandou area consists of different types of land-uses such as:

- institutions (primary and secondary schools, colleges, university (the University of Venda), hospitals, clinics, government offices, post offices, police stations).
- commercial (CBD- Designed as a supermall)
- Residential areas (one home household, multi-family household).
- Industrial areas situated in Shayandima Town.

- ***Sectors of the economy***

In Thohoyandou five sectors of the economy exist. These are primary, secondary, tertiary, quaternary, and quinary sectors. The primary activities are farming, fishing and quarrying. Secondary activities include manufacturing and construction. Quaternary activities include libraries and scientific research (University of Venda). The tertiary activities are the restaurants, media (Phalaphala Fm), insurance, law and healthcare facilities (Tshilidzini Hospital, Block G Clinic, Makwarela Clinic and Hayani Health care and many private surgeries). The Quinary activities in Thohoyandou are university (University of Venda), media, and health care.

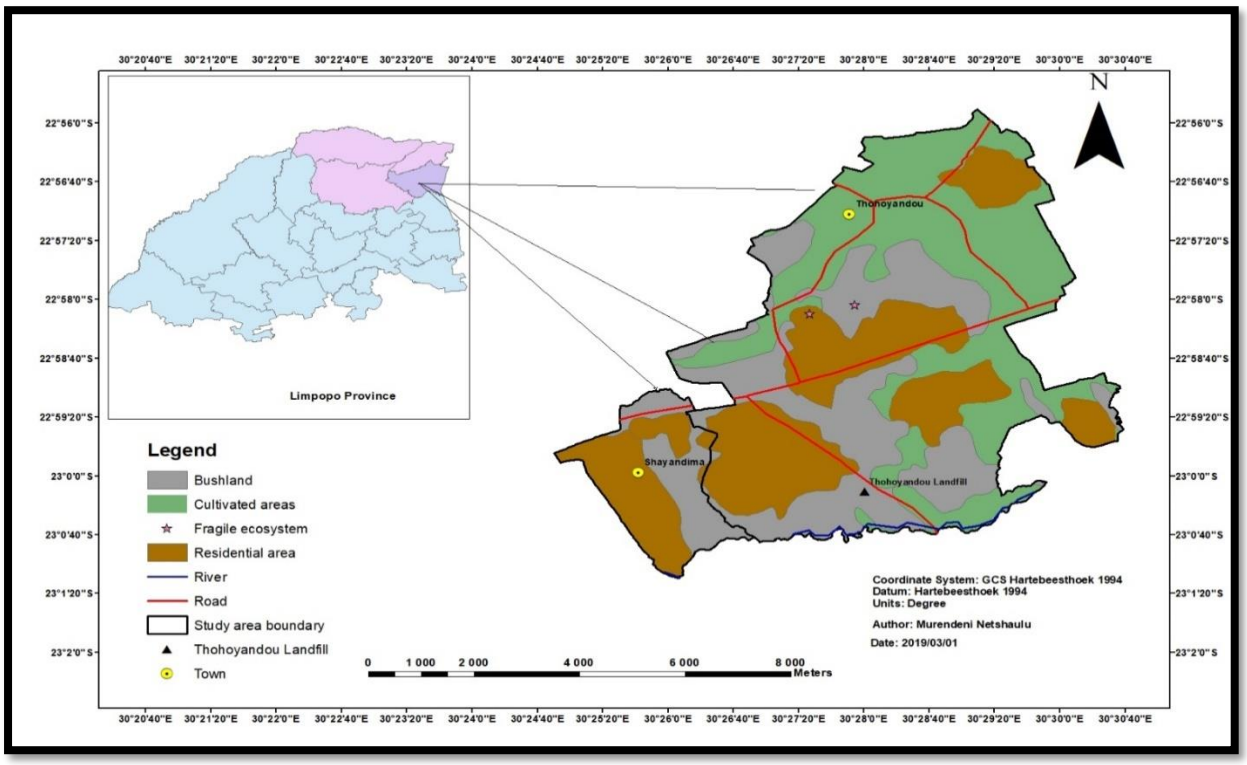


Figure 1:1(a): Map of the study area (Thohoyandou and its environs).

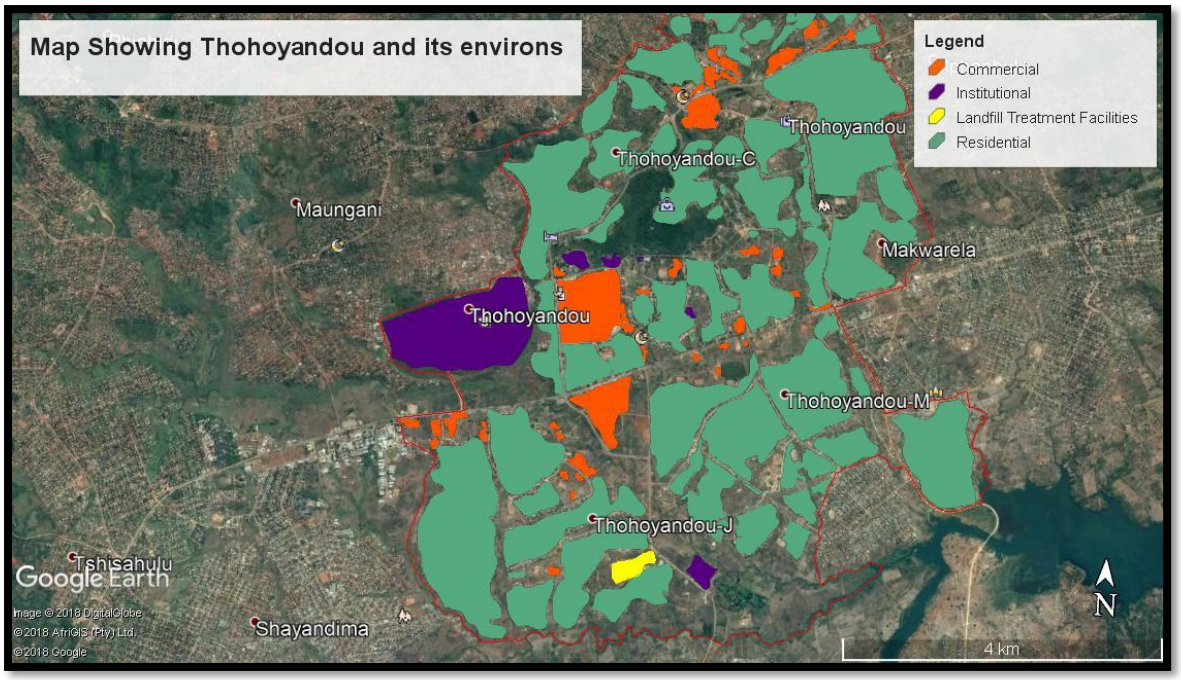


Figure 1.1 (b): Map showing the different land uses in the Thohoyandou and its environs areas (Sourced from: Google Earth, 2018)

1.6 Justification of the study

A study done by Nefale (2018) focused on the dominant types and sources of solid waste disposed at the Thohoyandou Block J (TBJ) landfill site, efficiency and effectiveness of operation of the TBJ landfill site and operational challenges. The similarity of this study and that of Nefale (2018) was that they both used a mixed method of approach. However, the difference was that Nefale focused on the disposal stage in the waste management process and the development of GIS database for effective solid waste management in Thohoyandou CBD and its environs, Limpopo Province. The current study focused on the entire management of solid waste from the generation, collection, storage, handling, waste recovery and waste treatment as well as the final disposal of the waste.

In a study done by Ogola *et al*., (2011) qualitative and quantitative methods were used. The quantitative method was applied through weighting waste generated in all the different waste generators. Statistical analysis was used to establish whether there was any significant relationship between the quantity of waste obtained from the households and the income groups. The development of a GIS database was different because it did not focus solely on the households as the generators; rather it also considered other waste generators such as the residential, institutions, and the commercial (business) establishments. The research did not seek to establish the significant relationship between the quantity of waste generated and the household income.

Development of a GIS database for effective solid waste management in Thohoyandou CBD and its environs was unique because it looked at the whole waste management as a system: from the solid waste generators, the collection of waste, transfer of the waste and the final disposal facilities. Most importantly, it used GIS techniques to evaluate the locational suitability of the solid waste landfill. The study has both practical and theoretical significance. The study would produce a GIS database prototype that would help in the management of solid waste in Thohoyandou and its environs. In addition, waste operators/ handlers at the Municipality, would know ***what*** kind of solid waste management-related infrastructure was currently available and ***where.*** This research would therefore provide valuable input for informed decision making.

The study also provides a theoretical base with respect to the:

- Solid waste generators and the sources;
- The waste facilities (how facilities characterise the waste as well as the types and quantity of solid waste generated and disposed);
- Extent to which the landfill complied with the environmental, health and safety regulations. The results can be used to improve the compliance of the landfill with the environmental, health and safety regulations;
- Locational suitability of the landfill.

Ramachandra (2006: 2) stated that 'knowing the sources and types of solid wastes as well as the information on composition and the rate at which waste is generated/ disposed of is, therefore, essential for the design and operation of the functional elements associated with the management of solid waste'. The identification of the solid waste generators and the types of waste generated would help limit the potential for harm as it enables the correct handling procedures appropriate to waste type to be followed (Dennis, 2000:293). The Thulamela Local municipality is most likely to benefit from this research because it would contribute to the sustainable management of the solid waste. The research has environmental, economic and social benefits.

The environmental benefit is that, since the research looked at the compliance of the solid waste landfill with the environmental, health and safety regulations, this would contribute to social and environmental benefits. Where the solid waste landfill was not complying, measures could be taken for it to be more compliant. More compliance would mean less environmental damage (less soil, air, and water contamination), in some cases, less nuisance for the people living around the landfill, and more safety for the workers who handle waste. For example, if the solid waste landfill was non-compliant in terms of the personal protective clothing, then

measures could be taken to ensure that it becomes complaint. This would mean that there is a social benefit because people would be safe from injury. According to the set minimum requirements of 1998 for the disposal by landfill, the more compliant the solid waste treatments are with the environmental regulations, the lesser the environmental damage.

1.7 Definition of key concepts

Database: A database is a collection of interrelated stored data that serves the need of multiple users within one or more organisations- that is, an interrelated collection of many different tables (Teorey *et al*., 2011: 2). A GIS database is defined as "a computer-based system that can handle a variety of information, including both locational and attribute data of a particular feature. It not only displays and produces maps but can also record and analyse descriptive characteristics of map feature" (Kordi *et al*., 2016: 235).

Waste: Rhyner *et al.,* (2017: 6) defined solid waste as "unwanted or discarded material with insufficient liquid content to be free flowing. waste materials arising from domestic, trade, commercial, industrial, agricultural and mining activities, and from the public services". According to South Africa (2008) in terms of National Environmental Management: waste act (NEMWA), waste is defined as any substance that, whether or not that substance can be reduced, reused, recycled, and recovered- (a) that is surplus, unwanted, rejected, discared, abandoned or disposed of; (b) which the generator has no further use for the purpose of production; (c) that must be treated or disposed of and includes waste generated by the mining and medical. According to the NEMWA, Waste includes domestic waste, building and demolition waste, business waste, and inert waste. Waste may be viewed as a left-over, a redundant product or material of no or marginal value of the owner and which the owner wants to discard. Being waste is not an intrinsic property of an item but it depends on the situation in which the item appears as defined by the owner or in other words, how the owner values the item. What is waste to to one person may not be waste to another person (Christensen, 2011).

Waste management: waste management system is defined by four phases which include: (a) waste generation which includes the waste categories, waste type, waste quantity and composition; (b) collection and transport: Source separation, waste collection centres, recycling centres, collection and transport and bulk transfer; (c) treatment: separation of waste in material recovery facilities, incinerators, biological treatment, and other operations or processes changing the characteristics of waste (Christensen, 2011). Government of South Africa (2007) defined waste management as the necessary measures that are taken to

prevent, minimise the amount of waste that is produced and the risk posed to health and the environment.

Geographic Information Systems (GIS): "A system for capturing, storing, checking, integrating, manipulating, analysing and displaying data which are spatially referenced to the Earth" (Heywood *et al.,* 2011). A computerised system that includes locations of all geographical characteristics of an area of land and items which may include elevation, houses, public utilities, or the location of bodies of water, aquifers and flood plains, (Sasikumar and Krishna, 2009: 286).

1.8 Structure of the Dissertation

Chapter 1 establishes the background to the study, research problem, research aim, specific objectives, research questions, delimitation of the study, description of the study area, justification/significance/ motivation of the study, and the definitions of key concepts.

Chapter 2 reviews relevant literature on the concept of waste management focusing on the sources of solid waste, generation and composition of solid waste, rate at which waste is generated, the different categories of waste, the segregation of waste, the storage of waste and the final disposal of the waste. The research also looked at the various methods of waste recovery and treatment. The study reviewed the waste management in developing countries focusing at the drivers of waste generation and the implications of those drivers. The study also considered the influence of a capitalist economy in the generation of waste. The section reviewed the government interventions to reduce plastic bags (Environmental Levy Scheme) and individual attitudes and value systems as they relate to waste management. The environmental, health and safety regulations were also reviewed as the study also looked at the application of GIS in solid waste management. Lastly, the chapter highlighted the conceptual framework that underpinned the study.

Chapter 3 focused on the materials and methods used to collect, analyse the data, and present the results.

Chapter 4 focused on the results and discussion on the solid waste generators in Thohoyandou and the nature and the estimate of the amount of solid waste generated. This chapter also presented the results and discussion of the various solid waste facilities available in Thohoyandou and the nature and acceptable level of estimate amount of waste.

Chapter 5 focused on the results and discussion on the extent to which the Thohoyandou Landfill complied with the environmental, health and safety regulations.

Chapter 6 focused on the results and discussion on the locational suitability of the Thohoyandou Landfill using GIS and AHP.

Chapter 7 focused on the results and discussion of the GIS database that was constructed.

Chapter 8 focuses on the conclusion and the recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literature that is related to solid waste management. The study reviewed the literature relating to the concept of waste management, solid waste management, solid waste generators, the composition of waste, the rate of solid waste generation, the categorisation of waste, segregation, storage and collection of solid waste from generators. The study also reviewed the waste management in developing countries, challenges of solid waste management as well as methods of solid waste recovery: recycling, recovery, thermal treatment, biological treatment, and landfills in developing countries. Furthermore, the influence of the capitalist economy in the generation of solid waste was discussed. The application of GIS and AHP in the management of solid waste with regards to evaluating the locational suitability of landfills was reviewed. In addition, the GIS database management systems were considered. Lastly, the study reviewed the South African environmental, health and safety regulations of landfills.

2.2 The concept of waste management

Waste management includes the collection, transportation, storage, treatment, recovery, and disposal of waste (Bilitewski and Hardtle, 1997). According to Ramachandra (2006) solid waste managemnt is associated with the waste generation, its storage, collection, transfer and transport, processing and disposal manner in accordance with the best principles of public health, economics, engineering, conservation, aesthetics, public attitude and other environmental considerations.

2.2.1 Sources of solid waste generation

According to Sasikumar and Krishna (2009); and Reddy (2016) solid waste is generated in the residential premises (households), commercial and business establishments, street sweepings, institutional premises (such as schools, hospitals, government offices, clinics and town halls). Solid waste is also generated from the construction facilities but solid waste from households is the major fraction of municipal solid waste (Hering, 2012).

A research study carried out by Ogola *et al.*, (2011) titled ‘Management of municipal solid waste: A case study in Limpopo Province, South Africa’. aimed to determine the relationship between the different levels of household income and quantity of the waste generated. The study used quantitative method to weigh the waste generated in all the waste generators.

During the field survey, waste separation and measurements on site were performed at individual households from three income groups based on the municipality categories of income according to the size of the residential stand. A 10-litre plastic bin and 100 kg weighting scale were used to collect and weigh the waste selected for sampling from households. Gloves and refuse bins were used for sorting the waste. The face marks and work suits were also utilised for protection during the sampling and measurement period.

The data was analysed using statistical analysis. The significant relationship was based on 95% confidence level. The study found that food waste was the highest across all the income groups. The trends of the waste were as follows: Paper-20% > plastics-18% >glass-11% > cans- 11% >garden waste –6%.

Table 2-1: Total waste composition from the three income groups (source: Ogola et al., 2011)

Waste component	Low -income group (kg/week)	Middle income group(kg/week)	High-income group (kg/week)	Total waste generated (kg)/week	Average waste generated (kg)/week
Paper	183	658	422	1263	421
Cans	153	437	88	678	226
Glass	261	347	112	719	240
Plastics	181	571	406	1158	386
Food wastes	341	1227	640	2208	736
Garden waste	194	154	33	381	127
Total waste generated per week	1313	3392	1702	6406	2135

Through field observation, the study found that the waste from households was not sorted. Instead, the waste was all mixed in refuse bags. According to Ogola *et al*., (2011) when waste is not sorted, it reduces the quality of recyclable materials like paper and cardboard boxes due to the mixing of the waste. The study found that the waste refuse bags from households are collected once a week on a specific day in each suburb. The waste is collected by the municipality trucks.

Table 2-2: Percentage of total waste composition generated per week from the three income (source: Ogola et al., 2011).

Waste component	Low - income group (%)	Middle-income group (%)	High-income group (%)	Average waste generated/week (%)
Paper	14	19	25	20
Cans	12	13	5	11
Glass	20	10	7	11
Plastics	14	17	24	18
Food wastes	25	36	37	34
Garden waste	15	5	2	6

Another study done by Alam *et al*., (2008) reviewed existing solid waste management (SWM) practices, measure solid waste generation by composition, and found the relation between the solid waste generation and population growth, assessed the collection, transportation, and transfer systems of solid waste in Kathmandu Metropolitan City. The study used questionnaires, interviews, field work. The data was analysed quantitatively. The findings were that organic waste had the highest in volume, followed by paper and plastic waste. Organic waste accounted for 60-70%, while plastic was 9.17%, and paper was 8.5%. Their study indicated that there would be a dramatic change in plastic production due to the increase in the use of plastic.

In terms of the waste storage, the study found that there were two types of storage practices which included the segregated waste storage and the commingled storage. The commingled storage was the more prevalent form between the two practices. About 80% of households stored waste was in a commingled form, while the rest segregated the waste and stored the organic waste portion separately.

In terms of solid waste, the study found that the municipality was responsible for the collection of solid waste in the city. There were three modes of waste collection, namely, the roadside collection, door to door collection and communal container collection. The study found that there was no fixed route for the transportation of waste to the disposal facility. The transport route was dependent on the driver. The study found that the type of vehicles used for bulk transportation were tractors, dump trucks. handcarts, tricycles, and open trucks.

2.2.2 Composition of solid waste

Factors that determine the composition of household, bulky, and commercial waste

The factors included the community, area, and the population size; percentage of commercial waste mixed with household waste; historical development caused by changes in consumer behaviour and life style, standard of living, economy, and the effect of business cycle; seasonal changes; number of people living per building (Irwan *et al*., 2011; Alqader and Hamad, 2012).

Importance of determining the composition of solid waste

It is very important to estimate potential materials recovery, identify source of component generation, to facilitate design of processing equipment, to estimate physical chemical, thermal properties of the waste.

2.2.3 Rate at which solid waste is generated

Rates and quantities of solid waste generation, composition and disposition are different across Africa because they are linked to the local economies, level of industrial development, waste management systems and lifestyles. According to Sharholy *et al*., (2008) the quantity of the solid waste generated depends on various factors such as food habits, standard of living, degree of commercial activities and seasons.

Table 2-3: Sources of the generation of Municipal Solid Waste (Source: Coad, 2011)

Sources of generation of Municipal Solid Waste	
household/ residential waste	Household waste – food waste, house cleaning, old papers, packaging, bottles, crockery waste, furniture materials, garden trimmings.
Commercial Waste	Waste generated at business premises, shops, offices, markets, departmental stores (paper, packaging materials, spoiled, discarded goods), large hotels and restaurants, markets selling vegetables and fruits, fish. Organic and inorganic chemically reactive and hazardous waste.
Institutional waste	Schools (primary, secondary, colleges and universities), government offices, hospitals, Community halls, religious places
Street sweepings	Unconcerned throwing, littering made by pedestrians, traffic, vehicular traffic, spray animals, roadside tree leaves, rubbish from drain cleanings and debris

Industrial waste/ trade waste	Manufacturing and processing trade generated waste
Debris or construction rejects	Frequent digging of roads by various utilities comprising earth, brick stones, and wooden logs
Waste- offal, dead animals	Offal waste generated from slaughter- houses, food, packaging institutions and cold storage premises

2.2.4 Categorisation of solid waste

According to McDougall *et al*., (2008: 187) the standardisation of waste material categories is very important, but a more detailed classification is also required. What the material is made of and the detailed knowledge of its composition is a prerequisite for effective waste management. Plastics, for example, may exist as a thin film, rigid bottle or a multitude of other objects. Knowing that they are made of plastic may give guide to their suitability for energy and waste schemes, but further knowledge of their form is necessary to determine their suitability for material recycling.

The way the solid waste is collected and sorted determines which management options can subsequently be used, and in particular whether methods such as materials recycling, biological treatment or thermal treatment are feasible with respect to economic and environmental sustainability (McDougall *et al.,* (2008: 193).

According to Ramachandra (2006) solid waste can be organic and inorganic waste material. Solid waste comprises both a heterogeneous mass of waste from the urban community and a more homogeneous accumulation of agricultural, industrial and mineral waste.
Waste can be categorised as follows:

1. **Municipal solid waste (MSW)**

- Household waste, the content of the residential rubbish bag, meal leftovers, kitchen scraps, paper, packaging and other heating residues, small items that have become superfluous and textile
- Bulky refuse or other waste that cannot be placed into rubbish bag due to its size and unwieldiness. This may be packaging items, that have ceased to be useful or textiles
- Bulky refuse or large redundant items, for instance furniture, mattress, electric appliances, refrigerators and dish washing machines
- Garden waste, pruning, lawn clippings, branches and leaves

2. **Street sweepings and waste from street markets**

- The erosion and deterioration of street surfaces along with vehicular tyre rubber
- Leaves and branches falling from trees lining the streets
- Refuse from street markets
- Grit from the water service
- Paper and tobacco residue, animal faeces, dust
- Sludge from municipal wastewater plants

2.2.5 Segregation of solid waste

The segregration of solid waste needs to be done at the source (residential, industrial, institutional and commercial). Zhang *et al.,* (2010: 1628) stated that "Waste segregation at source will reduce the amount of solid waste generation and facilitate recycling materials, as well as reduce the overall cost of waste disposal". The waste can be collected separately by the use of different containers distinguished by different colours with labels and carefully written instructions (Zhang *et al.,* 2010). According to Obiri-Danso *et al.,* (2015) for the waste segregration system to be succesful depends mostly on the active participation of the solid waste generators in the different communities and how they comply with with the principles of sorting and the seperation of the waste.

Table 2-4: Characteristics of the type of waste (Source: Soncuya and Viloria, 1991)

	Types of waste	Waste components
1.	Old newspapers	Newspapers, comics, magazines
2.	Paper and cardboard	Wrapping paper, plastic bags, paper towels, writing paper, cigarette packages, books, and corrugated paper boxes
3.	Food (organic) waste	Vegetables and fruit discards and peelings, eggs shells, spoiled food and bread, meat and fish bones
4.	Plastic	Plastic bags, plastic containers, toys, and styro foam
5.	Textiles	Clothes, rags, carpets, hats and other fabric
6.	Rubber and leather	Rubber tyres, leather shoes, and handbags
7.	Petroleum products	Oil, and grease
8.	Yard waste	Grass, clippings, flowers, plants, and leaves
9.	Wood	Lumber, plywood boxes, furniture, toys and tree branches
10.	Aluminium cans	Cans and other Aluminium containers
11.	Metals	Wire, auto parts, iron, and steel
12.	Glass	Bottles, jars, and broken glass

13.	Inert materials	Rocks, stones, tiles, ceramics, bricks, sand, dirt ashes and ciders
14.	hazardous waste	Batteries, chemicals and pesticides

2.2.6 Temporary storage area

According to Alam *et al.,* (2008) there are two types of storing waste, which are the commingled waste storage and the segregated waste storage. From the study titled '*Generation, storage, collection and transportation of municipal solid waste – A case study in the city of Kathmandu'*(capital of Nepal), by Alam *et al.,* (2008), it was found that the commingled waste is the most popular form of storage. Approximately 84% of the households store waste in a commingled form while the rest segregate the waste.

2.2.7 Collection of solid waste

According to Awasthi *et al.,* (2016) the types of waste collection that exist are house-to-house and community bin. House-to-house is when the collectors go to each house to collect the waste and users must pay for it. The advantages of house-to-house is that it is convenient for the households, prevents littering, reduces community bins, and segregated collection of waste. However, the disadvantage of house-to-house is that collection is restricted to fixed collection times. The advantage of community bins is that it is less cost-intensive than house-to-house collection. The disadvantages are that community bins create nuisance from animals and vermin roaming the waste, and there is resistance from neighbours ("not in my backyard" syndrome) and there is a problem of illegal waste disposal because households find it inconvenient to carry their waste to the community bin. The municipalities are responsible for the collection of waste and they have to collect the waste using their own infrastructures or through private sector contracts. Vehicles used to collect waste are compactors, tippers, dumpsters, and stationary compactors (Awasthi *et al.,* 2016).

2.3 Methods of solid waste recovery and treatment

"Treatment occurs when the waste cannot be prevented or reduced (minimised) through reuse or recycling, then there is a need to reduce the volumes and/ or toxicity. Treatment technologies are processes that focus on stabilisation of waste, reducing toxicity, reducing volume before ultimate disposal, or in some cases, creating limited-use by-products" (Cheremisinoff, 2003: 4). According to Letcher and Vallero (2019) the treatment and disposal of the solid waste depends on its quantity and composition and the available funds to pay for it.

2.3.1 Resource recovery/ recycling/ waste to energy.

According to Chandrappa and Das (2012) the most important component of waste management is reduce, reuse and recycle (3R). In the developing countries waste recovery and recycling occur within a house itself. Reduce is defined as use objects, devices, or substances again, refillable containers, durable instead of disposables and unusable packaging. Recycling is to use waste materials in place of virgin materials to create a new product (Rao *et al.,* 2017). The advantage of recycling is that it saves resources and reduces environmental impact of waste by minimising the amount of waste that is disposed of in landfills.

Cheremisinoff (2003: 4) pointed out that "recycling and reuse of materials, the recovery of certain wastes for reuse is known as resource recovery, and the conversion of certain types of waste into useful energy such as heat and electricity, and hot water are strategies which recover and offset costs for overall waste management". The benefit of recycling is that it reduces the amount of Green House Gases release (GHG) into the atmosphere (Batool and Ch, 2009). Recycling means converting back into an unusual material, whereas recovery means extracting materials or energy from a waste for other uses (E and P Forum , 1993; Bashat , 2003).

2.3.2 Thermal treatment

The management/ treatment of solid waste by thermal gasification technology is increasingly viewed as the best suitable and economically viable approach for the management of solid waste such as residential waste, and commercial waste (Young, 2010). According to Mohee and Simelane (2015) and Sharholy *et al.,* (2008) thermal treatment involves the destruction of municipal solid waste using heat energy. There are many thermal processes, but incineration is currently the most widely used in the developing countries.

- ***Incineration***

"Incineration is the primary approach of waste treatment technology that converts biomass to electricity and the waste stock involves the organic matter of waste to be reached with excess oxygen in a combustion process in a furnace or boiler under high temperature" (Tan *et al.*, 2015: 114). According to Mohee and Simelane (2015) the main aim of incineration is to reduce the overall volume of waste, resulting in a lower quantity of ash to be landfilled and this has been found to reduce approximately 90 percent of the municipal solid waste (MSW). Furthermore, there are new incinerators that operate at temperatures high enough to produce a molten material and this can reduce the volume to 5% or even less (Jha *et al.,* 2003; Ahsan,

1999). Energy recovery by thermal conversion consists of heating the waste to a temperature that results in volatilization of moisture and organic compounds usually followed by combustion of all organic compounds and carbon with atmospheric air, (Klinghoffer and Castaldi, 2013). Incineration leads to energy recovery and destruction of toxic waste, such as waste from the hospitals (Sharholy *et al.,* 2008). The temperature in incinerators ranges from 980 and 2000 °C. According to Johnke (2012) the major compounds that are discharged or emitted through the incineration of MSW are water vapour and carbon dioxide. Incineration produces energy in the form of steam or electricity. The incinerator smoke contains toxic substances such as sulphur dioxide, dioxins, and oxides of nitrogen (Cheremisinoff, 2003). According to Yves Chartie (2013) incineration is a technique that is used to treat hazardous waste. According to World Health Organisation (WHO), approximately 75% to 90% percent of the waste generated across healthcare facilities is considered to be non-hazardous; the remaining 10-25% is considered hazardous. These hazardous wastes can consist of infectious, radioactive, or toxic substances.

- ***Gasification technology***

Gasification is the process of converting organic compounds, under controlled oxygen flow, into a mixture of gaseous species that is dominated by carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), and methane (CH_4) (Johnke, 2012: 233). On the other hand, Pal , (2017) points out that gasification is the solid waste incineration under oxygen deficient conditions, to produce fuel gas (syngas).

2.3.3 Biological treatment

“This process makes use of the enzymes of bacteria and other microorganisms to break down biomass. The microorganisms are used to perform processes of anaeobic digestion, fermentation, and composting”(Barik 2019: 13).

- ***Aerobic digeston***

According to Tchobanoglous *et al.,* (2004) anaerobic digestion is used to treat organic waste with the ability to recover energy in the form of biogas (mainly methane). In other words, anaerobic digestion converts some of the organic matter in MSW to methane and carbon dioxide (Saft and Elsinga, 2006). Barik (2019: 13) stated that “anaerobic digestion is helpful in lessening the amount of organic solid waste and recovering energy”. Aerobic digestion is s complex process because it needs a specific environmental condition and diferent bacterial populations to decompose the organic waste to the end product which is valuable mixture of gases (methane and carbone dioxide) referred to as biogas (Tan *et al.,* 2015: 114).

2.3.4 Landfill recovery system (LFGRS)

Landfills are regarded as the simplest, cheapest and the most cost-effective method of disposing waste (Samadder *et al.,* 2017). “Landfilling of general and hazardous waste remains the dominant technology solution in South Africa (Godfrey and Oelofse, 2017: 4). According to Tan et al., (2015) methane (often refrered to as a biogas) is one of the gases that are produced/ generated in landfills. The methane gas is captured and is used for generating energy. Tan *et al.,* 2015: 113) stated that “LFGRS is well-suited to a high percentage of biodegradable matter with high moisture content”.

- ***Landfill classification***

According to DWAF (1993) landfills are classified as communal, small, medium and large. It can also be classified according to the type of waste that the landfill accepts. There is the general and the hazardous waste. The general waste does not contribute a significant threat to the environment and to the public, if properly managed. General waste consists of household and garden waste. However, hazardous waste negatively impacts on the environment and public health even when the waste is in small quantities. This is because the waste can be corrosive, poisonous and highly toxic in nature. Landfill can also be classified as an open dump or controlled or sanitary landfill.

Landfill size classes

According to DWAF (1998) landfill size is classified into communal (C), small (S), medium (M) and large (L). With regards to hazardous waste, the size of the landfill is not considered. The larger the operation the more stringent the Minimum Requirements.

Table 2-5: Table showing landfill size classes (Source: DWAF, 1998)

Landfill size class		Maximum Rate of Deposition (MRD) (Tonnes per day)	
Communal	C		< 25
Small	S	>25	<150
Medium	M	>150	<500
Large	L	>500	

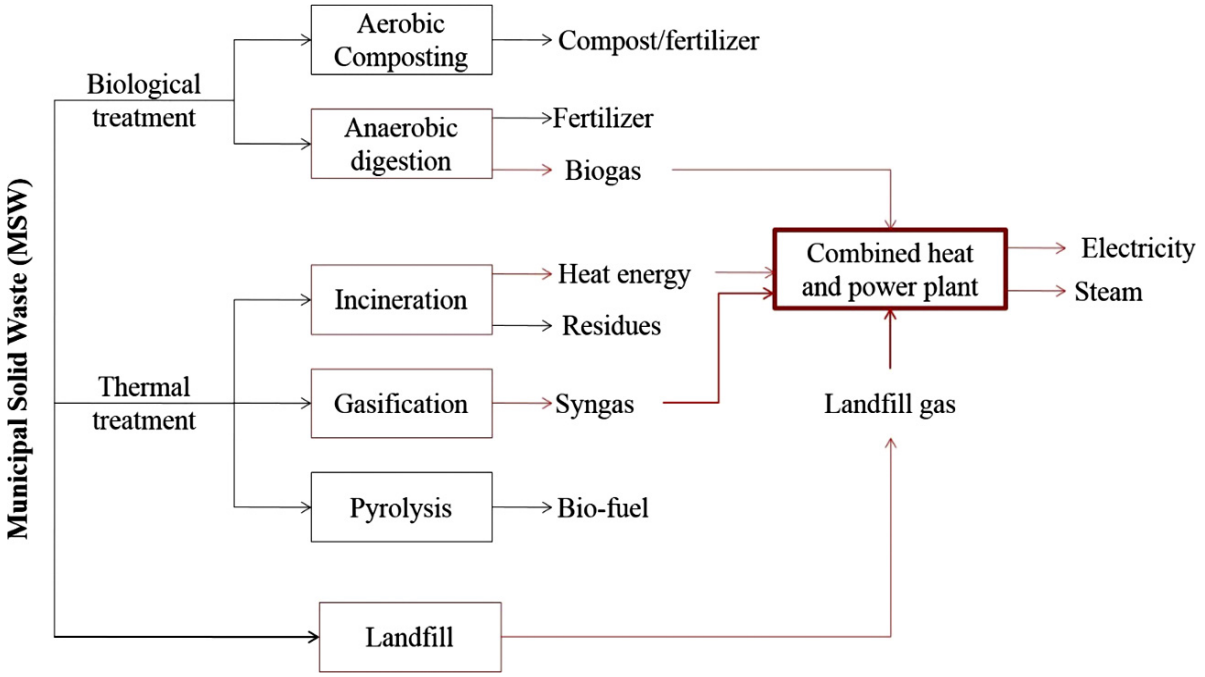


Figure 2:1: Solid waste treatment technologies and their products (Source: Tan et al., 2015)

Figure 2.2 shows the hierarchy of solid waste management waste. The waste management hierarchy is a ranking system that gives priority to waste minimisation, reuse, recycling, energy recovery and final disposal. The figure shows the different waste management approaches ranking them from the most sustainable to the least sustainable. This means that waste minimisation is the most favourable and most sustainable approach, while Disposal is the least favourable approach.

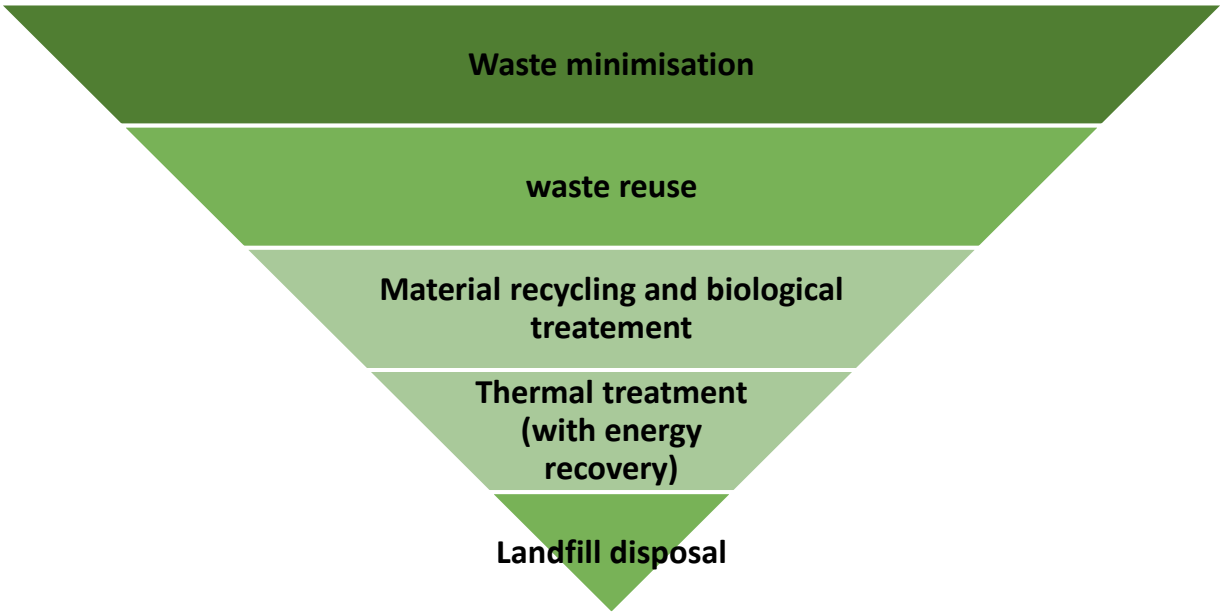


Figure 2:2: Hierarchy of solid waste management (Source: Tan et al., 2015)

Buy-back- centre is defined by Sasikumar and Krishna (2009:282) as a facility to which individuals bring recyclables in exchange for money.

2.4 Solid waste characterisation methods

According to Lagerkvist *et al.,* (2011) characterisation of solid waste is a difficult task because of the heterogeneity of the waste and its spatial as well as temporal variations. This makes waste characterization costly if good and reliable data with reasonable uncertainty is to be obtained. Therefore, a waste characterization is often narrowly defined to meet specific needs for information.

The purpose of characterisation of the solid waste is to provide data on waste quantities and composition for use in regional or national statistics as it is the basis for policy setting on recycling. To classify waste as hazardous or non-hazardous waste according to the national regulations, determines the legal framework for the handling of the waste. It also documents adherence to specified quality criteria for recycled materials, for example, according to metal scrap category. The efficiency of the introduced recycling scheme is done by quantifying recovered and non- recovered materials. Waste generation rate for residential is necessary for forecasting of waste quantities according to population growth. Characterisation of the waste quantity and composition is important for the design of the waste incinerator.
Sampling and the sample preparation are critical steps. There are three sampling methods that can be used to select solid waste. The sampling methods include random sampling, stratified random sampling and the systematic random sampling. The systematic sampling is the less used method for sampling waste. In random sampling, all parts of the waste have an equal chance to be sampled. This method is very appropriate when the waste is homogeneous. An example is the investigation of the waste generated in an area with only multi-family housing. Stratified random sampling is used when the waste is heterogenous.

Waste characterisation: analyses and testing

Waste characterisation is performed to obtain information about the inherent properties of waste and the performance under various conditions. The inherent properties are determined by the physical and the chemical analysis of the waste material, while the performance testing is made in experimental systems containing the waste and stimulating its performance under determined conditions, for example, compression testing, leaching testing and degradability testing.

The important physical analysis for solid waste includes picking analysis/ quantifying material fractions which are identifiable items, particle size distribution, moisture content, and densities. According to Christensen (2011) the useful terms that can be used for waste characterisation are the following: the waste categories, waste type, waste quantities, unit generation rates, material fractions, items and the substances. The waste categories are a broad class of waste coming from sources with the common characteristics. The main categories are the industrial, institutional, commercial, residential waste, and the construction and the demolition waste. The waste types are the subclasses of the waste categories and they contain common characteristics regarding the source and composition. For example, residential waste includes household waste, garden waste, bulky waste and household hazardous waste. Unit generation rates are defined by Christensen (2011) as the quantities of waste per defined time frame and per generating characteristic unit.

Material fractions are visually identifiable fraction in the waste with common features. These include paper, plastic, glass, organic kitchen waste. Each material fraction may be divided into sub-fractions. For example, paper: newspapers, advertisements, paper towels and magazines. Items are the individual objects of different natures present in a material fraction and therefore with common characteristics. Substances are individual chemical characteristics in the waste, which typically require analytical techniques to identify.

2.5 Waste management in developing countries

Developing countries such as South Africa are facing problems with regards to the management of waste by their municipalities. The problems are described by (Manaf *et al*., 2009: 2902-2906) and include “inadequate political support for action and government priority; lack of skilled personnel; limited re-use of organic waste; lack of awareness of the problems caused by poor waste management; planning and management; physical limitation to establishment of landfill site; no long-term planning or business planning; inadequate recycling and re-use; poor landfill siting; poor handling of clinical and hospital waste; and lack of finance”. The inability to try and solve or address these problems leads to health and environmental problems for the cities and this can have a serious impact on the economic development on agricultural exports and tourism. According to Reddy (2016) in the developing countries there is population increase, urbanisation and the increase in consumerism which result in the increase in solid waste generation.

2.5.1 Drivers of solid waste generation in the developing countries

Solid waste generation is the starting point of the waste system. It is defined in terms of waste categories, waste types, quantities, material fractions, and substances. According to Sigua (2018); Barik (2019); kumar (2016) and Alam *et al.,* (2008) the main drivers of the increase of solid waste generation are rapid population growth, urbanisation, economic level, and industrialisation. This is evident in the study that was conducted by Alam *et al.,* (2008) where it was found that there was a strong correlation between waste generation and the population increase. As the population increased, more solid waste was generated. "The generation of MSW is commonly claimed to be coupled with economic activity and the level of production in different sectors of a society, as it is an inevitable consequence of production and consumption activities in any economy" (Kumar, 2016: 34). According to Kumar (2016) there are four sectors that are based on economic levels in developing countries. These are the High-income group, Middle-income group, Lower-income group, and the slum areas. Kumar (2016) highlighted that cities with low and middle -income group generate more of the organic waste, while in the cities with high income waste generation is diversified with higher percentage of the paper and plastics. Research conducted by Medina (1997), Nilanthi *et al.,* 2006) have shown that there is a relationship between the standard of living and waste generation.

2.5.2 Challenges of solid waste in Developing countries

Solid waste in the developed countries is generally carefully regulated and tracked through a well-developed record-keeping system, but the developing countries may experience insufficient stuff, and resources to carry out the detailed record keeping. There is lack of recording of the waste composition and quantity (Bdour *et al.,* 2007). In the developing countries there is lack of clear definition, roles, responsibilities, and quantity data has made the treatment and disposal problematic. Waste management in the developing countries is given low priority because people are more bothered about hunger, health, unemployment, water, and wars than with waste management. Hence, millions of people in developing countries are living without an appropriate waste management system. According to Dhokhikah and Trihadiningrum (2012); Al-Emad (2011); Farzadkia *et al.,* (2009); and Gai *et al.,* (2009) developing countries are faced with inadequate mechanical equipment, lack of segregation at source, and complicated collection processes.

In most developing countries, the facility for leachate collection and treatment is excluded in the design of the landfill site. One of the adverse effects caused by solid waste disposal onto landfills is the contamination of surface and ground water by leachates. Landfill liners need to be part of the design because the liners act as a barrier to prevent leachate from contaminating

surface and ground water. Limited adequate leachate management system in developing countries could be due to the lack of required expertise, corruption, poverty, misappropriation of funds (Edokpayi *et al.,* 2018).

2.6 Influence capitalist economy in the generation of the solid waste

2.6.1 The government's intervention to reduce the consumption of plastic bags (environmental Levy Scheme)

- **Regulations governing the plastic bags in South Africa**

"In September 2002, the South African government representatives of labour and industry signed a memorandum of agreement concerning the use of disposable polythene shopping bags. The main elements of the agreement were: regulation of the minimum thickness of plastic bags; disclosure and transparency regarding the costs of plastic shopping bags; regulation of the type and amount of ink to be used on the printing on bags, promoting a market for recycled materials; imposing a levy to support this; preventing the importation of plastic bags" (Dikgang *et al.,* 2012: 59).

According to Green Home (2013) plastic bags create large amount of waste. Approximately 6 billion plastic bags annually are consumed by South Africans, (Dikgang *et al.,* 2012). According to Dikgang *et al.,* (2012) initially, plastic shopping bags were free of charge and were not recyclable. The plastic bags cost 30 cents for the consumers in May 2003. South Africa introduced a shopping plastic bag levy in 2003 to reduce the amount of plastic bag consumption and subsequent disposal. "The purpose of the levy is to discourage the use of plastic bags by consumers in order to protect the environment, decrease the amount of litter and reduce the volumes going to landfills each year" (House of Commons Environmental Audit Committee, 2007: 48). In some countries such as San Francisco, after a fee was instituted, plastic use was reduced by 78%. In South Africa this was not the case; there was less success. There was an initial short-term drop in plastic consumption, and people became used to paying for plastic bags and the demand began to increase. The tax did not change people's attitude, values and behaviour.

2.6.2 Individual attitude and value systems in the management of solid waste

"Attitude refers to an individual's feeling(s) and beliefs about some phenomenon which consequently would influence a person's behaviour towards that phenomenon. Attitude has three interrelated components: the affective, cognitive and behavioural component" (Raban , 2000: 41). The consumers play an important role in the waste management system (Barr, 2017). Individuals can help by buying products that would produce less waste and those made

from recycled materials. Secondly, by seperating the waste for recycling and composting kitchen and garden waste. Due to the fact that individuals have a vital role in the waste system, the problem of waste production is more likely to reduce if most households change their behaviour. Barr *et al.,* (2001) stated that " changes in the attitude and behaviour are vital if the waste problem is to be effectively tackled, because all individuals buy, produce, use this product, and dispose of it as waste" According to Scott and Jobber (2000) consumers who value the environment or who consider the environment to be essential will therefore evaluate the environmental consequences associated with the the purchase of the product. For example, an individual who is concerned with the amount of garbage generated, the individual will consider the disposal of the product's packaging which is an environmental consequence before buying the product. If the environmental consequences are important enough to the consumer, the conumer would rather purchase an environmentally friendly product instead.

The individual behaviours include the minimisation, reuse and recovery of the solid waste. Minimisation is defined by Barr (2017) as the reduction of the waste produced in the first place. On the other hand, Rogoff (2013: 19) defined minimisation as "activities and practices that reduce the amount of waste that is created". Rogoff (2013: 19) further added that waste reduction differs from the two waste diversion techniques (use and composting) because the other two techniques involve waste that has already been generated. The other term for minimisation is " prevention". The minimisation, preventing or the reduction of waste involves the individual shopping habits (Barr, 2017; and Rogoff, 2013: 19). Individuals need to buy less products with packaging. For example: not using plastic bags for packaging fruits and vegitables, taking a shopping bag rather than using plastic carrier bags contributes to waste minimisation. The changes that businesses undertake voluntarily to reduce the potential waste associated with the products can also contribute towards the minimisation or the reduction of the solid waste (Rogoff, 2013: 19).

Recycling

The advantage of recycling is that it conserves natural resources, reduces emissions from manufacturing items out of new materials, saves energy (heat/electricity), generates revenue and creates manufacturing jobs (Reddy, 2016:6). According to Rogoff (2013: 19) Extended Producer Responsibility (EPR) is a general policy approach which aims to shift the cost and manage consumer packaging from local solid waste agencies to those manufacturers who are producing this waste.

The EPR provides the following advantages:

- Causes the producers to change packaging designs and selection, leading to increased recyclability and/ or less packaging use.
- Provides additional funds for recycling programs, resulting in higher recycling rates.
- Improves recycling program efficiency, leading to less costs, which provides a benefit to society.
- Results in a fairer system of waste management in which individual consumers pay the cost of their consumption, rather than the general taxpayers.

2.7 South African environmental, health and safety regulations for solid waste management in landfills

2.7.1 Environmental regulations for solid waste management in Landfills (minimum requirement for the disposal of waste by landfills (1998)

- **Facilities and resources for landfill operation**

There should be enough resources and facilities to ensure that the landfill operation can conform to both the permit conditions and the relevant minimum requirements. For example, there should be enough staff to monitor, control and record incoming waste where required.

- ***Signposting and road access***

The signs need to be in an appropriate official language, stating the names, address and the telephone number of the permit holder and the responsible person, the hours of operation, and an emergency telephone number. The signage should state the type of class and the type of waste that can be accepted at the landfill. The waste that is not accepted at the landfill should be stated and should be erected in the vicinity of the landfill. It must be stated that disposal of non-acceptable waste types is illegal and can lead to prosecution. There should be a sign that should indicate route and the distance from the nearest main road. There should be suitable signs to direct vehicle drivers appropriately and to control speed.

- ***Road access***

Road access should always be maintained that will be able to accommodate the vehicles normally expected to utilise the facility. On-Site- roads must be surfaced and maintained as to ensure that the waste can reach the working face with the minimum of inconvenience in all weather conditions. Two-way traffic must always be possible in all weather conditions. Unsurfaced roads must be regularly graded and watered to control dust. No mud from the site may be tracked onto public roads.

- ***Waste acceptance procedures***

The waste classification system is very vital to ensure that general waste disposal receives only the general waste for which they are designed. Before the waste can be accepted at the landfill, the waste should be inspected by suitably qualified staff and the transporter must confirm that it is general waste.

- ***Access Control***

In order to facilitate the above waste acceptance procedure, access to the site must be controlled. The minimum requirements indicated that vehicles' access to a site must be limited to a single controlled entrance. This is to prevent or avoid unauthorised entry and illegal dumping of waste on the site. The site entrance must comprise a lockable gate which must be manned during hours of operation. There should also be security after operating hours. The landfill site should be adequately fenced.

- ***Operating plan***

An operating plan is a site-specific document that will be developed as part of the Landfill Permit Application Procedure. It describes the way in which the landfill is to be operated, commencing at the level and detail of daily cell construction and continuing through to the projected development of the landfill with time. Everything pertaining to the operation of a landfill should therefore be included in the Operating Plan, which is subject to regular update. The complexity of the Operating Plan will vary with the class of site.

- ***Resources***

Adequate facilities, equipment and suitably trained staff are required in order to ensure an ongoing environmentally acceptable waste disposal operation. There should be sufficient resources to meet the Minimum Requirements relating to the operation.

- ***Infrastructure***

The facilities at the landfill will vary in accordance with the size of the operation. Larger sites would typically have services such as water, sewerage, electricity, telephones, security and infrastructure such as weighbridges, site offices and plant shelters.

- **Daily covering of waste**

According to DWAF (1998) and Al- Anbari (2016) there should be daily covering of waste at landfills. This is done to avoid or minimise health and fire hazards. It is recommended that landfills should use a minimum soil cover thickness of 150mm to cover the waste. The recommended soil thickness used to cover the waste is important because it helps to avoid or minimise animal (such as rats, vultures, and dogs) and insect attraction (such as flies and mosquitoes) due to the smell of decomposing waste. When the recommended soil thickness is used it makes the food inaccessible to rats and other organisms (Jaramillo, 2003).

2.7.2 Health and safety regulations for solid waste management in Landfills (Occupational Health and safety Act (85 of 1993)

Handling and sorting of waste includes activities such hoisting with a crane, carrying bags or materials, driving a truck loaded with waste, and stacking waste into drums and barrels. Inappropriate sorting and handling of solid waste materials results in injuries. Training and awareness applicable to general safety principles like proper work practices, equipment, and control can help reduce the number of accidents during waste management. Waste handlers should have knowledge of methods of eliminating and minimising accidents such as bending, twisting, turning, falling objects, tumbling of improperly stacked materials which commonly cause injuries. Waste handlers should be aware of injuries that can occur when handling materials including the following: strains and sprains from handling waste improperly or from carrying waste that is too large/ heavy. Bruises and fractures are caused by the falling of improperly stored objects.

Health risks depend on (1) the composition of waste (toxic, temperature, sharps, infectious substances and other chemicals/ physical properties), (2) personal protective equipment and personal hygiene, (3) extent of the waste regulation, and efficiency of waste handling. In developing countries, a portion of the faecal matter would enter solid waste stream due to inadequate sanitation and sewerage systems. Many waste generation/ collection points are characterised by changing weather, undefined workspace and exit, absence of precautions, absence of lavatories and showers, absence of portable water supply, absence of clean eating area, absence of controlled lighting, absence of safe access, absence of first aid, absence for oxygen supply, uncontrolled work environment temperature.

A person's health can be affected due to injury and/or infection. This includes injuries caused by the handling of waste, respiratory sickness due to air pollutants, infections due to direct contact with infectious material, injuries called by fir, substance, slides, and sickness due to polluted water, increase in the vector population, noise, fires and toxicity. Waste pickers are

often prone to injury and sickness. Waste in the developing countries is mostly disposed of in open and unsafe land. As a result, there are a lot of safety issues in developing countries because waste is collected manually without the use of personal protective equipment (such as gloves for waste with rough or sharp edges, eye protection, and steel-shoed safety boots or shoes), and insufficient health care workers to serve the waste handlers. There is lack of specific safety regulations for waste handling in an unorganised sector, and the absence of safety training/ awareness. In order to manage fires in landfill, there should be (1) prohibition of deliberate burning, (2) prohibition of smoking on site, (3) inspection of incoming loads, (4) control of deposition of waste, (5) good compaction and cover, (6) maintenance of firefighting extinguishers /equipment, (7) maintenance of adequate water supply, and (8) wearing protective clothing (PPE's).

2.8 Application of GIS in solid waste management

2.8.1 Application of GIS and AHP methodology when evaluating the suitability of waste treatment facilities

According to Khan *et al.,* (2018) GIS is a computerised system that aids in decision making purposes and has the capability of managing, analysing and displaying geographic data. According to Moeinaddini *et al.,* (2010) GIS plays an important role when evaluating the locational suitability of landfills. From the research study titled *" Selection of MSW landfill site for Konya, Turkey, using GIS and multi-criteria evaluation,"* Nas *et al.,* (2010) concluded in his paper that GIS technology has the ability to save time. Sumathi *et al.,* (2008) added that GIS not only saves time but also saves costs of evaluating the suitability of landfills. According to Moeinaddini *et al.,* (2010) the other advantage of using GIS technology when evaluating the locational suitability of landfill is that it provides a digital data bank for long-time monitoring of the site. The other benefits of using GIS to evaluating landfill as stated by Moeinaddini *et al.,* (2010: 193) is that it provides the following: selection of an objective exclusion zone process according to the set of provided screening criteria, zoning and buffering, performing 'what if' data analysis and investigating different potential scenarios related to population growth and area development, as well as checking the importance of various influencing factors, handling and correlating large amounts of complex geographical data, and visualization of the results through graphical representation (Sumathi et al., 2008). The intergration of GIS and AHP is a powerful tool to solve the landfill site selection problem (Basagˇaogˇlu *et al.,* 1997; Allen *et al.,* 2003; Sener, B. *et al.,* 2006; Sener, S. *et al.,* 2010).

2.8.2 AHP Methodology

Mu and Pereyra-Rojas (2016: 5) stated that the "Analytical Hierarchy Process (AHP) was developed by Professor Thomas Saaty in 1980". The AHP allows for structuring the decisions hierarchically (to reduce its complexity) and show relationships between objectives (criteria) and the possible alternatives. The AHP technique is widely used by scholars in the decision-making process such as locating possible landfill sites and evaluating current landfill sites. The combination of the use of GIS and AHP methodology has been used by (Rathore *et al.,* 2016; Khodaparast *et al.,* 2018; Uyan, 2014; Lin and Kao, 1999). This technique is used in decision making processes. In addition, Sener *et al.,* (2006: 387) pointed out that "the AHP method uses pairwise comparison for determining the weight of the criteria by which two components are considered at a time which resulted in the reduction of complexity. The pairwise comparison for the determination of weights is more suitable than direct assignment of the weights, because one can check the consistency of the weights by calculating the consistency ratio in pairwise comparison; however, in direct assignment of weights, the weights depend on the preference of decision maker".

- ***Steps to develop the model for decision making***

The first step of the AHP analysis is to build a hierarchy for decision, which is also known as decision modelling. The second step is to derive the relative importance (weights). This is done because not all criteria will have the same importance. It is known as relative because the obtained criteria priorities are measured with respect to each other (Mu and Pereyra-Rojas, 2016: 8).

Table 2-6: Saaty's Pairwise comparison scale (Source: Mu and Pereyra- Rojas, 2016: 9)

Verbal judgment	Numeric Value
Extremely important	9
	8
Very strongly more important	7
	6
Strongly more important	5
	4
Moderately more important	3
	2
Equally important	1

2.8.3 Criteria for evaluating the locational suitability of landfills

Evaluating the suitability of a landfill is a complex process because it involves a lot of criteria (Chang *et al.,* 2008) which must combine the legislations and environmental, socio-economic, and technical factors (Sener *et al.,* 2006; Nas *et al.,* 2010; Eskandari et al., 2015; Hamzeh et al., 2015). According to Nas *et al.,* (2010) landfills should be located and designed according to the necessary condition that prevents ground and surface water pollution, and soil pollution. Landfill should be situated far away from areas with high population density to avoid health problems. Landfills should be located near existing roads for saving road developments, transportation and collection costs. The slope should not be too steep or too flat.

Sener *et al.,* (2010) argue that there are two criteria that are used to evaluate the locational suitability of landfills which are the environmental and economic criteria. The environmental criteria include aspect, distance from settlements, distance from surface water, and distance from protected areas, geology / hydrology, and land-use. On the other hand, the economic criteria comprise the slope and distance from the road. According to DWAF (1998), for a landfill to be in a suitable location, the environmental, economic and public acceptance considerations should be investigated. The environmental consideration relates to the potential threats of the operation on the physical environment, especially on the water resources. This includes the topography, geohydrology, adjacent land uses, soils, and drainage. The public acceptance considerations look at potential impacts on public health and safety, quality of life, local lands and property values. According to Sharifi *et al.,* (2009) the environmental criteria is important because landfills release harmful substances to the public and the biotic environment to the surrounding area. On the other hand, the economic criteria look at the haul distance from waste generation areas, site size, access and land availability. The criteria are selected according to the regional conditions, therefore, distance to airports is not included.

- ***Distance from water sources (ground water, surface water)***

The distance from the ground and surface water is important because landfill releases gases and leachates which may cause health problems on the organisms that depend on water (Karimi *et al.,* 2018). According to Chandrappa and Das (2012) the drainage patterns, distance from major water bodies and water shed boundaries should all be considered. “Landfills should not be adjacent any ground water sources such as springs, or ground water wells. The international practice is that a minimum distance of 500m from any water sources is required for a landfill site”, (Kontos et al., 2015). On the other hand, Karimi *et al.,* (2018) suggested that a landfill should be located at least 750m away from water sources. In the the research by Akbari *et al.,* (2008) the distance from the water sources was 400m.

- ***Slope***

Acording to Sharifi *et al.,* (2009) the slope of the land is important when evaluating the suitability of landfill because slope influences the soil erosion, drainage, site access and visibility, and protection from prevailing winds (Abd-El Monsef and Smith, 2019). Steeper slopes are not appropriate for landfills (Sener *et al.,* 2010) because a steeper slope promotes runoff of pollutants from the landfill and this will result to contamination of water and soil. In addition, when slopes are excessively steep, it would entail deep excavation costs (Kahraman *et al.,* 2018). On the other hand, Akbari *et al.,* (2008) and Karimi *et al.,* (2018) argue that slopes that are too flat are also not suitable for a landfill; instead, areas that are suitable have medium slopes surronded by hills and are no more than 20% slope. Kao and Lin suggested that a slope needs to be less than 12% for it to be suitable for a landfill because there would be less runoff. The slope should not be steep or too gentle. If the slope is too steep it would be challenging or too difficult to construct and maintain. On the other hand, if the slope is flat this affects the run-off drainage.

- ***Distance from protected areas (fragile ecosystems)***

These are very sensitive areas which are of exceptional ecological interest for nature conservation (endangered or threatened species or plants). An example of fragile ecosystems are wetlands or karst areas. Wetlands are areas that are saturated with water and this could be permanent or seasonal.Wetlands are so important because their ecosystems are the most biologically diverse. They are home to a range of animal and plant species (Abd-El Monsef and Smith, 2019). “This criterion is significant due to the potential pollution or degradation of sensitive ecosystems. Solid waste management should not degrade natural environment or areas of unique ecological or aesthetic interest (Kontos *et al.,* 2005). According to Manoiu *et al.,* (2013) landfills should be located more than 500m from protected area.

- ***Distance from road networks***

According to Sener *et al.,* (2010) and Moeinaddini *et al.,* (2010) the distance from existing roads should also be considered when evaluating locational suitability of landfills. Landfills should not be located too close or too far away from existing roads. The distance from roads should be considered to avoid visual impacts (Lea˜o *et al.,* 2004; Khoshand *et al.,* 2018; Nas *et al.,* 2010: 495). According to Khoshand *et al.,* (2018) if a landfill is located too close to the main roads then there will be environmental problems such as traffic, esthetic nuisance and issues related to scavangers. Futhermore, Nas *et al.,* (2010) and Ngumom and Terseer (2017) indicated that if the landfill is located too close to the main road more money will be needed for the development of roads, transportation, and collection. According to Effat and

Hegazy (2012); Ghobadi et al. (2013); Yildrim and Guler (2016) the approperiate distance from road network is 100m though Akbari *et al.,* (2008) suggesed that landfills should be located at least 300m away from roads. A 30 m buffer was used by Zeiss and Lefsrud (1995). Baban and Flannagan (1998). On the other hand studies done by Ghose *et al.,* (2006) used a buffer of 1km. There was another study by Lin and Kao (1999) which indicated that 1km was too far away from roads which would mean more economic cost for constructing new roads.

- ***Land-use***

Landfills that are located near land-uses such as industrial sites are considered unsuitable for a landfills site and the suggested distance from these land-uses is 300m (Akbari *et al.,* 2008). Landfills are not expected to be close to schools, churches, hospitals and private and publisc institutions (Ngumom and Terseer, 2017). Furthermore, Ngumom and Terseer (2017: 982) stated that "As distance increases the suitability also increases." However, recycling and buy-back centres should be located close to industrial sites, and the community. It is important to ensure that the operations associated with the site will not create nuisance for the community located in the immediate vicinity, (Karimi *et al.,* 2018).

- **Proximity to urban areas (Towns) or residential areas**

Nas *et al.,* (2010) and Akbari *et al.,* (2008) pointed out that landfills should not be located near urban areas or residential areas to protect the health of the general public from the environmental impacts of the landfill, not to hinder the future developments and not to decrease the land value of the area. According to Donevska *et al.,* (2012) and Karimi *et al.,* (2018) people who live near landfills are likely to be affected by noise, odour, dust, health concerns, property value and dislocation. In the study by Akbari *et al.,* (2008) a buffer of 300m was applied when selecting a landfill site. According to Ngumom and Terseer (2017), as the distance from the settlements and urban areas increases, the suitability of the area increases. According to the Macedonian and European Legislation, the landfills should be located at least 500m from the residential areas (Gorsevski *et al.,* 2012). According to the Turkish legislation, landfills at a distance less than 1,000m from urban areas are not allowed (Uyan, 2014: 1634). As a result Uyan (2014) used a buffer of 1000m to evaluate the suitability of the landfill.

- ***Geology***

According to Karimi *et al.,* (2018) the other aspect to consider when evaluating the locational suitability of a landfill is the type and thickness of bedrock and the geological genus. According to Eskandari *et al.,* (2012) there should be sufficent depth from bedrock. Deep bedrock is prefered over a shallow bedrock. Shallow bedrocks have a higher risk of ground water

contamination. A minimum of 0.005km depth was proposed by Eskandari et al., (2012). According to Barakat *et al,.* (2016) limestone and clay lands are not suitable because of the wide gaps and high permeability, while metamorphic rocks have dual behaviour according to their source and are suitable. Soil is an important criteria when evaluating the locational suitability of landfill. Soil has an effect on the groundwater recharge and quality due to its permeability. According to Monavari *et al.,* (2012) soil permeability depends of the texture and depth of the soil. Soil texture ranging from silt to clay silty is regarded as suitable because they have low permeability, Clay to mixture is mid-suitable, and gravel and limestone is regared as unsuitable because they have high permeability. When evaluating the depth of the soil, 1500m and more is regrded as suitable, 100-500m is mid-suitable, and 0-25 and 25-100cm is regarded as unsuitable.

- ***Climate***

Climate is also an important factor that needs to be taken into consideration when evaluating a suitability of a landfill. When looking at climate parameters such as rainfall, temperature, humidity and wind speed should all be considered (Chandrappa and Das, 2012). According to Ayoade (2000) temperature has an effect on the composition of the solid waste generated. The moisture content of the solid waste in wet climates may be approximately 50% by weight. During the wet seasons, the organic waste tends to be in higher quantities than in dry seasons. Under moist conditions especially in the tropics, organic waste serves as breeding ground for diseases and vectors such as rats, mosquitoes and flies. In addition, weather conditions may affect the type of gaseous pollutants produced at the landfill. According to Monavari *et al.,* (2012) Landfills should not be located in an area with freezing conditions because such conditons have an impact on the biological acitvity. In freezing conditions, there is less or no biological acitvity and this is extemely difficult for the solid waste to decompose.

- ***Aspect***

“Landfills potentially have adverse effects because of emissions of unpleasant odors and pollutants carried by the wind. The negative impacts rise significantly when the prevailing wind direction blows toward residential areas. Therefore, it is necessary to consider predominant wind direction in landfill site selection” (Karimi *et al.,* 2018).

- **Proximity to cultivated areas**

According to Abd-El Monsef and Smith (2019) landfills shuld not be loacted close to cultivated areas. According to the study done by Sener *et al.,* (2010); and Monavari *et al.,* (2012) the distance to surface and ground water was given the highest priority.

2.9 GIS database for solid waste management

A dataset is a collection of organised facts. A geographic database also known as geodatabase is a collection of geographic data sets. A Database Management Systems (DBMS) is defined as "a software application designed to organise the efficient storage and access to data" (Longley *et al.,* 2015). A geodatabase can have four representation of geographic data. This includes the vector data for representing features, raster data for representing images, gridded thematic maps and surface; triangulated Irregular Network (TIN) for representing surfaces; and addresses and locators for finding a geographic location (Zeiler, 1999: 8).

2.9.2 The benefits of constructing a Database Management System (DBMS)

According to Longley *et al.,* (2015) Geodatabases can provide security, controlled update, backup and recovery, query language, data load capacity, data model, indexes, database administrative tools.

- ***The types of database DBMSs***

Longley *et al.,* (2015: 196) stated that " Database Management Systems (DBMS) are classified according to the way the database organises, stores, and manipulates data. There are three types of DBMS that are used in GIS: the relational Database Management System (RDBMS), Object Database Management System (ODBMS), and Object-relational Database Management System (ORDBMS)". According to Heywood *et al.,* (2011) there are five types of database model which are the Hierarchical, network, relational, object- relational, and object- oriented data models.

- ***Relational Database Management System (RDBMS)***

There is the type of data that is represented in a form of series of two-dimensional tables (Longley *et al.,* 2015; and Heywood *et al.,* 2011). According to Butler (2008) the benefit of a relational database is that it can represent and manage relationships in tables.

2.10 Conceptual framework

For effective management of solid waste, there needs to be the application of GIS. GIS has the capability of capturing, storing, manipulation, analysis and display of geographic data for decision making purposes such as locating or evaluation the locational suitability of solid waste facilities such as landfills using a variety of environmental criteria, economic, and social criteria such as slope, proximity to residential areas, proximity to cultivated areas, proximity

roads, proximity water sources (rivers, dams, streams, lakes, and underground water), proximity to fragile ecosystems, and proximity to towns. The criteria are explained in detail on the environmental regulations such as the minimum requirements for the disposal of waste by landfill. The criteria help minimise water, soil, and air contamination. The GIS tool can aid in route optimisation when collecting waste using the landfill truck which minimises driving distance and maximises vehicle loads. Routes for the collection of solid waste can be established with the use of computer models. When the driving distance is minimised, it saves money. GIS database also contributes to the effective solid waste management. This is because GIS databases have the capability of storing related data such as the solid waste generators and the nature of solid waste generated; the available solid waste facilities (recycling facilities, buy-back centres, and landfill) and the nature of waste that is accepted; compliance of the landfill with the environmental, health, and safety regulation; and the locational suitability of landfill. The GIS database helps querying of the data with regards to the condition and quantity of the available resources at the waste facilities. The environmental, health and safety regulations are very crucial for the effective management of solid waste. The regulations help minimise nuisance due to landfill operations, contamination of water, soil, and air. The health and safety regulations help to minimise injuries and accidents in the workplace.

In terms of waste management of waste at a household level, the theory of planned behaviour explains how an individual's knowledge, attitude and behaviour influence the management of solid waste. The theory of planned behaviour (TPB) explains the relationship of knowledge, attitude and behaviour. The theory was developed in the 1980's to try and explain all behaviours. The intention or behaviour of a person is shaped by the attitude, subjective norm, and perceived behavioural control. Behavioural intention reflects one's determination of subjective probability and the willingness to adopt a particular action. Attitude has been considered as a responsibility and subjective evaluation of an individual's opinion towards an object, for example, an individual decides whether to segregate the waste at source and recycle waste or not. Some people believe that it is the municipality's responsibility to segregate the waste at source or that they are creating jobs for other people, and that kind of attitude does not contribute to the effective management of solid waste. The subjective norms are the social pressure from people around us such as friends, parents, the media, neighbours, and government. The subjective norm determines an individual's behavioural intention. For example, when a person such as a teenager goes to the supermarket, the majority of them don't go there with their own plastic bags because it is perceived as not being "cool"; the person would rather buy a new plastic bag from the store. As a result, there is an increase of plastic waste generation which is seen today as a world-wide problem. The actions taken by the government such as awareness campaigns, the regulations, clean-up

campaigns, and segregation of waste campaigns have a huge role in the effective management of solid waste. When the government takes more action, people would see the importance of recycling, reusing, reducing of waste on the environment and economy. The other challenge is that a person may have knowledge of the effective management of solid waste, but does not participate in the segregation, recycling, and reducing of solid waste. People would rather be forced to do something than do it voluntarily or people would do something when there is some sort of punishment or reward. If people could change their attitude towards waste- recycle more, reduce more, segregate waste at source more, and reuse more, then people would have low footprint. People would also try to bring about eco-solutions by inventing things from the waste.

Effective waste management contributes to environmental sustainability, as there is the minimisation of air, water and soil contamination, illegal dumping in the area, injuries and accidents in the workplace (health and safety regulations), and nuisance for people living around waste.

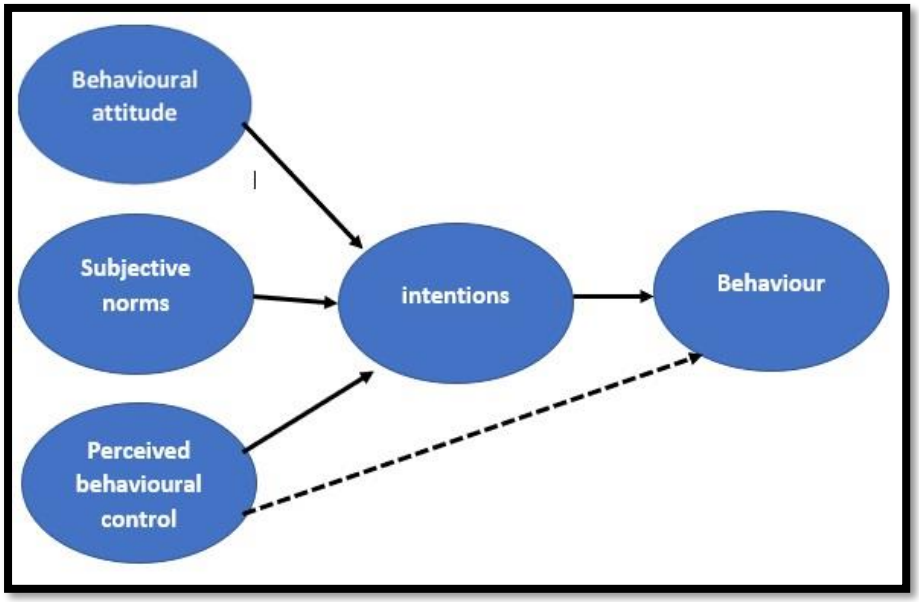


Figure 2:3: Theory of planned behaviour (source: Raban , 2000: 41).

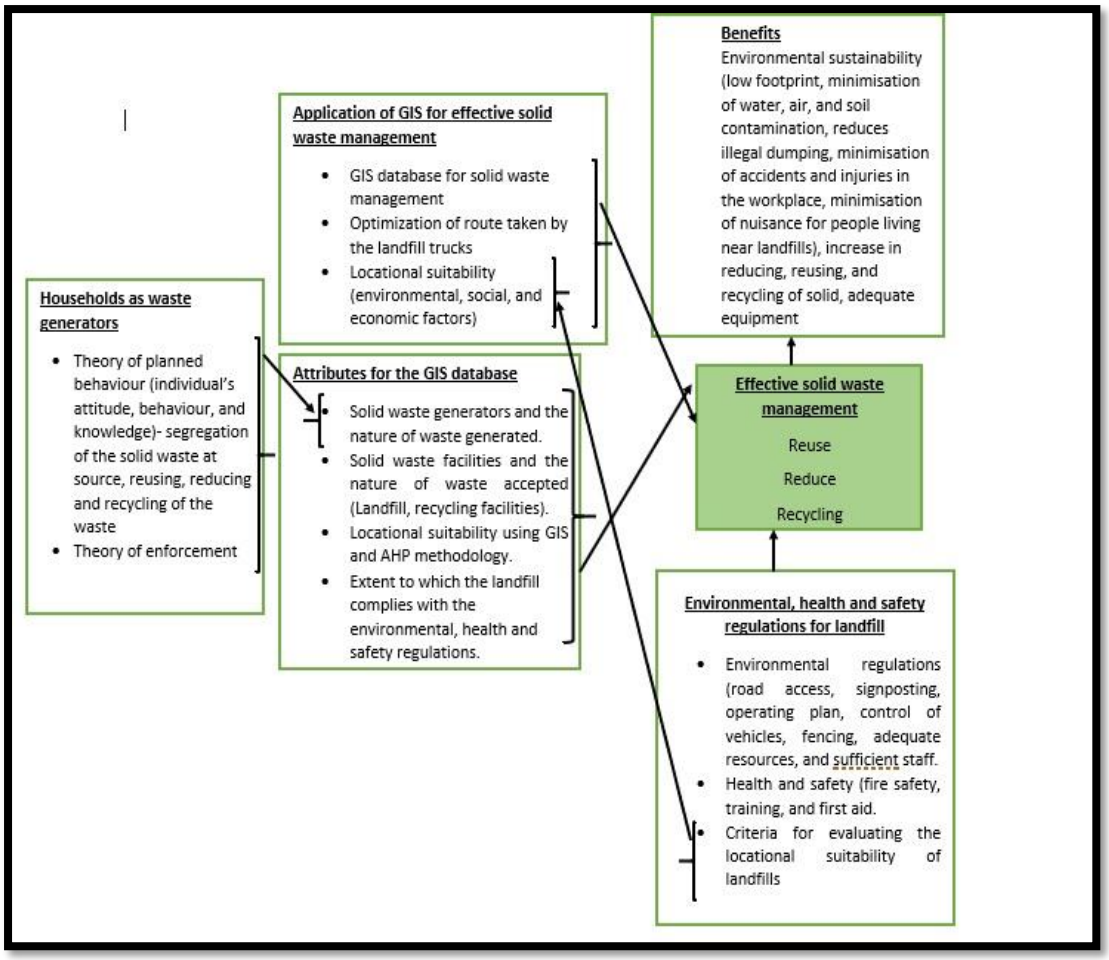


Figure 2:4: The conceptual Framework

2.11 Chapter summary

The chapter discussed the concept of waste management which included the different sources of waste generation such as the household, institutional, commercial, and industrial sites. The way in which waste is handled was discussed, and these are issues such as the segregation of waste at source, the storage of waste, and how waste was collected. The different methods of waste recovery and treatment were highlighted. The recovery methods included recycling, reusing, and reducing of the waste. on the other hand, the different ways of treatment of waste included the thermal, chemical, and the biological. The chapter also discussed waste management in developing countries and the challenges of managing solid waste in those countries. The chapter also looked at the influence of the capitalist economy in waste management, the government interventions with regards to reducing the solid waste generated. The individual's attitude and value systems, the south African legislations such as the minimum requirements for the disposal of waste in a landfill and the occupational health and safety regulations, and the application of GIS were discussed. The next chapter looks at the methodology used in the study.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter focused on the research methodology which explained the procedures to be taken to achieve the main aim and the specific objectives of this study. This chapter dealt with the research design covering the type of research adopted, and the ethical consideration; the method of data collection and data analysis; and the chapter summary. The chapter also addresses issues such as validity and reliability.

3.2 Research design

The study used a mixed research approach which is both qualitative and quantitative research. Qualitative developed from social sciences which helps researchers to study social and cultural phenomena. In addition, qualitative research attempts to explore issues about a problem, and it includes data collections such as observation, interviews and questionnaire, documents and texts (Myers, 2009). Prior the data collection, the researcher did a pilot study. The aim of a pilot study was to try out the research approach to identify the potential problems that may affect the quality and validity of the instruments (Blessing and Chakrabarti, 2009). The truthfulness of the data is very essential in a qualitative approach. According to Krefting and Creswell (1998) the truthfulness can be used by utilising four strategies: credibility, dependency, transferability, and conformability, and constructed parallel to the analogous quantitative criteria of internal and external validity, reliability and neutrality. The quantitative approach puts emphasis on quantities of entities. The data can be obtained from questionnaires, surveys, and experiments.

Research paradigms are very important in conducting research because they affect the selection of data, the methods of research employed, and the mode of explanation (Griggs , 2000). The study adopted postmodernism. According to Myers (2009) postmodernism assumes that social reality is historically constituted and that it is produced and reproduced by people. The paradigm recognises that the ability to change social and economic circumstances, is constrainted by various forms of social, cultural and political domination. The aim of postmodernism is to openly critique the status quo, and seeks to bring about cultural, political and social change.

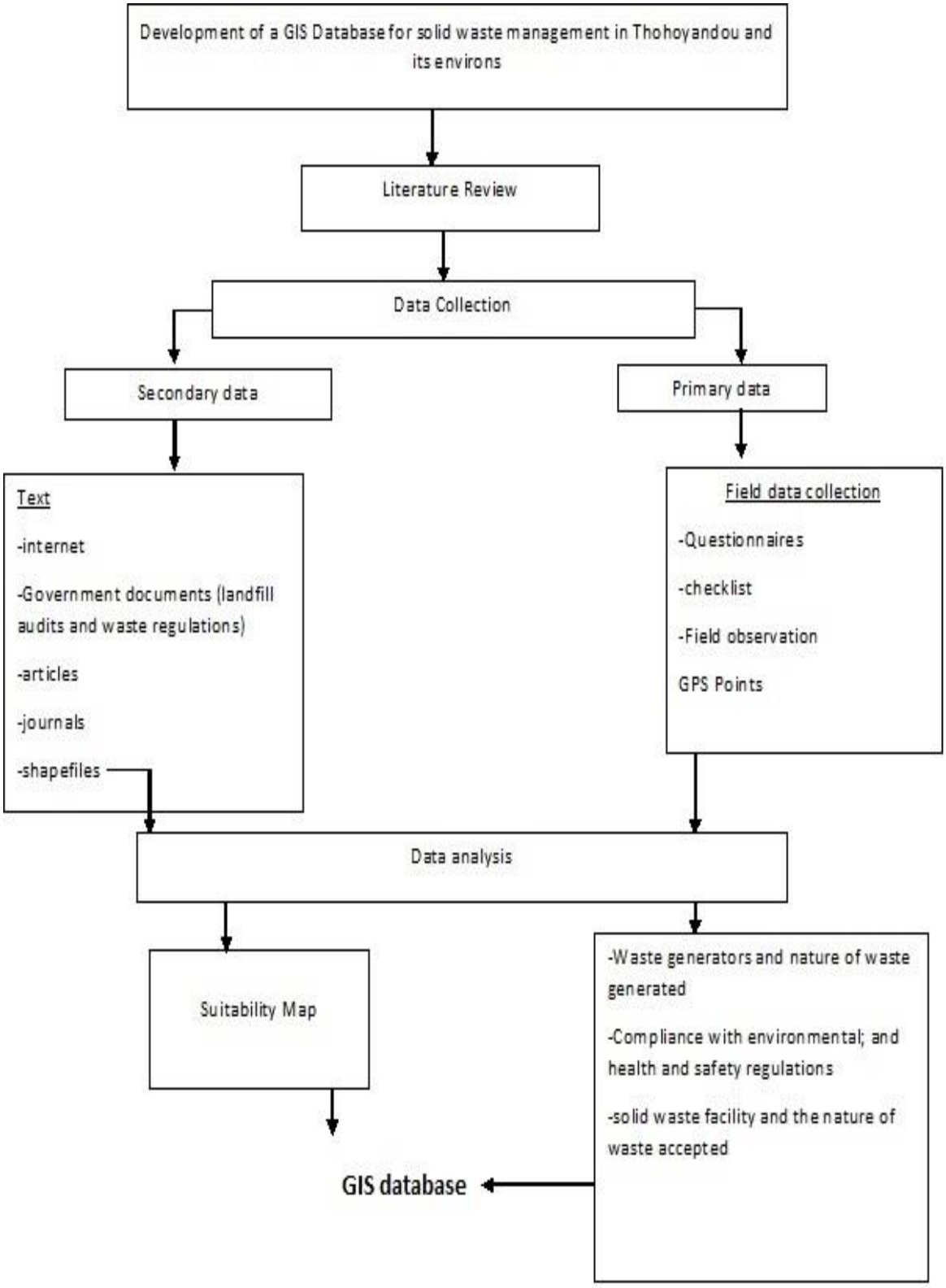


Figure 3:1: Summary of the research design

3.2.1 Type of research adopted

The study used a cross-sectional research design. According to Kumar (2011) the other term for cross- sectional is one-shot or status study.

3.2.2 Sampling procedures

According to the Department of Education, Thohoyandou has 9 primary Schools, 1 university (university of Venda), 10 high/ secondary schools and 7 colleges. Convenient sampling was used to sample the residential areas. The study only sampled households in Thohoyandou P-West which consists of 391 households, Thohoyandou P-East which has 591 households, and Thohoyandou Golgotha consists of 102 households (Census 2011). There are approximately 5 government offices.

Table 3-1: Table illustrating the different sectors and their sampling method and the sampling size

Institutions	**Sampling method**	**Sample size**
Schools [Primary, Secondary, Combined (primary + secondary) and tertiary]	None (i.e. whole population)	27
Post offices	None (i.e. whole population)	3
Police stations (Thohoyandou)	None (i.e. whole population)	1
Community hall (known as Thohoyandou Town Hall)	None (i.e. whole population)	1
Type of business (commercial) establishments		
Large restaurant	None (i.e. whole population)	4
Large hotel	None (i.e. whole population)	1
Departmental stores	None (i.e. whole population)	3
Residential/ domestic/ households		
Thohoyandou P- East (522)	Simple random sampling	90
Thohoyandou P- West (391)		
Thohoyandou-Golgotha (102)		
Industrial		
Recycling facilities	None (i.e. whole population)	2

The study used simple random sampling to sample the households because the households were too many. No sampling was done for the commercial sector (i.e. restaurants, hotels, shops, and business establishments), industrial, and institutional sectors (schools, and the government offices). This was done because there were a few commercial, industrial, and institutional establishments.

- ***Sampling of the Household***

GPS co-ordinates of the households that are situated within Thohoyandou Golgotha, P-East and P- west were obtained from google maps and were imported into the GIS Software. The households were then numbered and pieces of paper with numbers were inserted in a plastic bag. Only houses that were within Thohoyandou Golgotha, P-East and P- west were potential respondents and any house had an equal chance of being selected. With their eyes closed, the participants picked one of the 90 pieces of numbered papers, and the 90 respondents were given a questionnaire and the questionnaire cover letters. The questionnaire and the cover letter were given to them directly by the researcher.

The sample size was obtained from the formula represented below:

$$SS = \frac{Z^2 \times (P) \times (1-P)}{C^2}$$

Where:

SS= Sampling size
Z = Z value (e.g. 1.96 for 95% confidence level)
p = percentage picking a choice, expressed as decimal (.5 used for sample size needed)
c = confidence interval, expressed as a decimal

$$= \frac{1.4^2 \times (0.27) \times (1-0.5)}{0.05^2}$$

=90 households

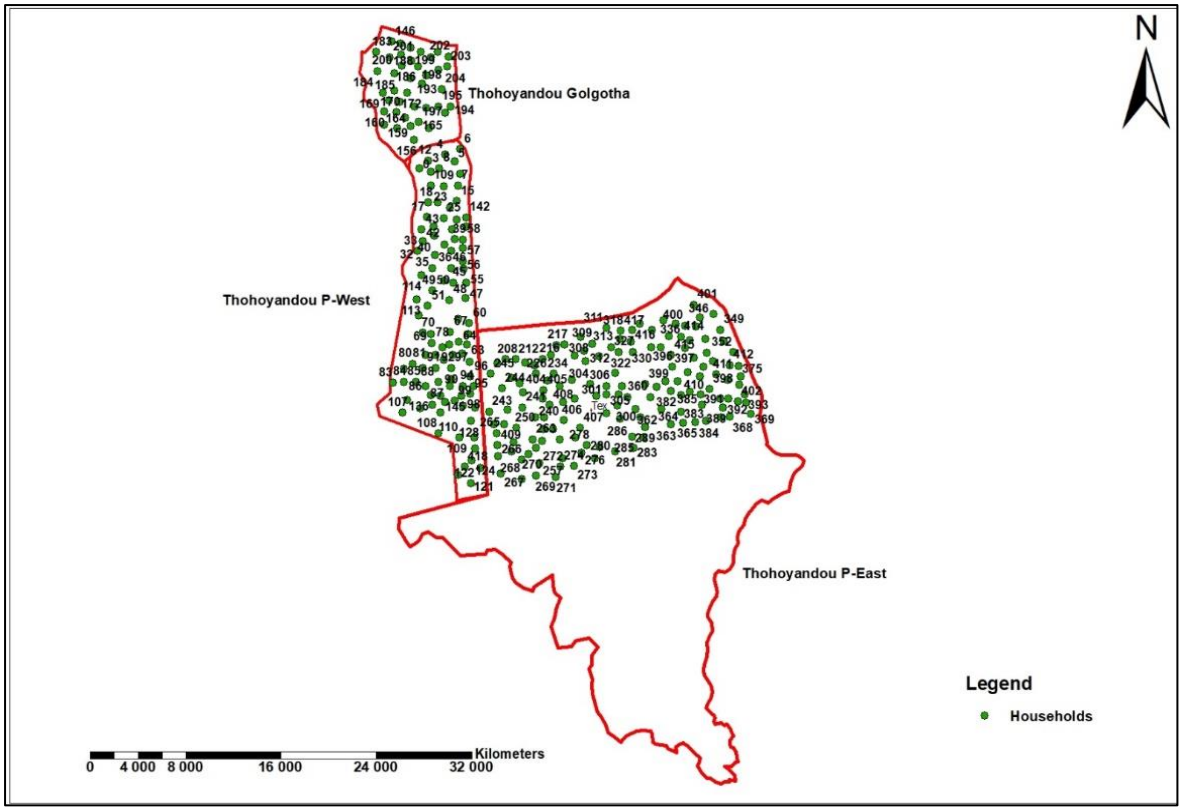


Figure 3:2: Digitised household at Thohoyandou P-west, East, and Golgotha used for sampling purposes

3.2.3 Ethical considerations

Permission to access the solid waste facilities was needed to collect data in the form of observations, and questionnaires and checklist to get data on the extent to which the landfill complied with environmental, and health and safety regulations. The respondents who took part in the questionnaire needed to be well informed about the kind of data that was needed from them and why it was needed. The participants needed to be informed of what they and the researcher would benefit from the research, and the details as to where and when the questionnaire or interviews would be conducted. The participants needed to be informed whether there were any foreseeable risks or any discomfort if they decided to take part in the study. The respondents also needed to be informed that if they are not interested in taking part in the questionnaire, they could withdraw from participating. The respondents also needed to know that their privacy was protected. In other words, they would be anonymous. Prior to data collection an ethics clearance certificate was obtained from the University of Venda Research Centre (Appendix F).

3.3 Method of data collection

The study used both primary and secondary data. Primary data was obtained from the questionnaires, informant interviews, checklist, observation and GIS modelling. Secondary data was obtained from the government documents such as the regulations and the recent landfill audit that was conducted.

3.3.1 Document analysis

The secondary data on the environmental, health and safety regulations was obtained from government documents/publications. The environmental regulations were extracted from the Minimum Requirements for Waste Disposal by Landfill 1998 and National Environmental Management: Waste Act 59 of 2008- National Norms and Standards for Disposal of Waste to Landfill (GNR636 of 2013). Prior to the extraction and the construction of the checklist, the researcher needed to analyse the permit to determine the exact landfill class. This was imperative to determine the exact class of the landfill for the results to be reliable. Evaluating the compliance with the wrong landfill class standard would affect the results of the study. A small and general landfill cannot be evaluated using the standard of a large and hazardous waste. The health and safety regulations were extracted from the Occupational Health and safety Act (85 of 1993). The extracted regulations were included in the checklist. The checklist was constructed to establish the extent to which the solid waste facilities complied with the environmental, and health and safety regulations. The other secondary data that was utilised were previous audits from the solid waste facilities. The audits were used in the discussion section. Furthermore, the other secondary data that was needed included recent articles and books which had information concerning the relevant criteria to evaluate the locational suitability of the solid waste facilities. This was very crucial information because it showed the relevant criteria that are used; the conditions of the criteria (for example: landfills that are less than 500m from water sources are unsuitable, while landfills that are more than 500m are considered suitable); and the weighting of each criterion which shows the most important to the least important criteria.

3.3.2 Field observation

“Field observation is predominantly a qualitative research design; it is also used in quantitative research, depending upon how the information has been generated and recorded. In qualitative research, an observation is always recorded in a descriptive format whereas in quantitative research it is recorded either in categories or on a scale. It can also be a combination of both – some categorisation and some description or categorisation accompanied by a descriptive explanation. You can also change a descriptive recording into

a categorical one through analysis and classification" (Kumar, 2011). This is when the researcher goes to the field several times to observe with the aim of observing without interfering (Struwig *et al.,* 2001).

Field observation involved looking at what was happening and recording events on the spot. A week was spent at the solid waste facilities to gain first-hand experience and comprehensive notes were documented. Observation was used in the study to evaluate the extent to which the solid waste facilities complied with the environmental, and health and safety regulations and to obtain the actual condition of the facilities, resources, infrastructure of the solid waste facilities. The data was filled in the checklist. Non-participant observation was employed. This is when the researcher does not participate in the activities of the group, but the researcher remains passive and later draws conclusions from what was seen. Field observation was used in the study to establish the type of solid waste that is generated by the households, commercial, institutional and the industrial sectors. In addition, Field observation was also used to assess the nature the solid waste that was accepted at the solid waste facilities.

3.3.3 Field work

To determine the waste composition that was generated from the households, commercial establishments, institutions and industrial sectors, the researcher needed to get the weekly programme for refuse removal so that the researcher would know when to do waste composition before the waste was collected and transported to the various solid waste facilities in Thohoyandou.

Determination of the solid waste mean weight and composition

To obtain data for waste generated, the researcher used gloves and refuse bag for the sorting of waste. The facemask and work suit were used for protection. The waste was weighed on the scale and after the waste was segregated (sorted) into different categories such as paper and cardboard, metal, plastic, glass, organic and other waste. After the waste was sorted the waste was weighed again in their different categories.

Formula for determining the weight generated

$W_g = (W_t - W_b)$

Where:

W_g = Waste generated

W_t = gross weight of bin and waste

W_b = weight of the empty bin

3.3.4 Checklist

Leedy and Ormrod, (2015) defined a checklist as a list of behaviours or characteristics for which a researcher is looking. The researcher—or in many studies, each participant—simply indicates whether each item on the list is observed, present, or true or, in contrast, is not observed, present, or true. The checklist was used in the study to establish the extent to which the solid waste facilities comply with the environmental, and health and safety regulations. The checklist was derived from the Department of Water Affairs and Forestry, Second Edition, 1998. Waste Management Series. Minimum Requirements for Waste Disposal by Landfill - Section 10 "Landfill Operation; National Environmental Management: Waste Act 59 of 2008- National Norms and Standards for Disposal of Waste to Landfill (GNR636 of 2013); and the Occupational Health and Safety Act of 1993. The camera was used to take pictures of the items that were observed at the field. The checklist was constructed based on the standards of the class G: S: B^{+} which means that Thohoyandou is a General Small landfill that produces significant leachate.

3.3.5 Questionnaire

Kumar (2011) defined a questionnaire as “a written list of questions, the answers to which are recorded by respondents”. According to Babbie and Mouton (2001) the purpose of a questionnaire is to obtain facts and opinions about a phenomenon from people who have knowledge of a specific issue.

- ***The first questionnaire***

The questionnaire aimed to target the solid waste generators. According to literature the solid waste generators are the domestic/household waste, commercial waste, industrial waste, institutional waste, street sweepings, industrial/ trade waste, and debris or construction rejects, (Coad, 2011). The questionnaire aimed to obtain data on the nature of solid waste generated (the type of waste generated, the mass of the waste generated, whether there was sorting of waste at source, how frequent is the waste collected, and the mode of solid waste collection).

- ***The second questionnaire***

The second questionnaire aimed to target the solid waste facility operators/ recyclers, /waste supervisors at the solid waste facilities such as the buy-back centres, recycling centres and the landfills. The questionnaire aimed to obtain data on the characteristics of the solid waste disposed at the facilities such as the solid waste facility’s name, the type of solid waste facility it was (i.e. Landfill, buy-back centre or recycling centre). The other data that was collected is

the type of waste (i.e. glass, paper, paper, plastic, tins) that was disposed of at the solid waste facilities, whether there was the sorting of the waste, and the weight of the solid waste disposed of per week. The reliability and validity were very crucial in the study. A pilot study was done before the actual data collection process. The aim of the pilot study was to verify whether the questions on the questionnaire were clear and that there was not any ambiguity.

3.3.6 Key informant Interview

This is primary data and is the qualitative method of data collections. The study used an unstructured interview. The unstructured interview was conducted at the solid waste facilities to account for the unavailable essential items or rather the lack of compliance. This was very important because it helped the researcher to suggest recommendations for the study. The people who were interviewed were the solid waste handlers and the responsible person at the solid waste facilities. The interview was conducted in person (face to face). The researcher took notes and probed for more information. The interview was done in English. The responses that were obtained from the waste handlers and responsible person were presented on the checklist on the Observation/ Comment section in a purple front colour. **Observation**- is a description of what the researcher saw at the Thohoyandou Landfill. The **comment** section was additional information that addresses the reasons for items that were partially and not compliant.

3.3.7 GIS modelling

This was used in the study to evaluate the locational suitability of the solid waste facilities in Thohoyandou and its environs with the use of GIS and AHP. The model builder in ArcGIS 10.5 was used to determine whether the Thohoyandou Landfill was situated in a suitable area by using the different criteria such as slope, proximity to the water sources, roads, residential areas, cultivated areas, fragile ecosystems such as wetlands, and towns. The evaluation was done based on the literature review of the applicable criteria, consultation with the experts and the South African regulations. “The criteria used in the study were based on the local characteristics, expert’s opinion, availability of the data, the national regulations and standards, and the related studies” (Karimi *et al.,* 2018). Regions that had poor geological conditions were given a lower score, an indication of its poor suitability, while those with good geological conditions were given higher scores.

3.3.8 Global Positioning System (GPS)

GPS was very crucial in this study because the location (geographic co-ordinates) of the solid waste generators and the solid waste sites needed to be established. The GPS points were included in the GIS database.

3.3.9 GIS database modelling

The GIS database was constructed on Microsoft Access and then transferred to Wix software. There are a variety of approaches to manage information technology (IT) project. Two approaches that are commonly used by GIS designers are the system life cycle (SLC) and prototyping. The study used the system life cycle, which is also known as the "waterfall models". The system life cycle advocates a linear approach to managing the development and implementation of IT systems. The system life cycle was used because the output from the first stage of the process informs the second phase, and the outputs from the second phase affect the third phase, and so on. The second reason is that it provides a very structured framework for the management of GIS project, which is so important when good time management is an essential aspect for the project. It is very easy to budget for resources required by the waterfall approach because the requirements of the system are established at an early stage of the project.

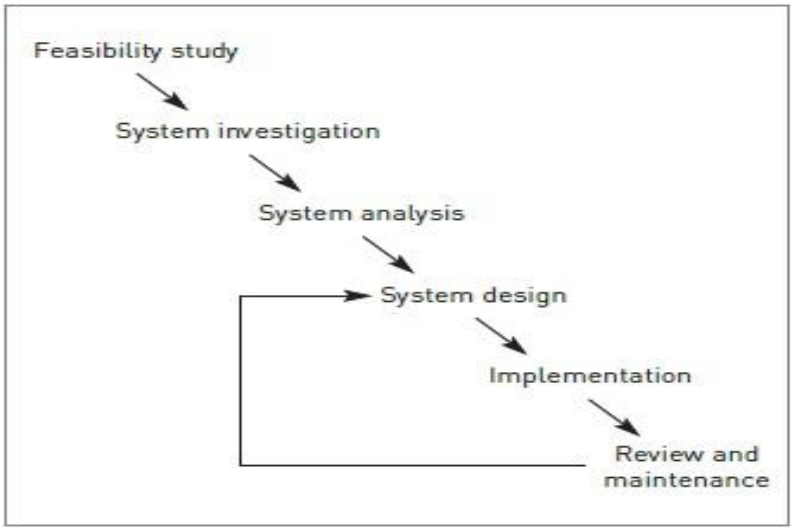


Figure 3:3 The system life cycle "waterfall" model (source: Heywood et al., 2011)

When the GIS database prototype for the solid waste management is developed the user can comment and additional information can be included. According to Heywood *et al.,* (2011) there are a variey of database data models. Amongst those that have been used for attribute data in GIS are the Hierarchical, network, relational , and object relational data models. The

frequently used data model is the relational. The relational database model at present dominates in GIS. The data were organised in a series of two dimentional tables, each of which contains records for one entity. The study used relational data model. “In the relational database each entity set is represented by a table, while each row in the table represents the data for an individual entity. Each colume holds data on one of the attributes of the entity set” (Maguire *et al.,* 1991). Modelling was a prerequisite in the context of the development of computer applications. Butler (2008: 27-28) stated that “one needs a good data model to produce a good geodatabase design”. Designing a geodatabase requires six steps which are shown on figure: 3.2.

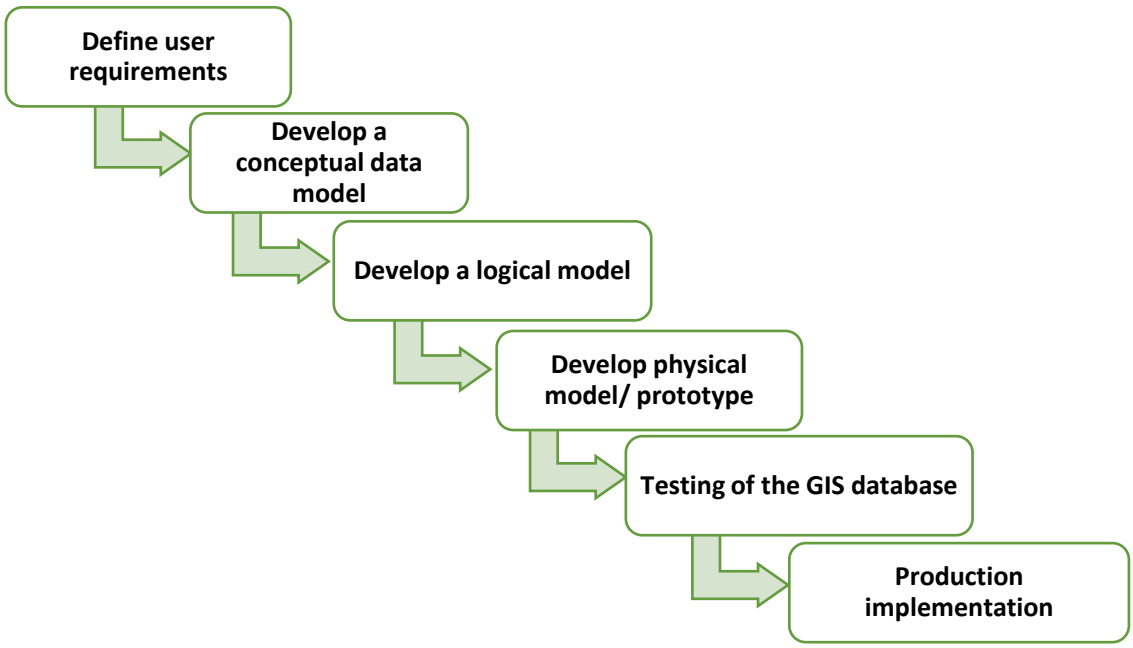


Figure 3:4: Six steps that are used to develop a GIS database (Source: Maguire et al., 1991)

Database design involves the physical and the logical database design. Database creation of the practical designs depends on the type of software used and the data model. The physical design of the database involves translating the logical design (produced during the data modelling stage) (Heywood *et al.,* 2011). Maguire *et al.,* (1991) indicated that the physical design is concerned with the location of the different parts of the database within the file. In the logical database design, the first step is the use of data analysis techniques to develop a clearly defined conceptual model of the relationships between different datasets. If the conceptual model is not constructed properly, the likely outcome would be an inefficient database structure with unnecessary redundancy in the data storage and poor match to users’ requirements for data access and retrieval. According to Maguire *et al.,* (1991: 253) there are a variety of data analyses or data modelling techniques that are used but the entity

relationship model approach has met with the widest acceptance. Therefore, the study used the entity-relationship model to do the logical design for the database which is presented on figure 3.5.

Entity Relationship (ER) diagram

Agouris and Stefanidis (1999: 82) stated that "the Entity relationship diagram has three components- which are the entity sets, attributes, and relationships. In the ER diagram the "mini world" is partitioned into entities which are characterised by attributes and interrelated via relationships". Entities are 'things' or 'objects' which have an interdependent physical or conceptual existence. Entities are characterised by attributes. An attribute, or a set of attributes which uniquely identifies instances of an entity, which is called the key. Entities interact or connect with each other through relationship'. According to Heywood *et al.,* (2011: 118) "each entity has a distinctve characteristic and is usually described by a noun". The entities for the research are: the solid waste treatment sites, towns and their environs, landuses and the waste generated. Its characteristics are attributes which are:

- Solid waste facilities sites: Attributes include the Site ID, Site Type, Site Name, Site GPS co-ordinates, Site compliance with the environmental, health and safety regulations, the Site Locational Suitability
- Towns and its environs: This includes the Town ID, the Town Name, Town GPS Co-ordinates, Town area
- Waste generated: Waste generated ID, waste class, waste weight, waste rate of generated (Kg/ Week), waste handling (segregation, collection, storage, type of waste treatment and recovery used, sector ID
- Land uses: This comprises of the land use ID, land use Type, land use GPS Co-ordinates, Town ID.

The relationship between the entities can be described using a verb, Thus, solid waste treatment site ***is located*** in a Town; the Town ***consists of*** land uses; the land uses ***generate*** solid waste; the solid waste is ***transferred to*** the solid waste treatment sites.

According to Agouris and Stefanidis (1999) and Heywood *et al.,* (2011: 118) there are three kinds of relationships. These are the: one-to- one, many-to-one, and the many- to- many.
For example, in this study a:

- One-to-many relationship is that there is a Town (Thohoyandou) and several Solid waste facilities sites; there is one Town which consist of many land uses.

- Many-to-many relationship is that there are many land-uses which produce or generates many solid wastes; the many solid waste generated are transferred to several (many) solid waste facilities.

Table 3-2: Entities, class and their attributes that will be involved in the GIS database

	Entity	Class	Attributes (characteristics)
1	Solid waste facilities	Point	The Attributes include the Site ID, Site Type, Site Name, GPS (longitude), GPS (Longitude), Site compliance with the environmental, health and safety regulations, the Site Locational Suitability
2	Towns and its environs	Polygon	This includes the Town ID, the Town Name, GPS (longitude), GPS (Longitude), Town area
3	Land uses	Polygon	This comprises of the land use ID, land use Type, land use GPS (longitude), GPS (Longitude), Town ID
4	Waste generated	Point	Waste generated ID, waste class, waste weight, waste handling (segregation, collection, storage, Land use ID,

At the end of the study a GIS database prototype for the solid waste management in Thohoyandou and its environs was developed. The proposed GIS database prototype for solid waste management in Thohoyandou and its environs was expected to have seven (7) main modes of interrogation : “Home” which will display the map of the study area and the description of Thohoyandou and its environ map; the “solid waste generated” would be able to query data on the solid waste generators and sources, types of waste, waste composition, the rate solid waste generation, the weight of the waste; the solid waste facilities; locational suitability of Thohoyandou and its environs using the different criteria/ parameter: slopes, proximity to cultivated areas, proximity to fragile ecosystems, proximity to water sources, proximity to residential areas, proximity to towns, and proximity to road; and compliance-environmental regulations; compliance- health and safety regulations.

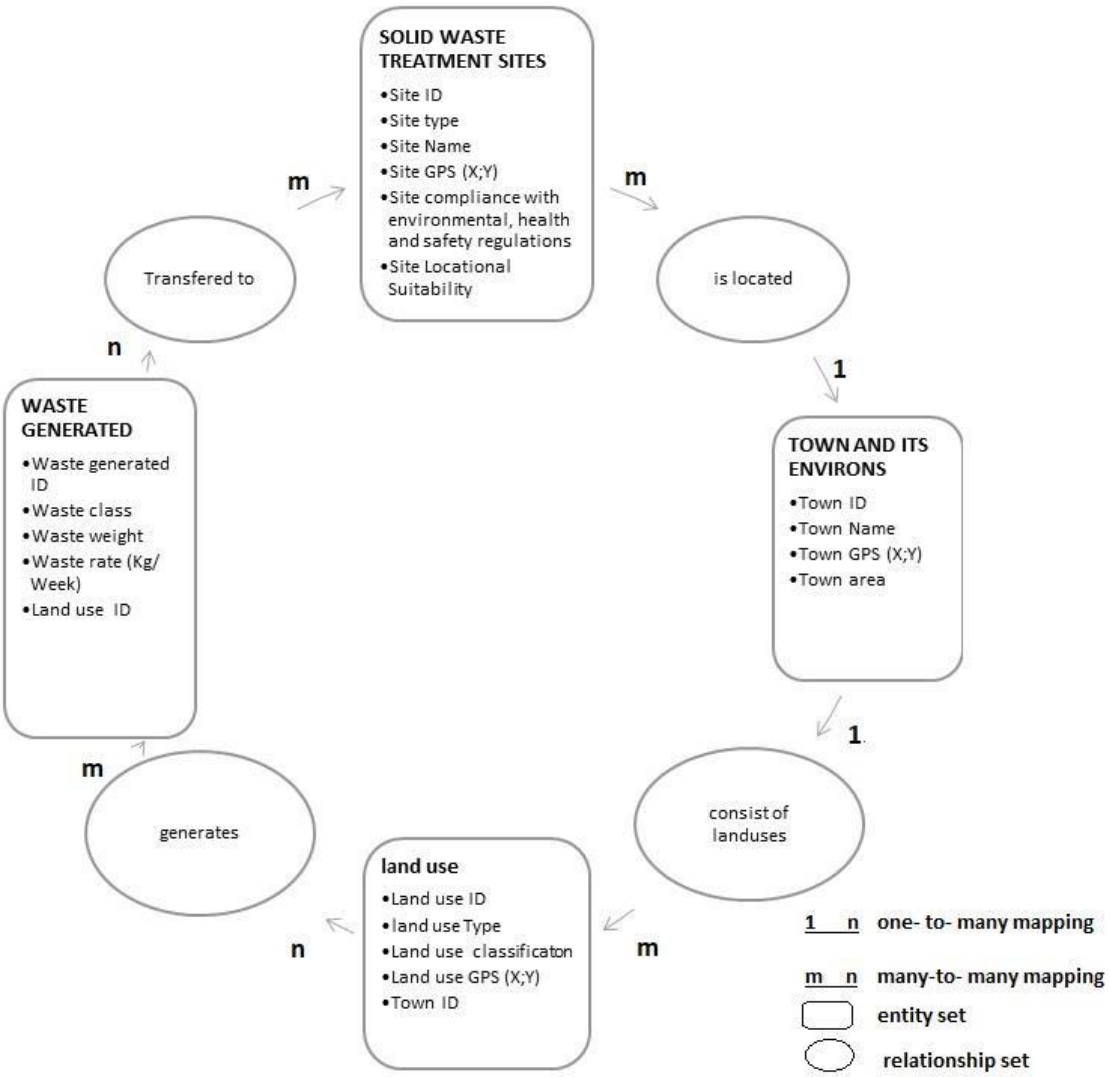


Figure 3:5: The conceptual model (Entity Relationship (ER)/ database schema diagram indicating the various entities involved in the database (source: Matsie and Palamuleni, 2017)

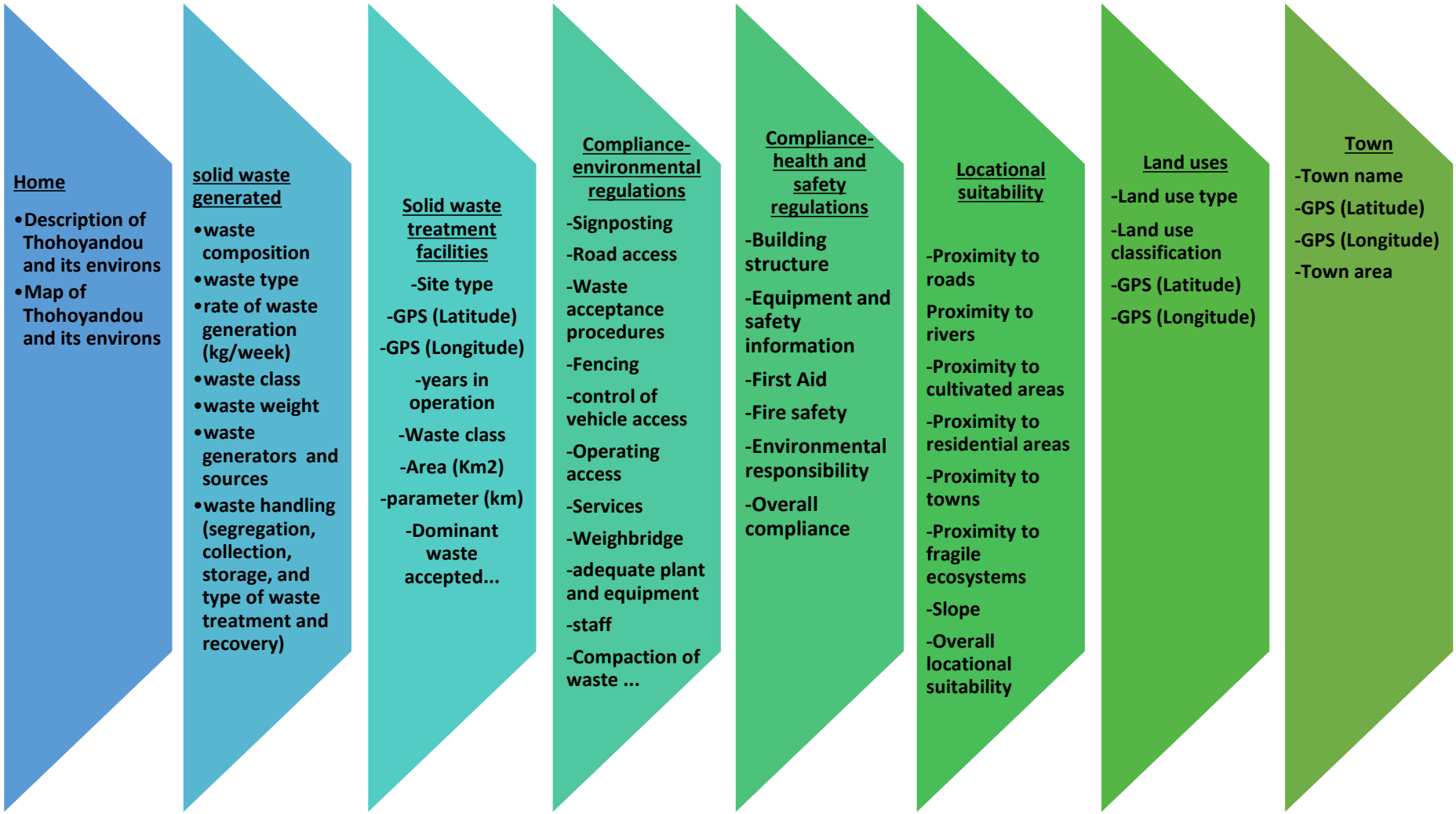


Figure 3:6: Seven (7) expected modes of interrogation for the GIS database prototype for solid waste management in Thohoyandou and its environs

3.4 Method of data analysis and presentation

3.4.1 Questionnaire

- **Solid waste generators**

The data was analysed using Microsoft Excel computer program. Descriptive statistics (percentages) was used and the data was presented using Pie charts and bar graph.

3.4.2 Checklist

Table 3.3 shows the scoring matrix to show the level of compliance. The data was analysed using Microsoft Excel computer program- Descriptive statistics (percentages). The data was presented using bar graphs.

Table 3-3: Scoring Matrix used to determine the overall level of compliance with the regulations

LANDFILL COMPLIANCE		
% Compliance	**Level of compliance**	**Colour coding**
80%-100%	Compliant	
50-79%	Partial Compliant	
0-49%	Non-compliant	

3.4.3 GIS Modelling using ArcGIS Model Builder

To weigh the different criteria used to evaluate the locational suitability of the Thohoyandou landfill, AHP was used to do pair-wise comparison, eventually prioritising from most important to least important. The data was analysed using Euclidian distance tool, reclassify tool, weighted overlay tool, con tool and majority filter.

- ***Euclidian distance tool***

According to ESRI (2016) the Euclidean distance tool is used in evaluating the locational suitability, when the distance to data representing the distance from a certain object is needed. Every cell in the Euclidean allocation output raster is assigned the value of the source to which it is closest, as determined by the Euclidean distance algorithm. The limitation of the Euclidian distance tool is that it only gives information according to Euclidean, or straight-line, distance. It may not be possible to travel in a straight line to a specific location; one may have to avoid obstacles such as a river or a steep slope.

- **Reclassify tool**

In the study slope was reclassified into 5 classes. The town, proximity to cultivated area, water sources, fragile ecosystem, residential area and road were reclassified into 2 classes. The classification method used in the study is Manuel.

- ***Multi-Criteria Decision Making (MCDM) tool for weighting the criteria***

Multi-criteria analysis is a set of mathematical tools and methods allowing the comparison of different alternatives according to many criteria, often conflicting, to guide the decision maker towards a judicious choice (Chakhar and Mousseau, 2008). The most commonly used Multi-Criteria analysis tool is the analytical Hierarchy Process (AHP) which is a pair-comparison technique to determine the relative importance of each alternative in terms of each criterion. Weighting is defined as 'a value assigned to an evaluation criterion which indicates its importance relative to other criteria under consideration" (Al-Anbari et al., 2018: 4).

3.5 Limitation of the study

3.5.1 Labour intensive data collection

The collection of waste from the waste generators was labour intensive. As a result, the researcher could not carry out the data collection alone. The researcher needed help to move the waste and weigh it. To overcome this problem, the researcher appointed research assistants. The appointed research assistants were briefed about the nature of the study and were also trained on waste classification. As a result, the researcher managed to collect data from the waste generators.

3.5.2 Factors affecting data collections

Data collection was done during September and October which is spring. Therefore, the data was biased towards that season and the study was a cross-sectional study. Seasonality of waste generated was not part of the scope of this study.

3.5.3 Appropriate conditions for evaluating the locational suitability of landfills

When reviewing the literature on the evaluation of the locational suitability using GIS and AHP, the researcher found that different scholars used conditions for evaluating a landfill site. For example, one scholar would indicate that landfills should be 500m away from the rivers, while on the other hand another would say 500m is too close from rivers and suggests that landfills should be 1000m away from the rivers. To overcome this challenge, the researcher averaged the distance from different scholars.

3.6 Chapter summary

The study used a cross-sectional design. A mixed research approach which is both qualitative and quantitative research was used to achieve the objectives. Primary data sources such as field observation, informal interviews and checklist were used in the study. Secondary data such as shapefiles, government documents such as Minimum requirements for the disposal of waste by landfill, Occupational Health and Safety Act (85 of 1993), and the Thohoyandou landfill audit report were used. The next chapter presents and discusses the results concerning the nature and estimate amount of waste generated, and the types of solid waste facilities and the nature of waste accepted in Thohoyandou CBD and its environs.

Table 3-4: The Research Matrix

Objectives	Research Questions	Data needed	Data Sources	Data Collection method	Data Analysis	Results and Presentation Method
Identify the solid waste generators/sources; determine nature, and estimate amount of waste in Thohoyandou and its environs	What are the waste generators and the nature, and the estimate amount of waste produced in Thohoyandou?	• Weekly programme for refuse removal • Solid waste generators and sources, The location (GPS co-ordinates of the waste generators • Classification of the waste • Waste composition • The type of waste generated • Quantity of the waste generated • The weight of the waste generated • The rate of which the solid waste is generated (Mass/Week) • Population data of the households in Thohoyandou P-West, P-East and Golgotha	• Solid waste recyclers and waste management supervisors • GPS • Statistics South Africa (StatsSA) for population data (households)	• Questionnaire • Field observation • GPS	• Descriptive statistics (Percentages) Microsoft Excel computer program	• Bar graphs and pie chart

Identify and assess the types of solid waste disposed at the solid waste facilities in Thohoyandou and its environs.	What are the solid waste facilities and the type of waste disposed in the facilities in Thohoyandou?	• Geographic co-ordinates of the solid waste facility • Name of the solid waste facility • Types of solid waste that is disposed at the facility • Classification of the solid waste method used at the facilities • Rate at which the solid waste is disposed (Kg/ Week) • Weight of the solid waste	• Waste facility recyclers or waste supervisors • GPS	•Field observations • Questionnaires • GPS	• Descriptive statistics (Percentage) (Percentages) Microsoft Excel computer program	• Pie chart and descriptive
Establish the extent to which the solid waste facilities comply with the environmental, and health and safety regulations	To what extent does the landfill comply with the environmental, health and safety regulations?	• Extent to which the solid waste treatment facilities comply with the environmental, health and safety regulations • Solid waste treatment Audits	• Solid waste treatment recyclers /waste managers • Internet (available online government documents or databases)	• Document Analysis • Field Observations (non-participant observation) • Checklist • Unstructured interviews • Recent landfill audits that were conducted	• Descriptive statistics (Percentage) Statistical Package for Social Science (SPSS version 11)	• Pie chart • Descriptive
Evaluate the locational suitability of the solid waste facilities using Geographical	How can the locational Suitability of the solid waste facilities be evaluated	Shapefile of: • Cultivated areas • Water Sources • Slope	• United States Geological Survey (USGS)	• Downloaded from the internet	• Euclidean Distance • Reclassification • Analytical Hierarchy Process (Pair-	• Suitability Map

Information Systems (GIS) and AHP	using GIS and AHP?	• Residential area • Fragile ecosystem • Town (Urban areas) • Roads	• GPS Co-ordinates		wise Comparison) • Weighted overlay • Con Tool • Majority Filter	
Develop a GIS database for the solid waste management in Thohoyandou and its environs.	How can the GIS database for the management of solid waste be developed?	• The key waste generators and sources (types of waste, the location, rate, quantity (1 week) of solid waste generated, the handling of the waste (i.e. Segregation, storage and collection of the waste, and classification of the solid waste) • The key solid waste facilities in Thohoyandou and its environs (the type of solid waste disposed; weight of the solid waste produced) • The extent to which the solid waste facilities comply with the environmental, health and safety regulations	• From the results of objective 1, 2, 3, and 4	• Keyboard encoding of geographic co-ordinates • Global Positioning System (GPS)	• Entity relationship model using Ms Access	GIS database Prototype

CHAPTER 4: SOLID WASTE GENERTORS AND WASTE FACILITIES

4.1 Introduction

This chapter presents the results and the discussion concerning the nature of the solid waste that was generated from the households, commercial (business) establishments and institutions. During field work the waste composition, the type of vehicles used for the transportation of waste, type of storage used, segregation of solid waste at source, and the collection of solid waste were established. This chapter also looked at the solid waste facilities that were available in Thohoyandou CBD and its environs.

4.2 The solid waste generators, and the nature of the waste that was generated

4.2.1 Waste composition that was generated

The study found that the main solid waste generators in Thohoyandou CBD and its environs are the households, commercial (business) establishments and the institutions. According to Sasikumar and Krishna (2009); and Reddy (2016) solid waste is generated in the residential premises (households), commercial and business establishments, street sweepings, institutional premises (such as schools, hospitals, government offices, clinics and town halls).

- *Waste generated by households*

Figure 4.1 shows the solid waste composition from households. The study found that 29% of waste that was generated from households was organic waste. Organic waste was the highest waste type generated from the households. The second highest waste type was plastic which contributed 19%, while 18% was paper, 16% glass, 11% cans, and 7% of the waste was other. The other waste included textile, rubber and leather, wood and garden waste. The results from the study were similar to those of Matsie and Palamuleni (2017) and Alam *et al*., (2008) because in both studies the highest portion of the waste generated was organic waste. The difference was that in Thohoyandou CBD and its environs, the second highest portion of the waste generated was plastic, while findings from Matsie and Palamuleni (2017) showed that the second highest porion of solid waste generated was paper.

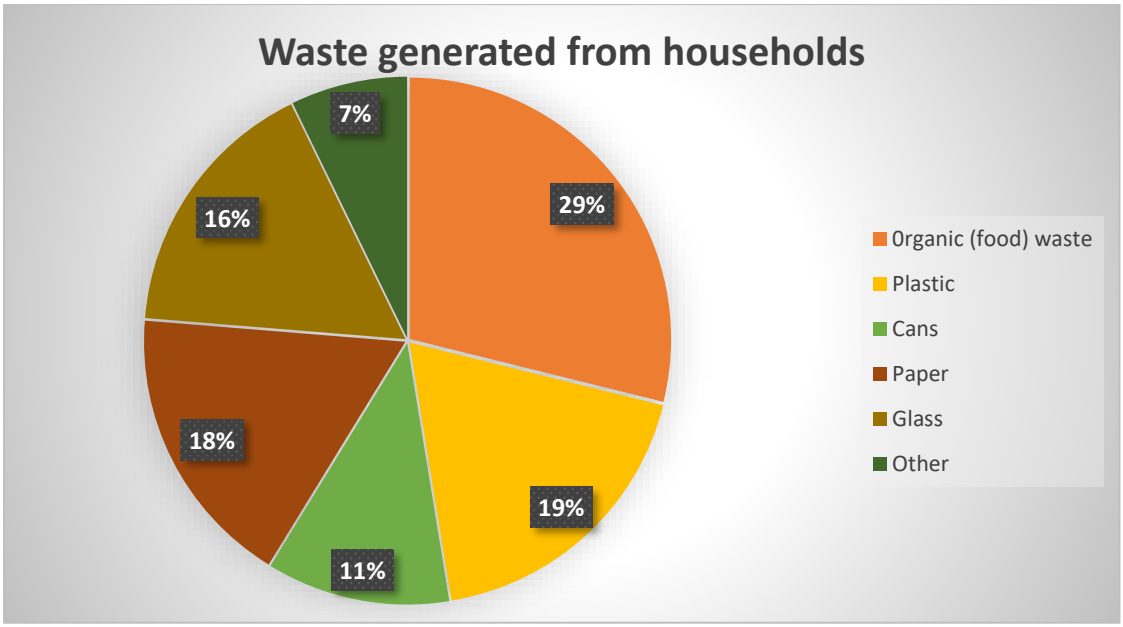


Figure 4:1: Composition of the solid waste generated from households.

Figure 4.2 shows the amount of waste generated for the households. The study found that 2077 kg of waste generated from households was organic; 1350 kg was plastic; 628Kg was cans; 1281 was paper, 1169 was glass; 786 was other waste.

Figure 4:2: Amount of waste generated from the households (Kg/week)

- *Waste generated by institutions*

Figure 4.3 shows the composition of waste generated by institutions. The study found that most of the waste that was generated by the institutions was paper/cardboard, which contributed 64% of the waste. The plastic waste contributed 28%, organic waste constituted 4%, Metal waste contributed 1%, and other waste contributed 3%.

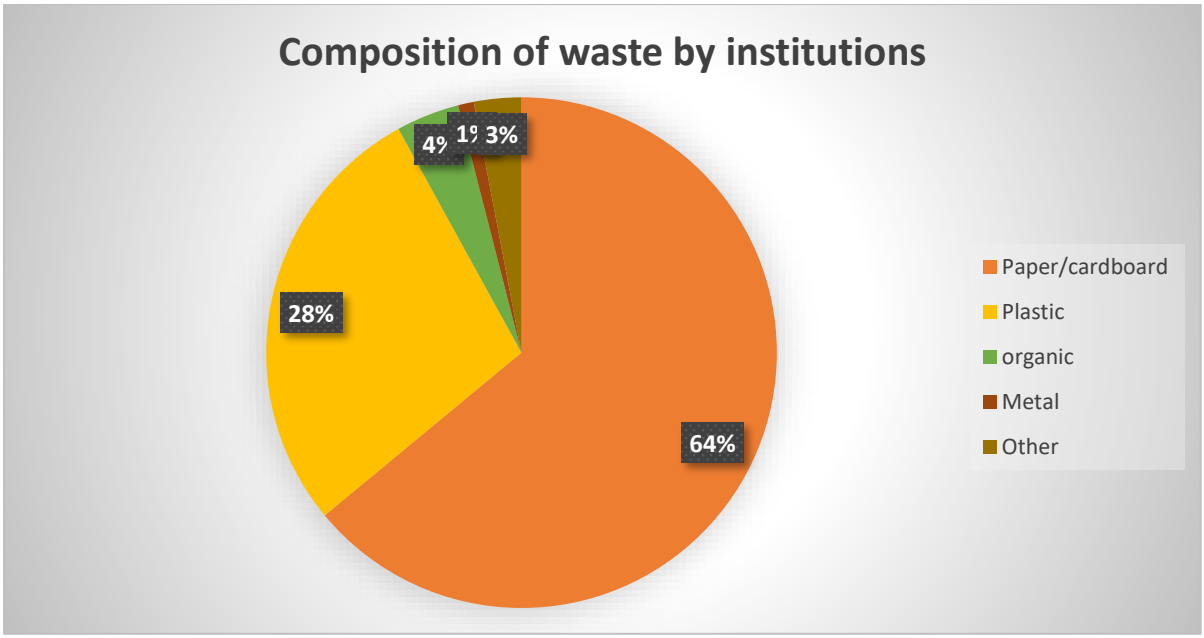


Figure 4:3: composition of waste generated by institutions

- ***Waste generated by business establishments***

Figure 4.4 shows the composition of waste that was generated by business establishments. The study found that most of the waste generated was paper/cardboard, which contributed 40%. This was because cardboard boxes were used for packaging products at the stores. 35% of the waste was organic (food waste), 24% of the waste was plastic, 1 % of the waste was glass. The results are consistent with those of Coad (2011) who also found that most of the waste generated in business establishments comes from cardboard boxes which are used for packaging bulky materials.

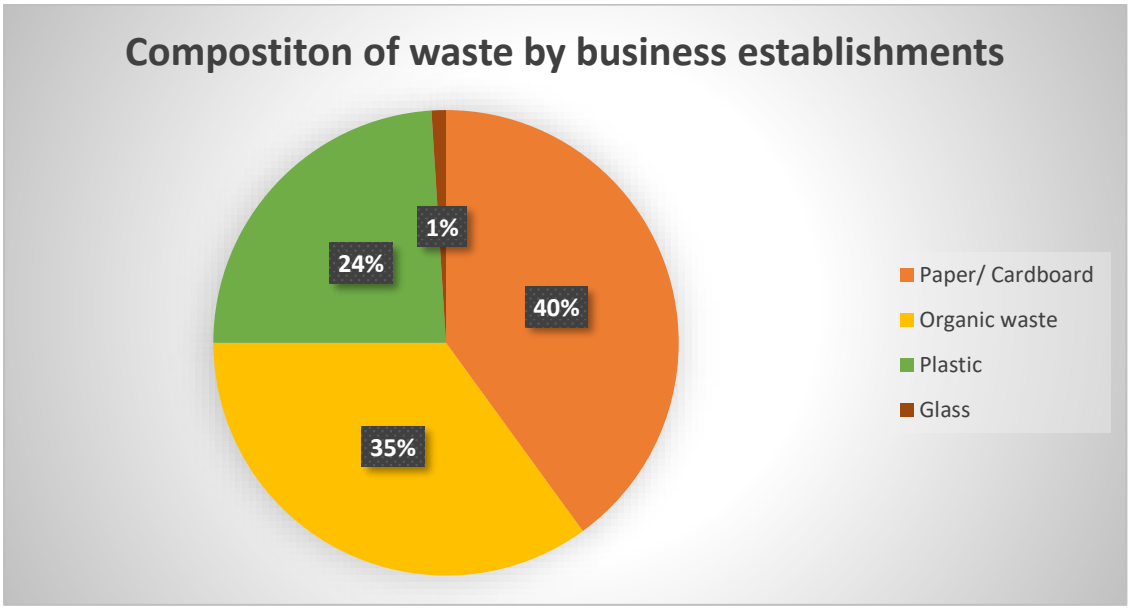


Figure 4:4: Composition of waste generated by business establishments

4.2.2 Segregation of the solid waste at source

The study found that there was no segregation of waste at the households. Instead, all the waste was mixed inside the refuse bags. When waste is not sorted, it reduces the quality of recyclable materials like paper and cardboard boxes due to the mixing of the waste (Ogola *et al*., 2011). Dhokhikah and Trihadiningrum (2012); Al-Emad (2011); Farzadkia *et al.,* (2009); and Gai *et al.,* (2009 lack of segregated at source is a challenge that is faced in the developing countries. The study also found that all the business establishments and most of the institutional sectors such as government offices and schools segregate the waste at source.

4.2.3 Type of storage containers used to store the solid waste

During fieldwork the researcher found that the waste from the households was stored in refuse bags which were placed along the streets. The results are similar to those of Ogola *et al.,* (2011) who found that waste from the households was stored in refuse bags. Commercial and institutional waste is stored in communal waste containers as well as waste bins.

Figure 4:5: Communal waste containers used to store the waste at the University of Venda

4.2.4 waste Collection

The study found that there were different schedules for the waste collection in Thohoyandou CBD and its environs. The schedule for the collection of household waste was different from that of commercial, and the institutional generators of waste. The waste from the household was collected once a week. The residential area in Thohoyandou was divided into blocks. Waste from Thohoyandou Block P-East was collected every Monday, Waste from Thohoyandou Block P-West and Thohoyandou Block C (Golgotha) was collected every

Tuesday. Commercial and institutional waste in Thohoyandou was collected every day. The Thulamela Municipality was responsible for the collection of solid waste in Thohoyandou CBD and its environs. According to Awasthi *et al.,* (2016) the municipalities are responsible for the collection of waste and they have to collect the waste using their own infrastructures or through private sector contracts. Vehicles used to collect waste are compactors, tippers, dumpsters, and stationary compactors. Thulamela Landfill trucks were used for the collection of waste from the commercial (business establishments), households and institutions except the University of Venda. The landfill truck is displayed on figure 4.6. The University of Venda uses tractor for the collection of waste. The mode of the solid waste collection in the households was door to door. The people would store the waste at the side of the road. According to Awasthi *et al.,* (2016) the advantages of house-to-house are that it is convenient for the households, prevents littering, reduces community bins, and segregates collection of waste. However, the disadvantage of house-to-house is that collection is restricted to fixed collection times.

Figure 4:6: Municipal vehicle used to collect waste in Thohoyandou area (Photo credit: Lumadi Muvhusi).

4.3 The nature and the type of solid waste that is accepted at the solid waste facilities

The researcher found that there were three solid waste facilities in Thohoyandou and its environs. From the three facilities one was a landfill called the Thohoyandou Landfill. The other two solid waste facilities were recycling facilities. One of the recycling facilities is called LTT Algemene Handelaars, and the other is called Nedtex Scrap Metals.

4.3.1 Thohoyandou Landfill

The Thohoyandou Landfill is situated in Muledane and has been in operation since 2004. The landfill has a perimeter of 1.7km and the area of the landfill is 0.15 km^2. The researcher found that the landfill is classified as a controlled landfill. The GPS Co-ordinates: -23.002606 S; 30.467152 E. The class of the landfill is G: S: B^+.

- **Dominant type of solid waste at the landfill**

The pie chart presented on Figure 4.7 shows the dominant solid waste that entered the solid waste. From field work, the researcher found that the dominant solid waste that enters the landfill is paper and cardboard boxes which constitute 45%. The second dominant solid waste that is disposed of there was plastic that constitutes 39%. The high percentage of paper, cardboard and plastic waste might be coming from the packaged products from the commercial sector and the households. Glass constitutes only 5%, metal contributed 4%, 2% of the waste was the organic waste, and the remaining 5% was the other waste which consisted of building rubbles from construction sites, textile (fabric). The study found that majority of the other waste was building rubble which was used by the Thohoyandou landfill as cover materials to avoid nuisances. Solid waste such as dead animals, tyres and rims of all sizes and furniture were not accepted by the Thohoyandou Landfill. As a result, the waste gets illegally dumped near wetlands, open land or rivers and this creates environmental problems. The results are similar to those of Nefale (2018) who found that the dominant type of waste found at the landfill was paper and cardboard, which was followed by plastic waste.

- **The method of solid waste recovery or treatment**

From the field observation, the researcher found that recycling and biological treatment are the methods that are practised at the landfill as a form of solid waste recovery. Biological treatment was aerobic composting and produced compost /fertilizers. During an informal interview the waste inspectors were asked whether landfill gas recovery was performed, and the waste inspectors indicated that there was no landfill gas recovery available, but expressed hope that it would be available in the future.

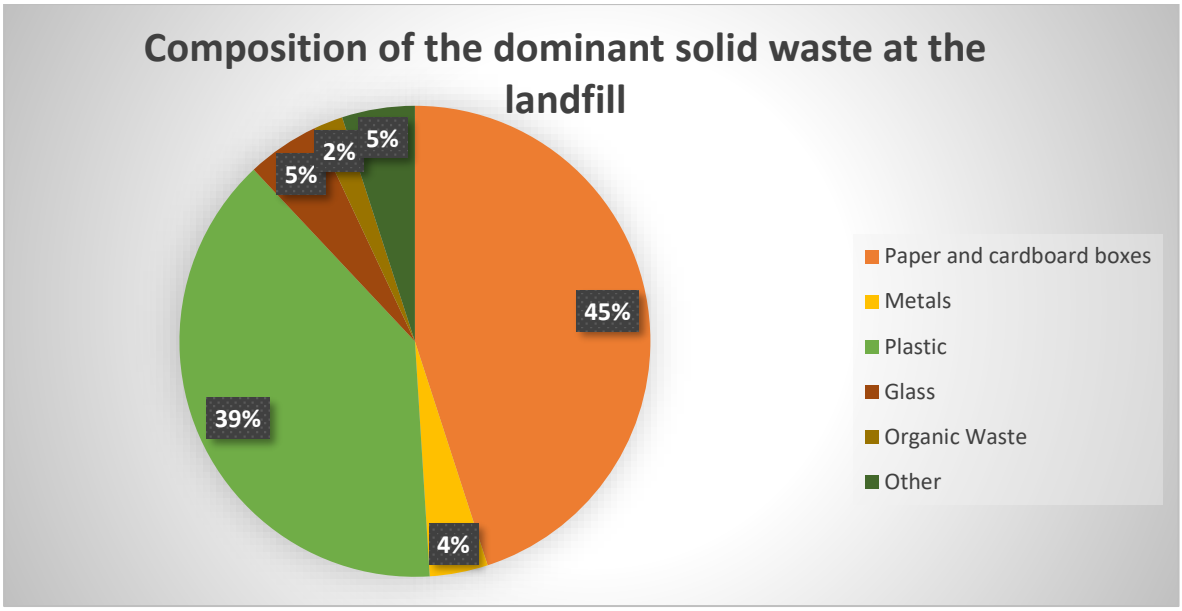


Figure 4:7: Composition of the dominant solid waste at the landfill

- **The origin of the solid waste that is accepted**

Figure 4.8 shows the origin of the solid waste that was accepted at the Thohoyandou landfill. From the field work, the researcher found that half (50%) of the waste that goes into the landfill is from the households. 30% of the waste comes from the commercial sectors (also known as the business establishments), 13% of the waste come from institutional sectors, 5% of the waste comes from the industrial sectors. The remaining 2 % comes from the construction and the waste consists of rubbles or construction debris. The researcher found that most of the solid waste at the Thohoyandou Landfill comes from the household. Solid waste from households is the major fraction of municipal solid waste (Hering, 2012). The findings are similar to those of Nefale (2018) who found that the majority of waste that was entering the landfill was from the household, followed by the commercial (business) establishments.

Segregation (sorting) of the waste at the Thohoyandou Landfill

This study found that the waste reclaimers are the ones who sort the waste such as cardboard boxes, paper, cans and plastic. The waste that has been sorted by the reclaimers is then transported and stored in recycling facilities located in Shayandima town. The staff at the Thulamela local Municipality sort the organic waste which was used for composting.

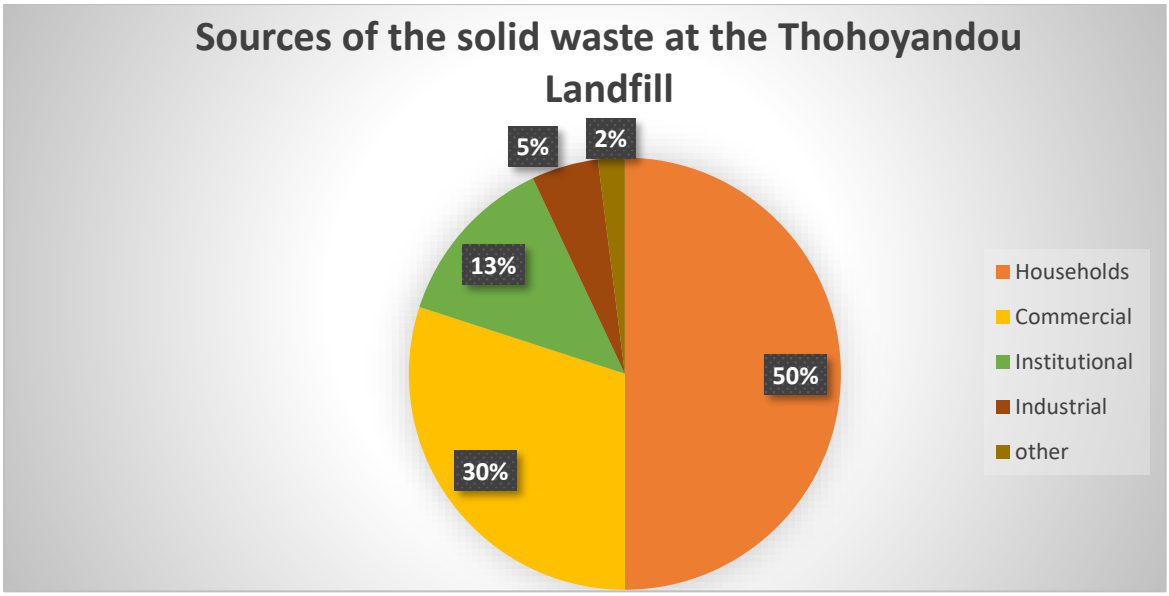


Figure 4:8: Origin of the waste that is accepted at the Thohoyandou Landfill

- **Quantity of solid waste that is accepted per month**

The waste inspector at the Thohoyandou indicated that there was no weighbridge but estimated that the quantity of waste that gets accepted each month is approximately 13-15 tons.

- **Collection of the solid waste**

The researcher found that the Thohoyandou Landfill used a fixed route when collecting the solid waste from the generators. The weekly programme for the refuse removal in Thohoyandou Town is represented on Table 4.2. The weekly programme for refuse removal indicated that waste from the household was collected once a week. The households at Thohoyandou were divided into blocks and each block was collected on a specific day at a specific time. The waste from Thohoyandou Block P-East was collected every Monday, and waste from Thohoyandou Block P- West and Golgotha was collected every Tuesday. The results are similar to those of Ogola *et al.,* (2011) which found that waste from the households was collected once a week on a specific day. Waste from the institutional and the commercial (business establishments) sector such as Thohoyandou Town Hall, Thohoyandou CBD, Provincial government offices (old parliament), Art centre, Magistrate offices, indoor sports centre, South African Police service (SAPS), Botanical Garden (Herbarium) and show ground was collected every day. The researcher found that construction and demolition were not collected at source; rather the owner of the waste is the one that needs to transport the waste to the landfill.

Table 4-1: Weekly programme for refuse removal for Thohoyandou Town

Monday	Tuesday	Wednesday	Thursday	Friday
Thohoyandou P-East	Thohoyandou Block P- West	Thohoyandou CBD	Vhembe Disaster management offices	Thohoyandou health care
Thohoyandou Block G	Thohoyandou Block C (Golgotha)		Thohoyandou CBD	
Thohoyandou CBD			Thohoyandou Unit E	
			Shayandima Industrial area	

Saturday	Sunday	Daily Collection
Thohoyandou CBD	Thohoyandou Road	Magistrate offices
Thohoyandou government buildings		Town Hall
		Indoor sports centre
		Art Centre
		Old mutual offices
		Show ground
		Provincial Government offices (old parliament)
		Botanical Garden (Herbarium)
		Thohoyandou CBD
		South African Police service (SAPS)

4.3.2 LTT Algemene Handelaars

The researcher found that LTT Algemene Handelaars is a private recycling facility that is located at Shayandima industrial site. The GPS co-ordinates of the recycling facility are: -22.994377 S; 30.434946 E. The perimeter is 89.7 m and the area is 468 m^2. The recycling facility has been in operation for less than 5 months and only accepts general waste.

- **Dominant types of solid waste accepted at the solid waste facility**

The recycling facility accepted recyclables such as cans, paper, boxes, plastic and glass. The type of waste that was accepted was indicated on the main entrance which is represented on plate 4.1. The composition of the waste that gets accepted at LTT Algeme Handelaars recycling is represented on figure 4.9 The researcher found that 60% of the solid waste that

gets accepted is paper and cardboard boxes, 20% of the waste is plastic, 15% are cans, and the remaining 5% of the waste is glass.

Plate 4-1: Signage of the private recycling facility in Shayandima industrial site (Photo Credit: Lumadi Muvhusi)

Plate 4-2: Sorted and compacted cardboard boxes that were ready for collection.

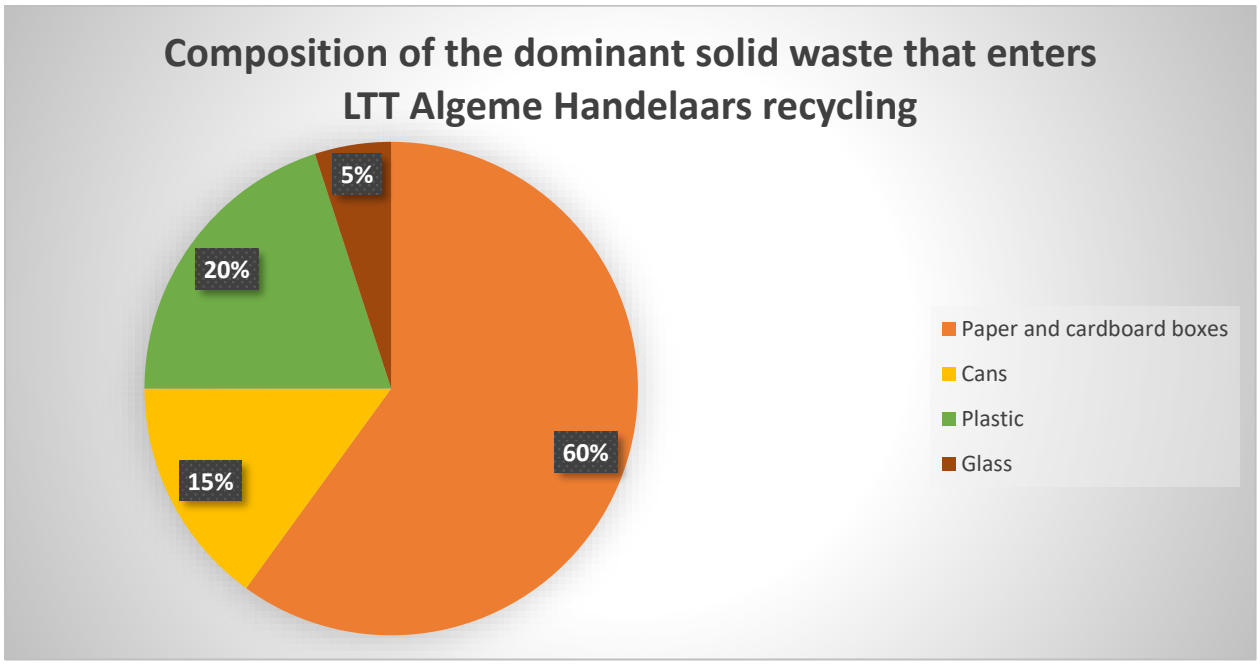


Figure 4:9: Composition of the dominant solid waste that enters LTT Algeme Handelaars recycling.

- **The method of solid waste recovery and where it takes place**

The study found that LTT Algemene Handelaars was a recycling facility that accepts ferrous and non-ferrous metals. The study found that the recycling process takes place in Louis Trichardt and not Shayandima Town.

- **Source of the solid waste**

Figure 4.10 shows the source of the waste, the researcher found that the majority of the waste (46%) of the waste that enters the recycling facility comes from the Thohoyandou Landfill. 22% from the institutions, 15% from the commercial sector, 11% from the household and 6% from the industrial sector.

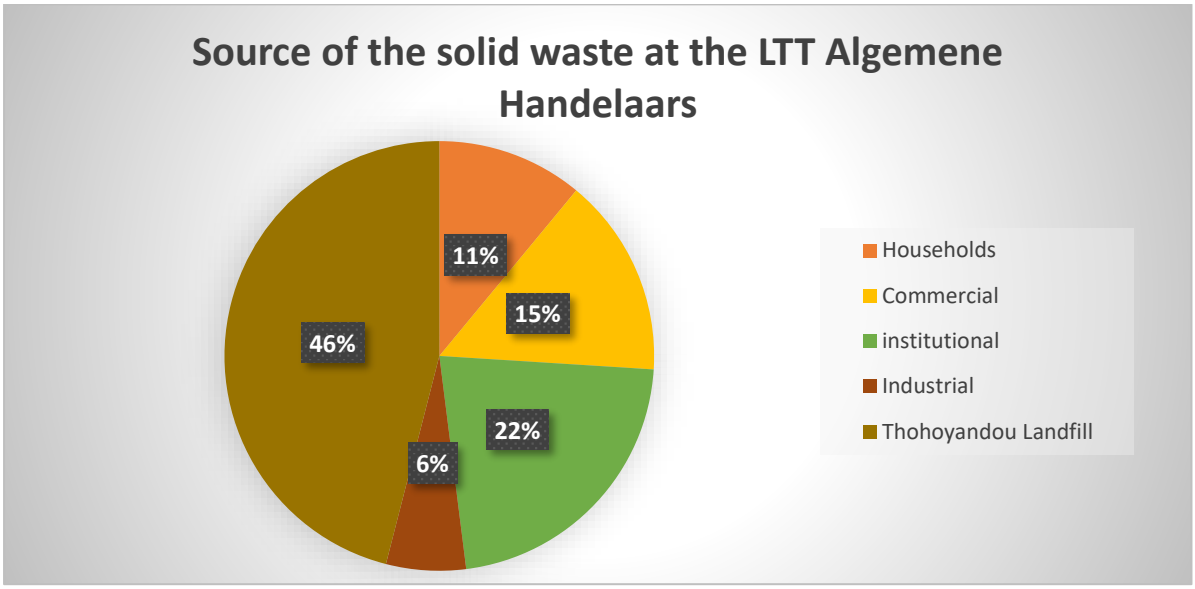


Figure 4:10: Source/origin of the solid waste that gets accepted at LTT Algemene Handelaars

- **Quantity of solid waste that enters the solid waste facilities per week**

During field work the recycling manager indicated that the amount of waste that enters the facility fluctuated but indicated that 5 tons of waste gets accepted per week. The recycling manager also indicated that the quantity of solid waste differs from time to time.

- **Collection of the solid waste**

The recycling manager at the recycling facility indicated that there was no fixed route for the collection of recyclables and that there was no weekly schedule for the collection of waste.

4.3.3 Nedtex Scrap metals

Nedtex Scrap metals is a private recycling facility in Shayandima. The geographic co-ordinates are -22.994377 S; and 30.434946 E. The perimeter is 83.0m and the area is 408m^2. The recycling facility has been in operation for less than 5 months and it accepts general waste.

- **Dominant type of solid waste accepted at the facility**

The researcher found that Nedtex recycled ferrous and non-ferrous metals only. Plat 4.3 shows the notice board that displays the type of waste that is accepted.

Plate 4-3: Signage of the metal recycling facility in Shayandima industrial site.

Plate 4-4: Unsorted metal.

Plate 4-5: Trailer that was used to store the metal waste.

Plate 4-6: Scale that was used to weigh the waste that is accepted at the recycling facility.

- **Quantity of solid waste that enters the solid waste facility**

When the recycling manager was asked about the quantity of waste that is accepted weekly, the manager indicated that four tonnes of waste gets accepted every week.

- **The origin of the solid waste that is accepted**

The study found that 80% of the waste that gets accepted comes from the households. 20% of the metal waste comes from the commercial (business establishments) and institutions.

- **Transportation of the solid waste**

The study found that the recycling facility does not transport solid waste from the generators; instead, the generators would transport the waste to the recycling facility.

4.4 Chapter summary

The chapter presented and discussed the results of the nature of waste generated from the households, commercial establishments and the institutions. The study found that the major type of waste generated from the household was organic waste. Paper and cardboard were a major waste source in the commercial (business) establishments and the institutions. The study also found that there was lack of segregation of waste at source at household level. The study also found that there were three solid waste facilities in Thohoyandou CBD and its environs. One of the waste facilities was a landfill and the other two were recycling facilities. One recycling facility recycled paper, cardboard, cans, plastic and glass. The other recycling facility recycled ferrous and non-ferrous metals. The study found that the majority of the waste that enters the landfill was from the households. The dominant type of solid waste that enters the landfill was paper and cardboard. The study found that the Thohoyandou landfill has a fixed schedule for the collection of solid waste. Waste from the households was collected once a week, and that from the institutions and the commercial (business) establishments was collected every day. The next chapter discusses the locational suitability of Thohoyandou landfill.

CHAPTER 5: THOHOYANDOU LANDFILL COMPLIANCE WITH THE ENVIRONMENTAL, HEALTH AND SAFETY REGULATIONS

5.1 Introduction

The Thohoyandou landfill started as an open dump which was not surrounded by settlements. On 18 February 2004, the Thohoyandou Landfill was established as a controlled landfill. The landfill was developed to serve the Thohoyandou Town. After the landfill was permitted, there was an increase of settlements around the landfill. When the Thohoyandou landfill was open dump, there were no standards or planning. There were no site preparations, and the open dump was poorly sited due to its proximity to the river (which is explained in greater detail in chapter 6.2.5). There was no management recording of waste entering the site, no measures taken to minimise the environmental impacts of landfills. When the landfill was permitted there were standards that needed to be followed to ensure that the landfill complied with the environmental, health and safety regulations.

As a result, this chapter focused on the results and discussion of the Thohoyandou Landfill compliance with the environmental, health and safety regulations. The environmental regulations were extracted according to the landfill class from the government documents which were the Department of Water Affairs and Forestry- Minimum Requirements for Waste Disposal by Landfill. The other document was the National Environmental Management: Waste Act 59 of 2008- National Norms and Standards for Disposal of Waste to Landfill (GNR636 of 2013). The environmental regulations considered the landfill faculty, control, resources, landfill operation, and the overall compliance, which is a combination of landfill faculty, control, resources, and landfill operation. On the other hand, the health and safety regulations were extracted from the Occupational Health and Safety Act (85 of 1993). The health and safety regulations considered the building and facilities, equipment and safety information, first aid, fire safety, environmental responsibility, and the overall compliance, which is a combination of building and facilities, equipment and safety information, first aid, fire safety, and environmental responsibility.

5.2 Compliance of the landfill with the Environmental regulations

5.2.1 Facility

Figure 5.1 shows the extent to which the Thohoyandou Landfill complied with the environmental regulations in terms of facility which focused on the signposting and the road access. The study found that the landfill was 87.5% compliant in terms of signposting. This

was because the signpost at the landfill entrance did not display that the disposal of non-permissible waste is illegal and can lead to prosecution. According to DWAFF (1998) it is imperative to clearly indicate that the disposal of non-permissible waste could lead to prosecution. According to Kusi *et al*., (2017) clearly indicating that the disposal could lead to prosecution on the signpost could help avoid uncontrolled dumping. In terms of the road access the landfill complied 100%. The overall compliance in term of facility in the Thohoyandou Landfill is 90%. In terms of signposting, the results are consistent with that of Nefale (2018). Nefale did a study at the Thohoyandou landfill, Nefale (2018) found that there was signposting at the landfill entrance which displayed the permit holder, the time of operations, the class of the landfill, and the emergency numbers. The signposting that were at the entrance of the landfill are on plate 5.2 plate 5.3, and plate 5,4.

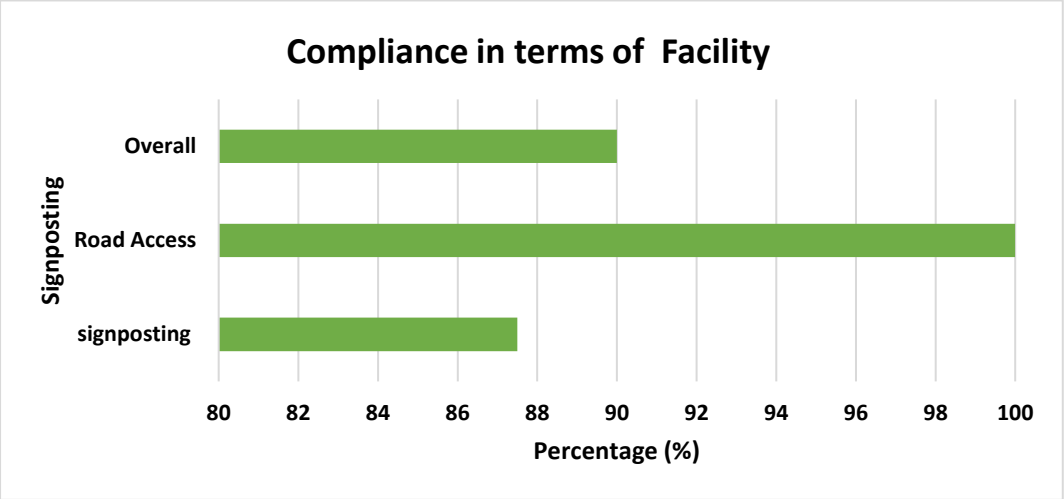


Figure 5:1: Compliance in terms of landfill facility

5.2.2 Control

Figure 5.2 shows the extent to which the Thohoyandou Landfill complied with the environmental regulations in terms of control. The control focuses on the waste acceptance procedures, fencing, control of vehicles access and the operating plan. The study found that the Landfill complied 66.67% in terms of the waste acceptance procedures. A qualified staff member would check whether the waste was general or not, prior to accepting the waste. Instead, hazardous waste was not diverted to an appropriate landfill site, so was hazardous waste that was dumped at the landfill. In terms of fencing, the landfill was 50% compliant. This was because the landfill was inadequately fenced, and the fence did not have overhang. According to DWAF (1998) landfills should be adequately fenced to avoid unauthorised entry and illegal dumping. The results are consistent with those of Nefale (2018) who studied Thohoyandou landfill and found that the landfill was inadequately fenced. As a result of the

inadequately fenced landfill, Nefale (2018) found cow dung within the landfill at the rehabilitated area and this was an indication that animals accessed the landfill and grazed inside the fence. In terms of the operating plan, the landfill complied 100%, and complied 100% in terms of the control of vehicles. The overall compliance with regards to control is 77.78%.

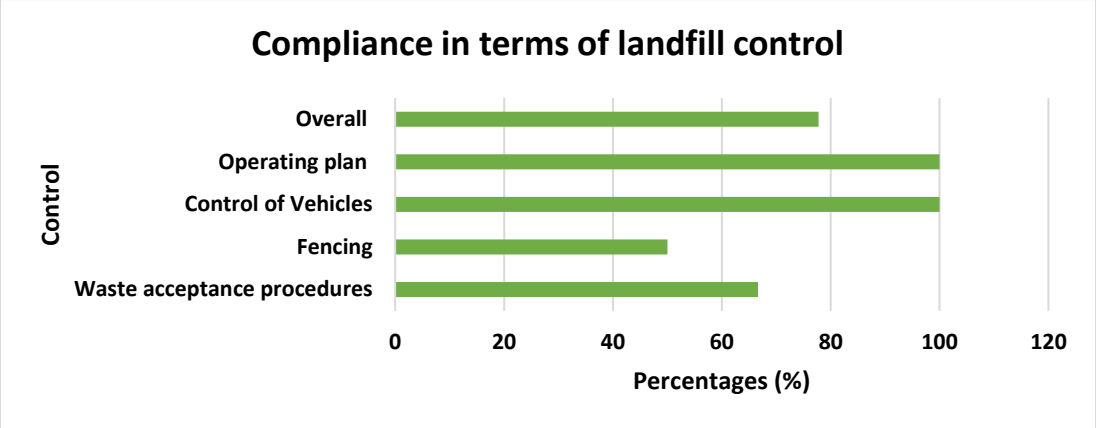


Figure 5:2 Compliance in terms of landfill control

5.2.3 Resources

Figure 5.3 shows the extent to which the landfill complies with the environmental regulation in terms of resources. Landfill resources are the services, weighbridge, adequate plant and equipment and staff. The Thohoyandou Landfill complied 80% in terms of the services. This was because there was water, sewerage, electricity and a site office, However, there was no telephone service at the site. In terms of weighbridge, the landfill complied 50%. This was because there was a weighbridge tariffs displayed at the landfill entrance. On the other hand, Collection of Waste disposal tariffs was partially compliant because there was no weighbridge to determine the amount of waste that is accepted at the landfill. The staff uses estimation to determine the amount of waste that was accepted at the Thohoyandou Landfill. The landfill complied only 30% in terms of the adequate equipment, and 91.67% for staff. The overall compliance was 66,67%. According to Dhokhikah and Trihadiningrum (2012), Al-Emad (2011), Farzadkia et al., (2009) and Gai et al., (2009) most developing countries encounter challenges regarding adequate resources. Challenges of inadequate resources are faced in the Thohoyandou and landfill.

Table 5-1: Checklist to establish the compliance of the solid waste facilities with the environmental regulations

COMPLIANCE WITH THE ENVIRONMENTAL REGULATIONS CHECKLIST

REF.	
	1 Department of Water Affairs and Forestry, Second Edition, 1998. Waste Management Series. Minimum Requirements for Waste Disposal by Landfill - Section 10 "Landfill Operation
	2 National Environmental Management: Waste Act 59 of 2008- National Norms and Standards for Disposal of Waste to Landfill (GNR636 of 2013)

C **Fully Compliant [score: 2]**

PC **Partial compliance [score: 1]**

NC **Non-compliant [score: 0]**

Site GPS

Latitude (y) **-23.002606** S

Longitude (x) **30.467152** E

Site type: **Landfill**

Site Name: **Thohoyandou Landfill**

	Requirements	Compliance C/ PC/NC	Observation/ Comments	Score
	Permit to operate the facility	**C**	The Site had a permit. The permit number is 16/2/7/A900/D16/Z1/P494 which was issued in terms of section 20(1) of the Environment Conservation Act, 1989 (Act 73 of 1980). The landfill is categorised as class G:S: B^+. The permit holder is the Thulamela Municipality. The permit was issued on the 18 February 2004.	
	A. FACILITY			
1	**Signposting**			

1.1	Signs in appropriate official languages indicating Route and distance to the landfill site from nearest main road	**C**	The waste inspector was asked whether there were signs in an appropriate language indicating the route and distance to the landfill site from the nearest road, the waste inspector indicated that there are two (2) signs. According to the Thohoyandou Landfill audit, which was done on the 5th September 2019, a third signpost is required along the newly constructed road from the Thavhani Town Mall.	2
1.2	Sign at entrance indicating in appropriate official languages	**C**	There was signage available in English, Tshivenda, and Xitsonga on one side at the entrance. English, Tshivenda, and Xitsonga are the dominant languages spoken in the area.	2
1.3	Contact details of Permit holder and Responsible person	**C**	The sign provides the name of the responsible person as well as the cell phone number of the responsible person.	2
1.4	Hours of operation	**C**	The hours of operation were stated on the main entrance. The landfill is open to public from Monday to Sunday (seven days a week) from 07h00-17h00.	2
1.5	Emergency telephone number	**C**	The emergency details are provided on the sign.	2
1.6	Class of landfill	**C**	The sign indicates the waste class. The waste class for the Thohoyandou landfill is G.S. B	2
1.7	Types of permissible and non-permissible waste	**C**	The notice board does clearly state the permissible waste and the non-permissible waste (Plate 4.3)	2
1.8	Disposal of non-permissible waste is illegal and can lead to prosecution	**N.C**	The notice board does not clearly state that Disposal of non-permissible waste is illegal and can lead to prosecution.	0
2	**Roads Access**			
2.1	Road access maintained to accommodate vehicles that normally utilise the facility	**C**	The road is not paved but the road is watered for dust control.	2
2.2	Roads to be surfaced, enabling waste disposal in all weather conditions	**C**	During the time of the observation, the road had been watered and it enabled waste disposal in all water conditions	2
2.3	Two-way traffic possible in all weather conditions	**C**	There was two- way traffic and the road were wide enough to accommodate the vehicles entering and exiting the landfill.	2
2.4	Roads watered in aid of dust control, with no mud formation	**C**	During field work the road was watered in aid of dust control and there was no formation.	2

B. CONTROLS				
1	**Waste acceptance procedures**			
1.1	Waste inspected prior to acceptance by qualified staff	**C**	A qualifies staff ensures that the waste is inspected prior to acceptance. On the other hand, there is a weighbridge that is not functional. As a result, the qualified stall estimates the amount of waste that is accepted at the landfill site. The waste operators are trained to identify the non-permissible waste load. **When the landfill waste inspector was asked why the weighbridge was not functional, he indicated that it is expensive to install a new weighbridge, but the weighbridge will be on 2020 budget.**	**2**
1.2	Hazardous waste diverted to appropriate landfill site	**N.C**	Hazardous waste is not diverted to the appropriate landfill site, instead the landfill is accepted and kept within the site. This is also recorded on the audit made in September the 5th. The hazardous waste that is kept are the fluorescent tubes and the used oil. This contradicts what the notice displayed.	**0**
1.3	Waste disposal tariffs displayed on notice board	**C**	During field observation a notice board of the waste disposal tariff was seen at the entrance of the landfill. The waste disposal tariff is displayed on plate 5.3	**2**
2	**Fencing**			
2.1	Fences - 1.8m high with an overhang	**PC**	There is a wall that is made from concrete and it is 2.8m tall but is not adequately fenced	**1**
2.2	Site boundary adequately fenced and clearly marked	**PC**	During the field observation, the site was inadequately fenced because some parts of the fence had huge gaps. When a fence is inadequately fenced, people can easily illegally dump waste and scavengers such as dogs can easily access the landfill. Cow dung was seen within the landfill premise during the time of data collection. This evident that animals enter the landfill. According to the landfill audit, the vandalised fences have created open spaces for animals to enter through. The fence is shown on Plate 5-1.	**1**

			When the waste inspector was asked why the fence there inadequate fencing at the landfill was, the waste inspector indicated that people vandalised the fence which created open spaces for animals to enter through.	
3	**Control of vehicle access**			
3.1	Single vehicle-controlled entrance	**C**	There is a single vehicle- controlled entrance	**2**
3.2	Security staff at gate	**C**	The are 3 security staff who work at the landfill.	**2**
3.3	Lockable gate, manned during operating hours	**C**	The landfill gate is always open during operation hours but after operation hours it is locked.	**2**
4	**Operating plan**			
4.1	Copy on site	**c**	There was a copy of the operating plan on site during the time of the field observation.	**2**
C. RESOURCES				
1	**Services**			
1.1	Water	**C**	There were taps with running water during field observation.	**2**
1.2	Sewerage	**C**	There is a sewerage at the landfill.	**2**
1.3	Electricity	**C**	There was electricity at the landfill during the time of the field observation.	**2**
1.4	Telephone services	**N.C**	There is no telephone service on site. The staff use their cell phone to communicate. According to the Audit that was recently compiled, the document on the comment section stated that “Current system of cell phone is entirely effective”. **When the waste inspector was asked why there was no telephone service, the waste inspector indicated that there was no money for the telephone service.**	**0**
1.5	Site office	**C**	There was a site office which was clean and tidy at the time of the field observation	**2**
2	**Weighbridge**			
2.1	Signpost: Waste disposal tariffs	**C**	Disposal Tariffs were seen at the entrance of the Thohoyandou Landfill. The landfill Tariffs is shown on plate 5.3.	**2**

2.2	Collection of Waste disposal tariffs	**P.C**	Small loads are paid in cash or by account. The Thohoyandou Landfill does not have a weighbridge instead they estimate the waste that is entering the site. Estimation of waste is not accurate.	**1**
3	**Adequate plant and equipment**			
3.1	Purpose-built landfill compactors, bulldozer and front-end loader	**P.C**	The following are available at the landfill: - The is no landfill compactor, - 1 bulldozer and front-end loader was seen during field observation. - 1 D6 Dozer Bulldozers - 1 Front end loader **When the waste inspector was asked why there was no landfill compactor, the inspector indicated that there was a compactor, but it broke down. The September 2019 audit report stated that "A replacement machine was brought to site. The machine is of less capacity to what is required'.**	**1**
3.2	Vehicle to transport cover material	**C**	There is1 truck to transport the cover material - 1 Hino Tipper Truck - 1 Bell TLB	**2**
3.3	Storage facilities for maintaining the landfill equipment	**NC**		**0**
3.4	Back-up equipment and operating staff	**N.C**	There are no back-up equipment and operating staff at the site	**0**
3.5	Equipment in good repair, not causing noise and air pollution	**N.C**	The equipment at the landfill are not in good repair because they break down often. The Audit report stated that "machines are continuously on breakdown, though service provider resorts to alternatives of hiring as contingency".	**0**
4	**Staff**			
4.1	Responsible/ managerial person on duty	**C**	During the field observation there was a responsible/ managerial person on duty.	**2**

4.2	Support staff	**C**	The staff at the landfill are the following: - 1 waste manager - 3 waste management officials - 1 Bulldozer operator - 1 TLB Operator - 3 General labour/ Litter picker - 1 Tipper Truck Driver - 1 Waste recorder - 3 Security Guards - 2 landfill operators - 1 Landfill site supervisor	**2**
4.3	Suitably qualified	**C**		**2**
4.4	Back-up staff	**PC**	- There are back up waste management officials, general labourers/ litter pickers, security guards, and landfill operators. On the other hand, there are no back up staff such as waste manager, bulldozer, TLB, Landfill operator, supervisor, waste recorder, and the Tipper Truck Driver **When the landfill manager was asked why there were no back-up staff, he indicated that there was no money that could be used to pay the back staff.**	**1**
4.5	Occupational Health and Safety measures in place	**C**	There was an Occupation Health and safety policy document at site	**2**
4.6	Protective clothing (PPE)	**P.C**	Not all the waste staff at the landfill were seen wearing protective clothing (PEE) such as safety gloves, safety boots, safety overalls, and dust marks. The waste reclaimers are the ones who don't all wear protective clothing at the site.	**1**
D. LANDFILL OPERATION				
1	**Compaction of the waste**			

1.1	Purpose built compactor in use- Compaction is best achieved if the waste is spread in thin layers and compacted by a purpose-built landfill compactor.	**N.C**	There is no landfill Purpose built compactor at the landfill	**0**
1.2	Waste should be fully covered at the end of each working day (A minimum thickness equivalent to the effective covering of 150mm of compacted soil is required).	**N.C**	The waste was not fully covered during the time of the field observation. **When the landfill inspector was asked why the waste was not fully covered, the waste inspector said that there were no cover materials. This is the reason the waste is not fully covered. The September 2019 audit reported stated that "inadequate covering been done in an effort to spare cover materials."**	**0**
1.3	Two-week cell capacity	**C**		**2**
1.4	Three days cover stockpile available, close to working face	**C**		**2**
1.5	Protection of unsafe excavations	**C**	There is protection of unsafe excavation	**2**
2	**Wet weather cell**			
2.1	Location close to entrance and all-weather roads	**C**		**2**
2.2	One-week capacity	**C**		**2**
3	**Leachates**			
3.1	Sporadic leachate reporting	**C**		**2**
3.2	Cells appropriately lined	**N.C**	There is no lining on the current cell therefore water can infiltrate into the ground.	**0**
3.3	Leachate management system to collect and drain leachate to a point where it can be extracted for treatment.	**N.C**	There is no lining on the current cell therefore water can infiltrate into the ground.	**0**
4	**Excavation for cover**			
4.1	Excavation floor sufficiently separated from the wet season high elevation of ground water	**C**		**2**
5	**Drainage**			**0**
5.1	Run-off and storm water diverted around waste body	**N.C**		**0**
5.2	Contaminated water and leachate contained on site	**N.C**		**0**

5.3	Contaminated water and leachate contained stored in retention sump or dam	**N.C**		**0**
5.4	0.5-meter freeboard for contaminated water impoundments and drainage trenches.	**N.C**		**0**
5.5	Final covered areas promote run-off with minimum erosion and/ or ponding of water.	**N.C**		**0**
5.6	Uncontaminated water to flow into natural drainage system	**N.C**		**0**
6	**Waste reclamation**			
6.1	Waste reclamation available (licence condition)	**C**		**2**
6.2	Any reclamation operation formalised in Operating plan	**C**		**2**
7	**Control of nuisances**			
7.1	Waste burning prohibited	**C**	Burning at the Landfill is prohibited on site.	**2**
7.2	Litter fences present and cleaned daily	**C**	The litter fences are cleaned every day.	**2**
7.3	Malodorous waste covered immediately	**C**	Malodorous waste is covered immediately to avoid smell	**2**
7.4	Equipment to comply with local authority by-laws on noise levels.	**C**	The equipment complies with the local authority by laws on noise levels	**2**
7.5	Vermin management measures in place	**C**		**2**
7.6	Dust kept to a minimum (watering)	**C**	During the time of the field work there was evidence that the surface was watered to control the dust.	**2**
			Total	**86/124**

.

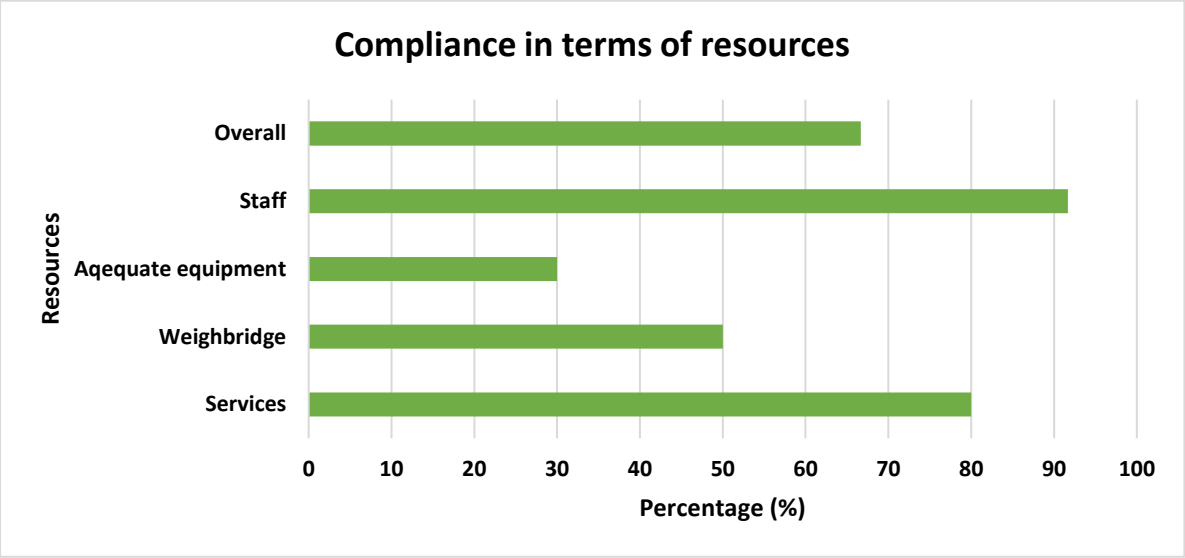


Figure 5:3: Compliance in terms of resources

5.2.4 Landfill operation

Figure 5.4 shows compliance in terms of landfill operation. Landfill operation includes compaction, wet weather cell, leachates, excavation for cover, drainage, waste reclamation and the control of nuisances. From the field observation, the researcher found that the Thohoyandou Landfill complied 60% in terms of compaction. According to DWAF (1998) Waste should be fully covered at the end of each working day (A minimum thickness equivalent to the effective covering of 150mm of compacted soil is required. The Thohoyandou Landfill complied 60% in terms of compaction because the waste was inadequately covered daily due to insufficient cover materials. It is important that the waste is adequately covered daily to avoid or reduce health impacts and to avoid fires. The study found that the landfill complied 100% for the wet weather cell, 33.33% for leachates, 100% evacuation for cover, 0% drainage, 100% for waste reclamation, and 100% for control of nuisances. The overall compliance in terms of landfill operation is 60%.

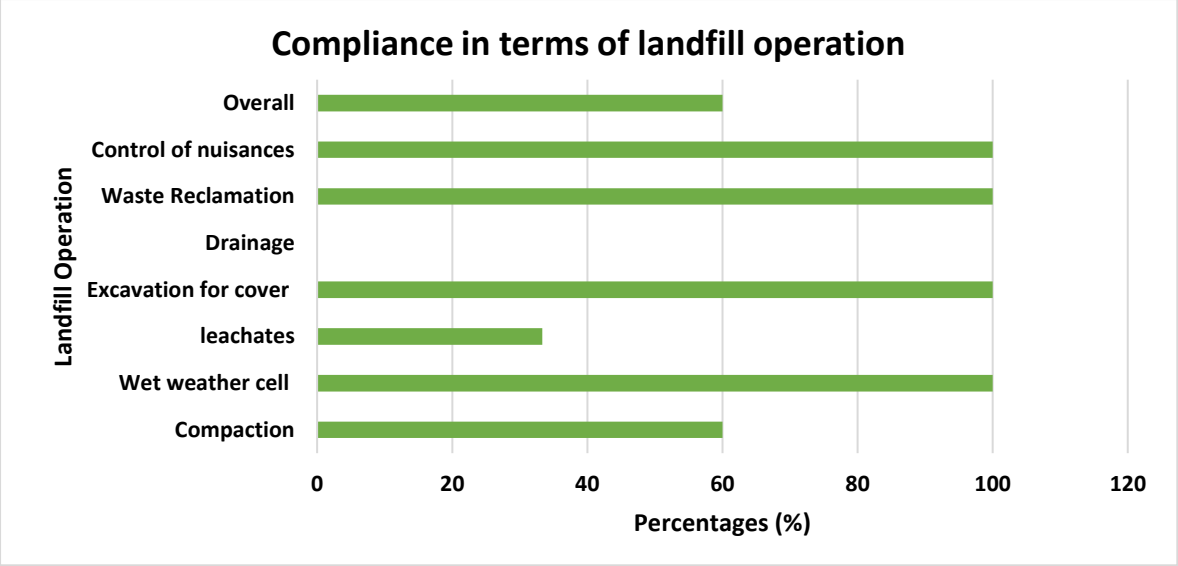


Figure 5:4: Compliance in terms of landfill operation

5.2.5 Overall compliance with the environmental regulations

Table 5.2 shows the overall compliance of the Thohoyandou Landfill with the environmental regulations. The study found that the overall compliance in terms of landfill operation is 60% which means that the landfill is partially compliant, and the colour coding given for partial compliant is orange.

Table 5-2: overall compliance of the landfill with the environmental regulations

LANDFILL COMPLIANCE		
% Compliance	**Level of compliance**	**Colour coding**
50-79%	Partial Compliant	

5.3 Compliance with the health and safety regulations

Health and safety regulations are very crucial in the workplace because they help prevent injuries or accidents. Workers need to be well-informed about the injuries they might encounter and should also be trained to avoid such injuries. Workers need to be trained on how to use equipment and do first aid if injured at work. Figure 5.5 shows the extent to which the landfill complies with the health and safety regulations. From field work, the researcher found that the landfill complied 100% in terms of building structure and infrastructure, environmental responsibility, fire safety and first aid. In terms of equipment and information the landfill complied 90,91%. This was because not all equipment was regularly inspected and maintained to ensure worker safety.

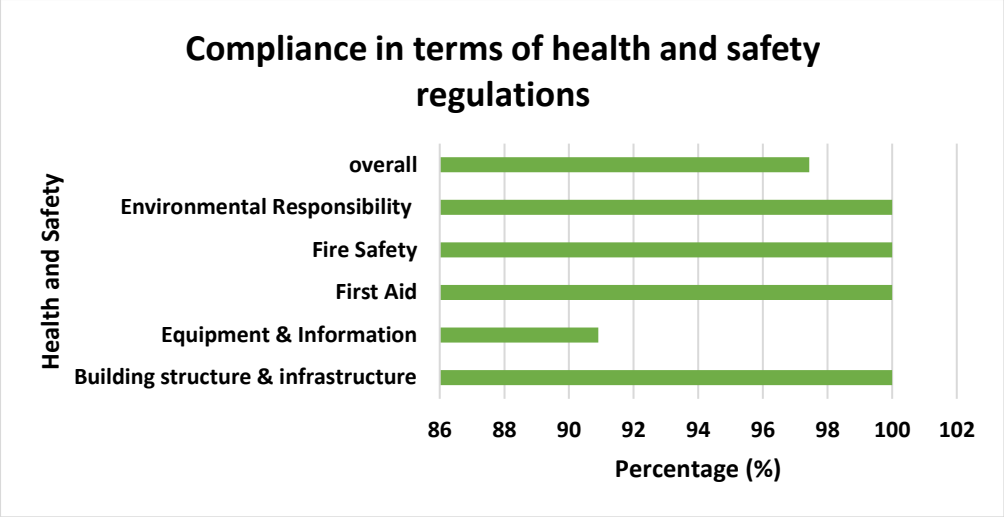


Figure 5:5: Extent to which the landfill complies with the health and safety regulations.

5.3.1 Overall compliance with health and safety regulations

Table 5.3 shows the overall compliance in terms of health and safety. The study found that the overall compliance of the Thohoyandou Landfill with health and safety regulations was 97,44% which is compliant and was represented by a green colour code.

Table 5-3: Overall compliance with the health and safety regulations.

LANDFILL COMPLIANCE		
% Compliance	**Level of compliance**	**Colour coding**
80%-100%	Compliant	

Plate 5-2: Site notice board at the main entrance detailing the responsible person, permit holder, hours of operation, emergency numbers and class of the landfill site

Plate 5-3: Site notice board at the main entrance showing the solid waste tariffs.

Plate 5-4: Notice board that was situated at the entrance of the landfill.

Plate 5-5: Vehicle to transport cover material

Plate 5-6: First Aid Kit that is on top of the shelf and the sign of fire extinguisher on the window sill

Plate 5-7: fire extinguisher that is located at the site office

Plate 5-8: Entrance of the Thohoyandou Landfill

Plate 5-9: sign on site to control speed

Plate 5-10: Vehicles that were parked near the site office

Plate 5-11: Site office

Plate 5-12:Vandalised fences

Plate 5-13: Waste inspector recording the details of the incoming waste

Table 5.3: Checklist to establish the extent to which the landfill complied with the health and safety regulations

COMPLIANCE WITH HEALTH AND SAFETY REGULATIONS CHECKLIST

REF. Occupational Health and Safety Act (85 of 1993)

C **Fully Compliant [score: 2]**

PC **Partial compliance [score: 1]**

NC **Non-compliant [score: 0]**

Site GPS

Latitude (y)…… S

Longitude (x) …… E

Site type: Landfill

Site Name: Thohoyandou Landfill

	Requirements	Compliance C/NC/ PC	Observation/ comments	Score
1. BUILDING STRUCTURE AND FACILITIES				
1.1	Building: any visible safety hazards/risks?	**C**	There were no visible safety hazards/ risks at the landfill site office during the time of the fieldwork.	**2**
1.2	Floor at the landfill site office and toilets: clean and free of obstructions, damage, holes, etc, to cause slipping/tripping?	**C**	During field observation, the site office floor was mopped	**2**
1.3	Facilities and hygiene: site offices and toilets etc clean and hygienic? Lighting sufficient and maintained?	**C**	The landfill site office and the toilets were clean and hygienic. The lighting was sufficient and was well maintained.	**2**
2. EQUIPMENT AND SAFETY INFORMATION				
2.1	**Machinery and equipment**: a. All equipment kept on record. B. Stored safely? C. Regularly inspected and maintained to ensure safe working order? D. Any defective items removed from facility?	**P.C**	All equipment was kept on record and safely stored, but not regularly inspected and maintained to ensure safe working order. All defective items were removed from the facility.	**1**

2.2	**Safe working procedures**: *printed* instructions on correct and safe use are present and visible? Do staff receive safety training?	**C**	There were printed instructions on correct and safe use were present and visible and the staff received safety training.	**2**
2.3	**Safety signs and notices**: all cautionary, danger, and warning signage present and visible?	**C**	All Cautionary, danger, and warning signage were present and visible.	**2**
2.4	**Access control**: a. Occupancy load certificate (with max. Number allowed in facility at any time) visible? B. Access control procedures enforced? Inspection of incoming load loads	**C**	Access control procedures were enforced. There was inspection of incoming load which is displayed on figure: 5.13.	**2**
2.5	**PPE**: A. All personnel trained in how to protect themselves from hazards identified in the solid waste treatment facility. B. Personal protective clothing and equipment used as required?	**P.C**	Not all the waste staff at the landfill were seen wearing protective clothing (PEE) such as safety gloves, safety boots, safety overalls, and dust marks. The waste reclaimers are the ones who don't all wear protective clothing at the site.	**1**
2.6	**Supervision**: a. Properly trained personnel present to supervise safe use of equipment at all times during opening hours?	**C**		**2**
2.7	**Universal precautions**: safe procedures in place to clean contaminated surfaces and dispose of items containing bodily fluids?	**C**		**2**
2.8	**Safety discussed**: safety, health and environmental concerns discussed in regular staff meetings?	**C**		**2**
2.9	**Reporting procedures**: A. Staff know how to report any unsafe/unhealthy conditions or accidents? B. Any incidents reported this term, and if so, were concerns attended to?	**C**		**2**
2.11	**Emergency contacts**: The information is present and visible.	**C**	The Emergency contacts are present and visible.	**2**
3. FIRST AID				
3.1	First aid box: The first aid box Present, the staff is told where it is, and the contents are up to date.	**C**	The First aid box is present, staff is told where it is, and the contents are up to date. The first aid box is presented on plate 5.6.	**2**

3.2	First aiders: There are visible contact details of health care centre, and readily available?	**C**		**2**
4. FIRE SAFETY				
4.1	**Emergency evacuation plan**: a. Is a detailed plan of action for emergency evacuation in place? “emergency evacuation plan of action generic b. Is the plan well displayed? C. System in place to monitor presence and identity of all individuals who enter and exit facility?	**C**		**2**
4.2	**Prohibition of smoking on site and prohibit deliberate burning**	**C**		**2**
4.3	**Maintenance of adequate water supply**	**C**		**2**
4.4	**Fire safety guidelines and talks**: a. Fire safety info on display? B. When was a fire safety talk/demo held for all occupants?			**2**
4.5	**Maintenance of Firefighting equipment**: a. Extinguishers and/or fire hoses in place and accessible - also to people with disabilities? B. Signage present to indicates their position? C. Seals unbroken? D. Last service date?	**C**		**2**
4.6	**Fire alarm**: a. What device/method is used to warn occupants to evacuate (automatic alarm/break glass/ whistle/hand bell/other)? B. If automatic: when was last signal test arranged with cpu? C. *Visible* instructions on how to activate alarm or warn others in an emergency?	**C**		**2**
4.7	**Potential fire hazards**: have you given careful thought to things that might be a fire hazard (e.g. Faulty electrics, piles of boxes/papers, flammable oil, heater left on under desk, etc)? Take action to sort it out!	**C**		**2**
5. ENVIRONMENTAL RESPONSIBILITY				
5.1	**Environmental sustainability policy**: The staff made aware of policy, in the work area there are visible efforts to save water and electricity, reduce waste.	**C**		**2**

5.2	**Safety education and Training**: (A) The staff made aware of the location and content of the safety manual. (B) protective measures employees should take to avoid exposure or injury. (C) physical, chemical, biological, laser and radiation hazards in the work area, including the signs and symptoms of exposure and allowable exposure limits. (D) procedures for responding to emergencies such as fire, chemical spills, and severe weather) as outlined in the emergency action plan. (E) proper recordkeeping. (F) proper waste management and disposal procedures. (G) procedures for obtaining medical care in the event of exposure/ injury. (H) Methods to detect the presence of contamination or the release of chemical, biological and radioactive materials.			
			Overall	**35/37**

5.4 Chapter summary

The chapter presented and discussed the results of the landfill compliance with the environmental, health and safety regulations. With respect to the extent to which Thohoyandou Landfill complied with the environmental regulations, the study found that the Thohoyandou Landfill was compliant in terms of road access, signposting, operating plan, control of vehicles, waste acceptance procedures, staff, services, control of nuisance, waste reclamation, excavation for cover, and wet weather cell. The landfill was partially compliant in terms of fencing, weighbridge, and the compaction of waste. The landfill was not compliant in terms of adequate equipment, drainage, and leachates. The landfill was partially compliant with the overall environmental regulations. The study found that financial challenges were the main reason for the lack of compliance at the landfill. However, the landfill was compliant with the overall health and safety regulations in terms of environmental responsibility, fire safety, first aid, equipment and information, and building structure and information. The next chapter presents and discusses the results of Locational suitability of the Thohoyandou landfill.

CHAPTER 6: THOHOYANDOU LANDFILL LOCATIONAL SUITABILITY OF THE SOLID WASTE FACILITIES

6.1 Introduction

To evaluate the locational suitability, seven parameters were considered. A combination of Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) was used. For decision making purposes to evaluate the locational suitability of the landfill, a hierarchy structure was constructed. Figure 6.1 shows the decision hierarchy for evaluating the suitability of the solid waste facilities in Thohoyandou and its environs. The Decision Hierarchy is divided into three levels. The first level is the main goal or aim which is to evaluate the suitability of the solid waste facilities. This level is indicated in the grey box. To achieve the hierarchy of the main aim/ goal, several criteria were set which include the environmental, social and the economic criteria. This is represented by the blue boxes. The criteria (e.g., social factors) is further divided into several sub-criteria such as slope, the proximity to residential areas, town, roads, rivers and land use. This is represented by the green boxes.

6.2 Locational suitability of the Thohoyandou Landfill

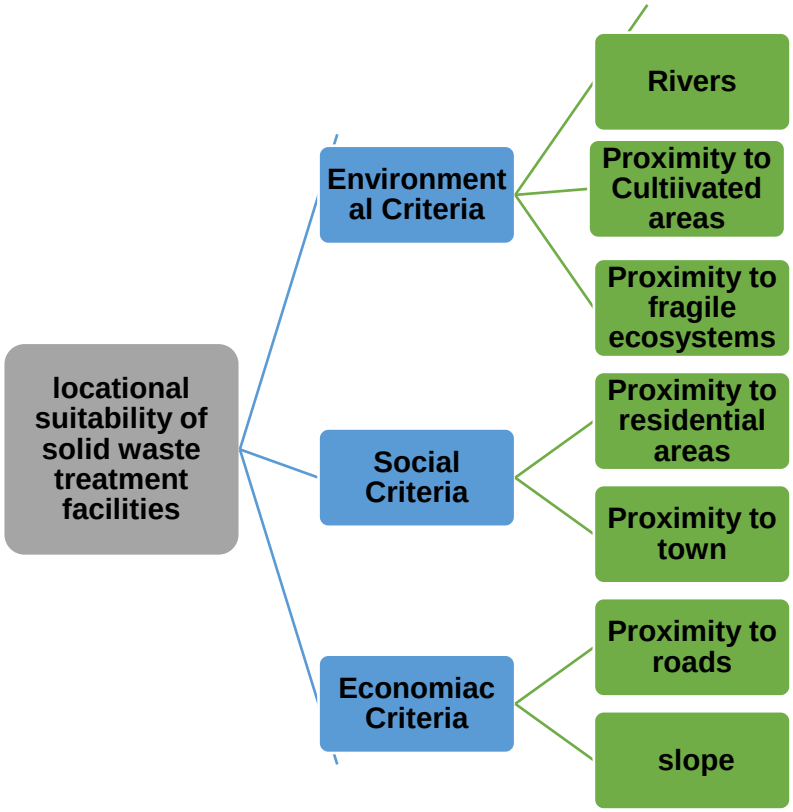


Figure 6:1: Hierarchy structure for evaluating the locational suitability of the solid waste facilities in Thohoyandou and its environs.

Table 6-1: Saaty's Pairwise comparison scale also known as the nine-point scale or the scale of relative importance

Intensity of importance	Definition
1	Equal importance or preferences
2	Equal to moderate importance or preference
3	Moderate importance or preferences
4	Moderate to strong importance or preferences
5	Strong importance or preferences
6	Strong to very strong importance or preferences
7	Very strong improtance or preferences
8	Very to extremetly strong importance or preferences
9	Extreme importance or preferences

Determination of the criteria weights

The criteria weights were determined by applying the Analytical Hierarchy process (AHP).

$$\frac{\text{Row element (R)}}{coloumn\ element\ \ (C)} \text{.....equation (1)}$$

The fractional value has been converted to the decimal value. The sum of each column is calculated by

- 1+0.33+9.00+8.00+0.33+4.00+3.00= 25.66
- 3+1+9.00+8.00+1.00+4.00+4.00= 30
- 0.11+0.11+1+1.00+0.14+0.14+0.12=2.51
- 0.12

Table 6-2: pair- wise matrix

	Slope	Residential areas	Surface water	Fragile ecosystem	Town	Road network	Land use
Slope	1	3.00	0.11	0.12	3.00	0.25	0.33
Residential areas	0.33	1	0.11	0.12	1.00	0.25	0.25
Surface water	9.00	9.00	1	1.00	7.00	7.00	8.00
Fragile ecosystem	7.00	7.00	1.00	1	5.00	7.00	7.00
Town	0.33	1.00	0.14	0.14	1	0.33	0.33
Road network	4.00	4.00	0.14	0.14	3.00	1	1.00
Land use	3.00	4.00	0.12	0.14	3.00	1.00	1
Sum	25.66	30	2.51	2.66	25	16.83	17.91

The Normalised Pair-wise comparison matrix

All the element of the column is divided by the sum of the column. This is calculated on 4.5.

Table 6-3: The normalized pair-wise comparison matrix in fractional value

	Slope	Residential areas	Surface water	Fragile ecosystem	Town	Road network	Land use
Slope	$\frac{1}{25.66}$	$\frac{3}{30}$	$\frac{0.11}{2.51}$	$\frac{0.12}{2.66}$	$\frac{3.00}{25}$	$\frac{0.25}{16.83}$	$\frac{0.33}{17.91}$
Residential areas	$\frac{0.33}{25.66}$	$\frac{1}{30}$	$\frac{0.11}{2.51}$	$\frac{0.12}{2.66}$	$\frac{1.00}{25}$	$\frac{0.25}{16.83}$	$\frac{0.25}{17.91}$
Surface water	$\frac{9.00}{25.66}$	$\frac{9.00}{30}$	$\frac{1}{2.51}$	$\frac{1.00}{2.66}$	$\frac{7.00}{25}$	$\frac{7.00}{16.83}$	$\frac{8.00}{17.91}$
Fragile ecosystem	$\frac{7.00}{25.66}$	$\frac{7.00}{30}$	$\frac{1.00}{2.51}$	$\frac{1}{2.66}$	$\frac{5.00}{25}$	$\frac{7.00}{16.83}$	$\frac{7.00}{17.91}$
Town	$\frac{0.33}{25.66}$	$\frac{1.00}{30}$	$\frac{0.14}{2.51}$	$\frac{0.14}{2.66}$	$\frac{1}{25}$	$\frac{0.33}{16.83}$	$\frac{0.33}{17.91}$
Road network	$\frac{4.00}{25.66}$	$\frac{4.00}{30}$	$\frac{0.14}{2.51}$	$\frac{0.14}{2.66}$	$\frac{3.00}{25}$	$\frac{1}{16.83}$	$\frac{1.00}{17.91}$
Land use	$\frac{3.00}{25.66}$	$\frac{4.00}{30}$	$\frac{0.12}{2.51}$	$\frac{0.14}{2.66}$	$\frac{3.00}{25}$	$\frac{1.00}{16.83}$	$\frac{1}{17.91}$

The fractional value has been converted to the decimal value. The weighted sum value is calculated by averaging all the elements in the row and dividing by the number of criteria. The weighted criteria were calculated by dividing the weighted sum value with the number of criteria.

Table 6-4: The normalized pair-wise comparison matrix in fractional value turned into decimal value

	Slope	Residential areas	Surface water	Fragile ecosystem	Town	Road network	Land use	weighted sum value	Weighted criteria
Slope	0.039	0.1	0.044	0.045	0.12	0.015	0.018	0.381	0.054
Residential areas	0.013	0.033	0.044	0.045	0.04	0.015	0.014	0.33	0.047
Surface water	0.351	0.3	0.398	0.376	0.28	0.416	0.447	2.568	0.367

Fragile ecosystem	0.273	0.233	0.398	0.376	0.2	0.416	0.391	2.287	0.3267
Town	0.0123	0.033	0.056	0.053	0.04	0.020	0.018	0.2323	0.033
Road network	0.156	0.133	0.056	0.053	0.12	0.059	0.056	0.633	0.090
Land use	0.117	0.133	0.048	0.053	0.12	0.059	0.056	0.586	0.083
Sum	0.9613	0.965	1.044	1.001	0.92	1	1		

The consistency is calculated to check whether the calculated values are correct or not. To calculate the consistency, the same pair- wise comparison matrix is not normalised. Each value of the column is multiplied with the criteria weight of.

Criteria weight	**0.054**	**0.047**	**0.387**	**0.692**	**0.033**	**0.090**	**0.083**
	Slope	**Residential areas**	**Surface water**	**Fragile ecosystem**	**Town**	**Road network**	**Land use**
Slope	0.039*0.054	0.1*0.047	0.044*0.387	0.045*0.692	0.12*0.033	0.015*0.090	0.018*0.083
Residential areas	0.013*0.054	0.033*0.047	0.044*0.387	0.045*0.692	0.04*0.033	0.015*0.090	0.0140*0.083
Surface water	0.351*0.054	0.3*0.047	0.398*0.387	0.376*0.692	0.28*0.033	0.416*0.090	0.4470*0.083
Fragile ecosystem	0.273*0.054	0.233*0.047	0.398*0.387	0.376*0.692	0.2*0.033	0.416*0.090	0.391*0.083
Town	0.0123*0.054	0.033*0.047	0.056*0.387	0.053*0.692	0.04*0.033	0.020*0.090	0.0180*0.083
Road network	0.156*0.054	0.133*0.047	0.056*0.387	0.053*0.692	0.12*0.033	0.059*0.090	0.0560*0.083
Land use	0.117*0.054	0.133*0.047	0.048*0.387	0.053*0.692	0.12*0.033	0.059*0.090	0.0560*0.083

The weighted some value is obtained by calculating each value in the row.

Criteria weight	**0.054**	**0.047**	**0.387**	**0.692**	**0.033**	**0.090**	**0.083**			
	Slope	**Residential areas**	**Surface water**	**Fragile ecosystem**	**Town**	**Road network**	**Land use**	**Weighed some value**	**Criteria weights**	$\frac{weighted\ sum\ value}{criteria\ weights}$
Slope	$2.106x10^{-3}$	$4.7\ x10^{-3}$	0.017	0.031	$3.96\ x10^{-3}$	$1.35\ x10^{-3}$	$1.494\ x10^{-3}$	0.062	0.054	=1.141
Residential areas	$7x10^{-4}$	$1.551\ x10^{-3}$	0.017	$8.102\ x10^{-3}$	$1.32\ x10^{-3}$	$1.35\ x10^{-3}$	$1.162\ x10^{-3}$	0.031	0.047	0.660
Surface water	0.019	0.0141	0.154	0.260	$9.24\ x10^{-3}$	0.034	0.037	0.527	0.0367	14.369
Fragile ecosystem	0.0147	0.011	0.154	0.260	$6.6\ x10^{-3}$	0.037	0.032	0.5153	0.692	0.745
Town	$6.642\ x10^{-4}$	$1.551\ x10^{-3}$	0.022	0.0367	$1.32\ x10^{-3}$	$1.8\ x10^{-3}$	$1.494\ x10^{-3}$	0.264	0.033	8
Road network	$8.424\ x10^{-3}$	$6.251\ x10^{-3}$	0,022	0.037	$3.96\ x10^{-3}$	$5.31\ x10^{-3}$	$4.648\ x10^{-3}$	0.088	0.090	0.178
Land use	$6.318\ x10^{-3}$	$6.21\ x10^{-3}$	0.019	0.037	$3.96\ x10^{-3}$	$0.531\ x10^{-3}$	$4.648\ x10^{-3}$	0.078	0.83	0.908

$\lambda_{max} =$ (1.141+0.660+14.369+0.745+8+0.178+0.908)/7

= 26.001/7

=3.714

Consistency index C.I.) $=\frac{\lambda_{max}-n}{n-1}$.....equation (2)

$$\frac{3.714-7}{7-1}$$

=-0.548

Consistency Ratio= consistency index/ random index

$=\frac{-0.548}{1.32}$

=-0.415

Therefore, -0.415<0.10, consistent

Table 6-5 Criteria and their appropriate ranges used in the study

Criteria	Sub criteria	Buffer/limitation	Suitability	Sun criteria weight	Rank
Economic criteria	Proximity to roads	<400m	Unsuitable	9%	3
		401m-500.	Suitable		
		501-4000m	Unsuitable		
	Slope	<12%	Unsuitable	5%	4
		12-20%	Suitable		
		20-25%	Unsuitable		
		>25	Highly unsuitable		
Social criteria	Proximity to residential area	0-700m	Unsuitable	5%	4
		Above 700m	Suitable		
	Proximity to cultivated land	500m	Unsuitable	9%	3
		Above 500m	Suitable		
	Proximity to town	0-700m	Unsuitable	3%	5
		Above 700m	Suitable		
Environmental criteria	Proximity to fragile ecosystems	0-1000m	Suitable	33%	2
		Above 1000m	Unsuitable		
	Proximity to water sources	0-600m	Unsuitable	36%	1
		Above 600m	Suitable		
			Total	100%	

6.2.1 Slope

The reclassified slope map is presented on figure 6.2. The map indicates that the Thohoyandou Landfill is situated in an area with a slope that is less than 12% which is regarded as too flat. Since the Thohoyandou Landfill is situated in a flat area, this means that there is high risk of leachate infiltration which would result in the contamination of ground water. Sharifi *et al.,* (2009) and Akbari *et al.,* (2008) indicated that landfills that are too flat are unsuitable because this would promote the infiltration of the leachates that are the by-product of landfill. The leachates are highly toxic which would result in ground water contamination.

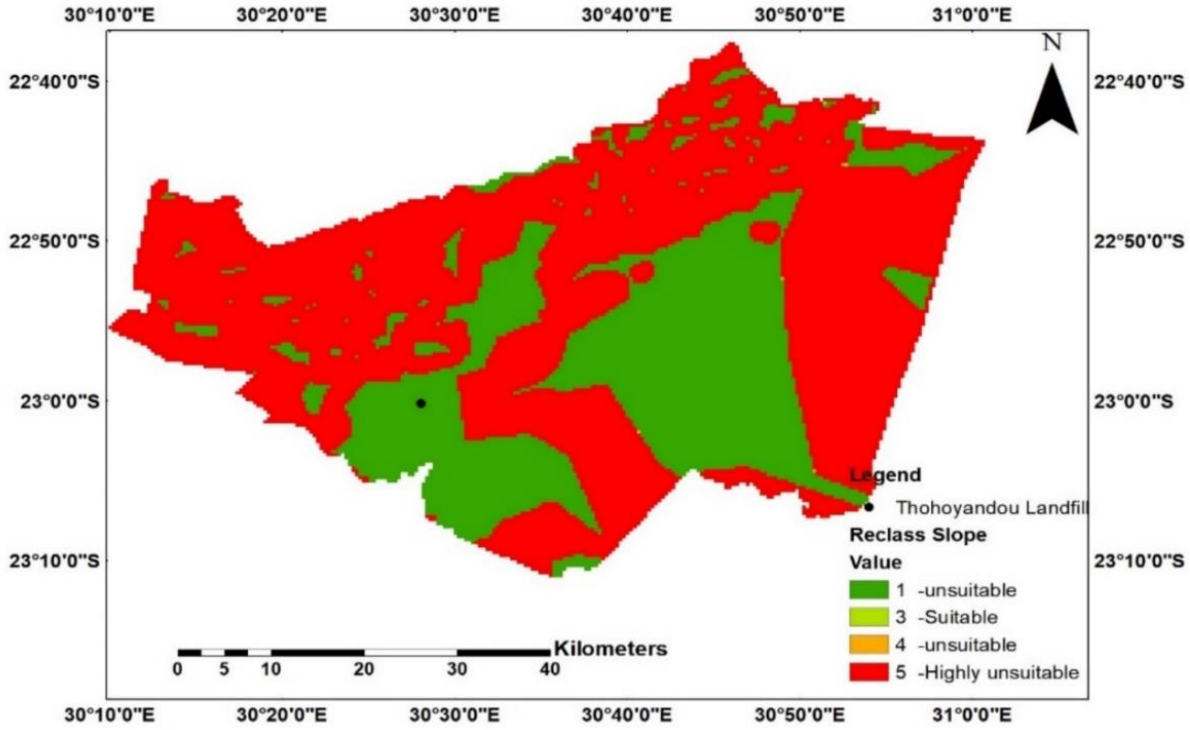


Figure 6:2: Reclassified distance to slope map

6.2.2 Cultivated land

Reclassified cultivated land map is represented on figure 4.3. Landfills should not be located near cultivated land (Abd-El Monsef and Smith 2019). The Thohoyandou landfill is located less than 100m from the cultivated land which means that the landfill is situated in an unsuitable location. According to Novara *et al.,* (2011) landfills cause soil contamination which reduces soil quality. When the soil quality is reduced this has an impact on the vegetation. As a result, this reduces plants yield.

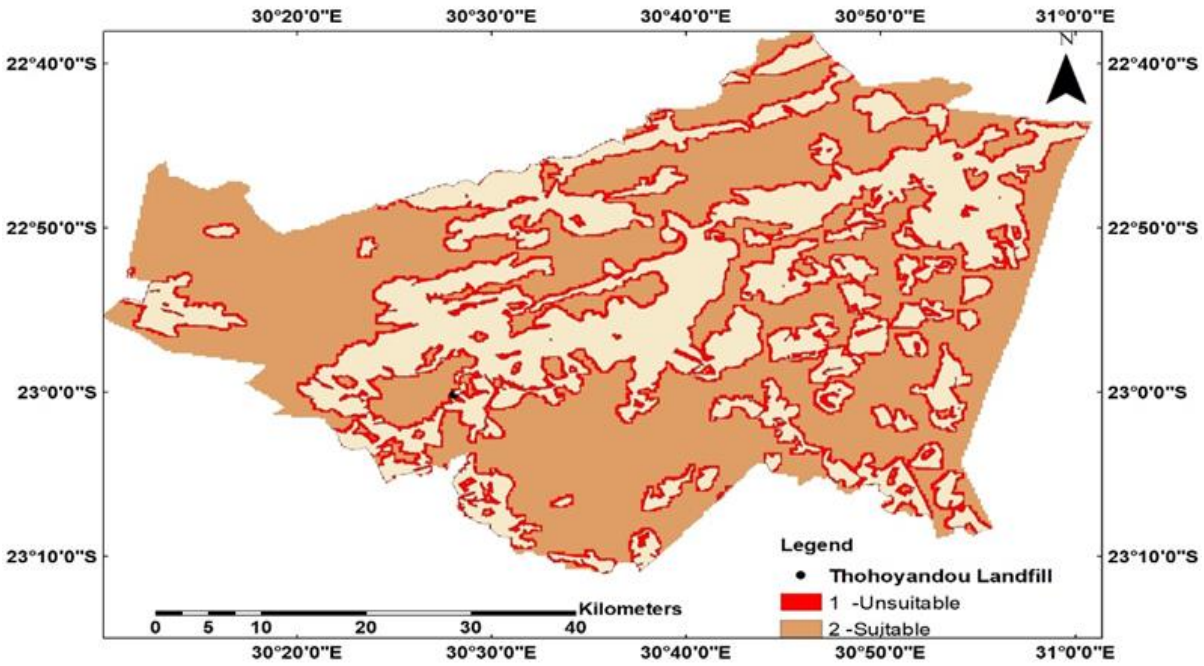


Figure 6:3: Reclassified distance to cultivated land map

6.2.3 Distance to fragile ecosystems

Fragile ecosystems are the wetlands and karst environments. In Thohoyandou and its environs there are no karst environments but there are wetlands. Wetlands are important because they are the most biologically diverse environments (Abd-El Monsef and Smith, 2019). The reclassified distance to fragile ecosystem map was constructed, and it is represented on Figure 4.4. The map shows that the Thohoyandou Landfill is located more than 1000m (1km) away from the fragile ecosystems which is suitable. This means that the possibility of soil and water contamination is very low.

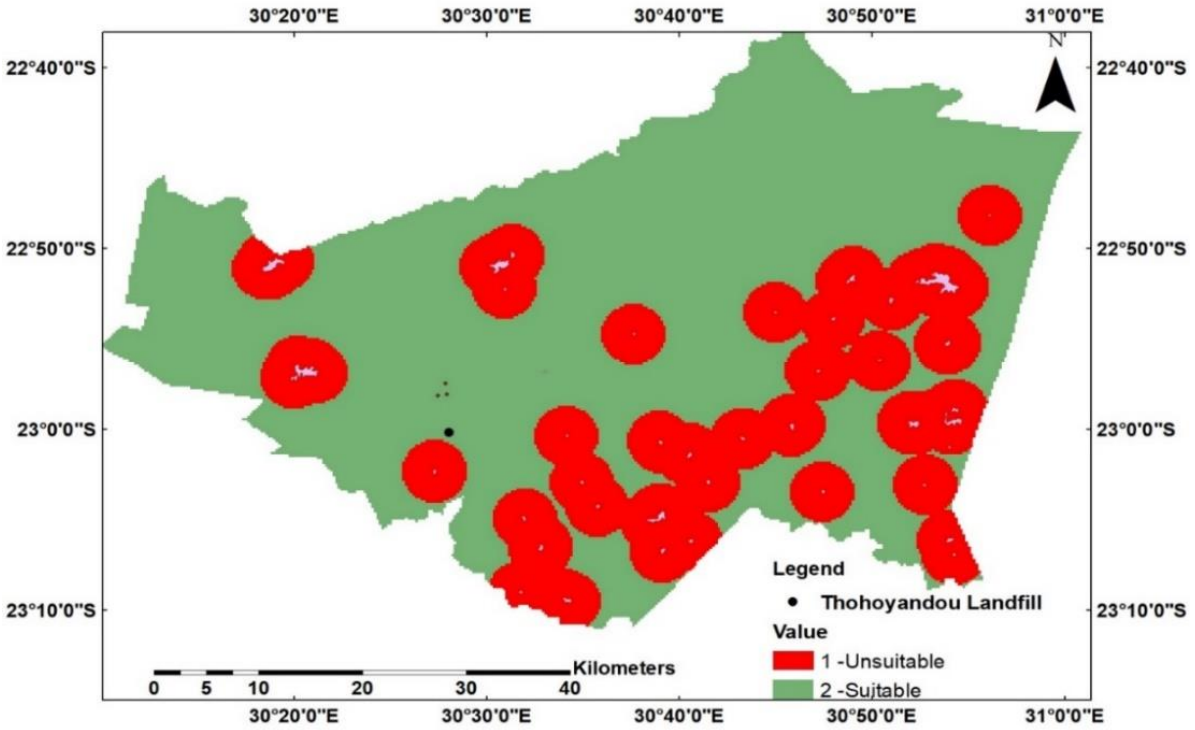


Figure 6:4: Reclassified distance to fragile ecosystem map

6.2.4 Distance to road networks

The proximity of landfills to existing road networks is a very important factor when evaluating the locational suitability (Şener *et al.,* 2010). A reclassified distance to road network map was constructed. The major roads were used in the study. The map is presented on Figure 6.6. According to the map, the Thohoyandou Landfill is located less than 300 m away from the road which is regarded as being too close to the existing road. A distance that is less than 300m is regarded as unsuitable because this would cause environmental impact such as visual impacts, traffic congestion, and nuisance (Khoshand *et al.,* 2018; and Nas *et al.,* 2010). During the field observation the traffic was observed to correspond with the findings of Khoshand *et al.,* (2018), Khoshand *et al.,* (2018) and Nas *et al.,* (2010).

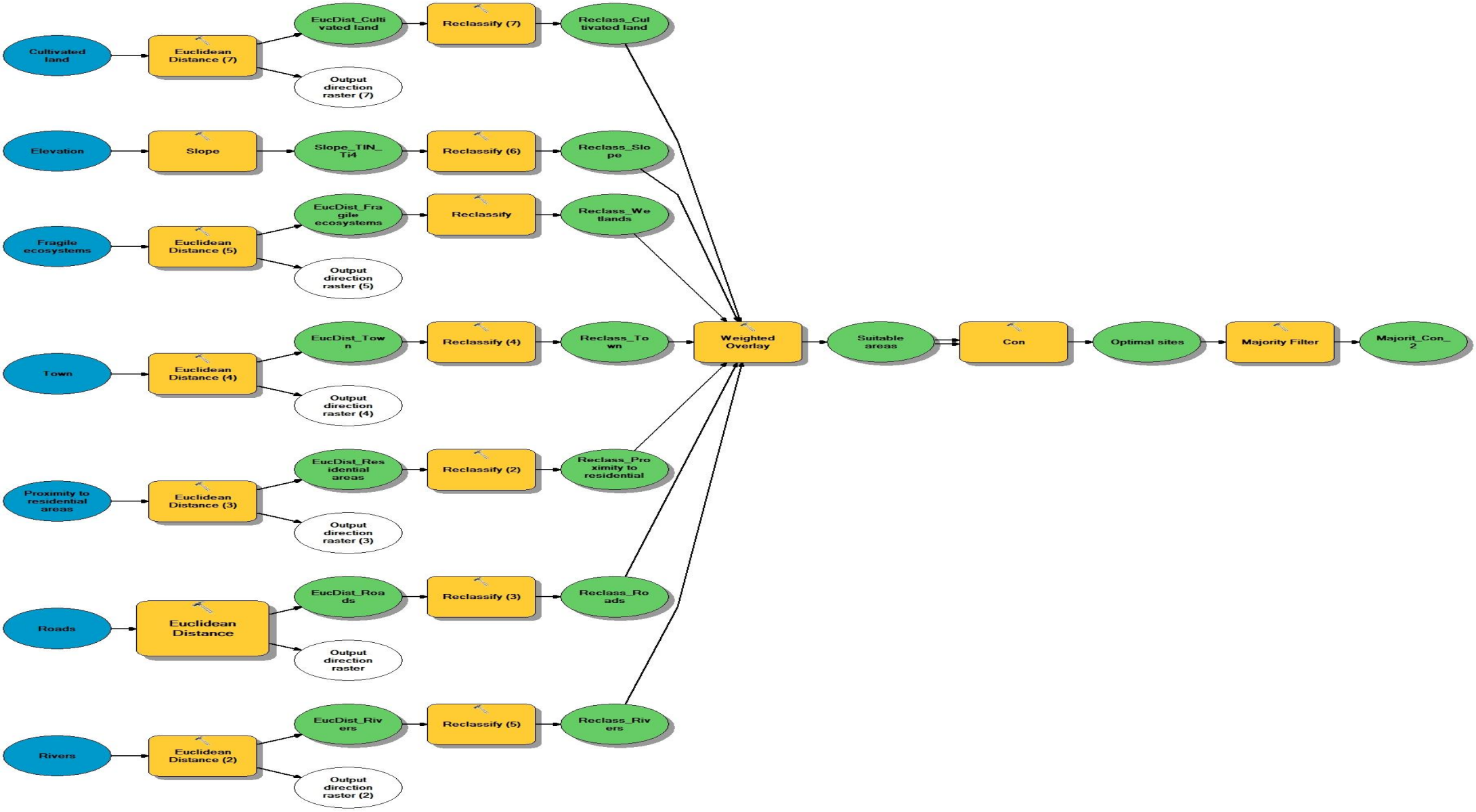


Figure 6:5: Illustration of the flow chart of the Model constructed using ArcGIS 10.5

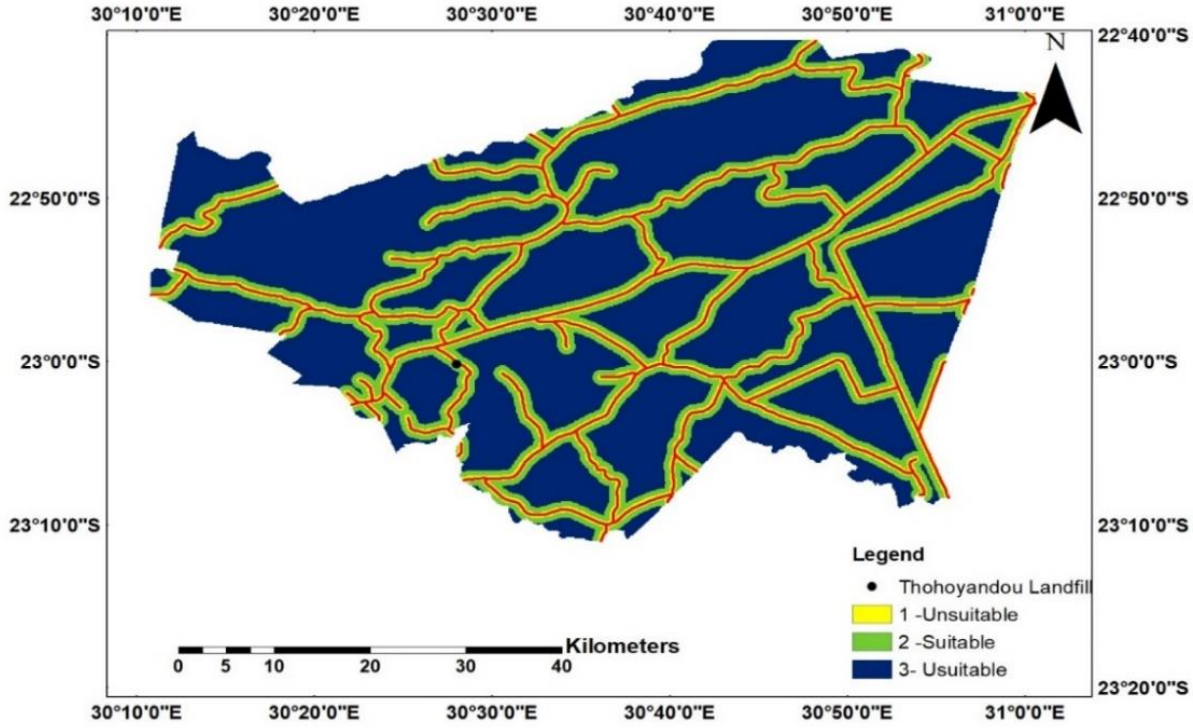


Figure 6:6: Reclassified distance to road map

6.2.5 Proximity to residential areas

Residential areas should be located at least 500m or more away from landfill (Gorsevski *et al.,* 2012. This is done to protect the general public environmental and social impacts of landfill. According to Donevska *et al.,* (2012) people who live close to landfills are affected by noise due to the landfill trucks, bird (such as seagulls), dust, odour, traffic congestion, animal (such as rodents and seagulls) and insect (such as flies and mosquitoes). The residential areas are located less than 500m from the landfill which is regarded as too close and this is unsuitable. The reclassified map of the residential area is presented on figure 6.7.

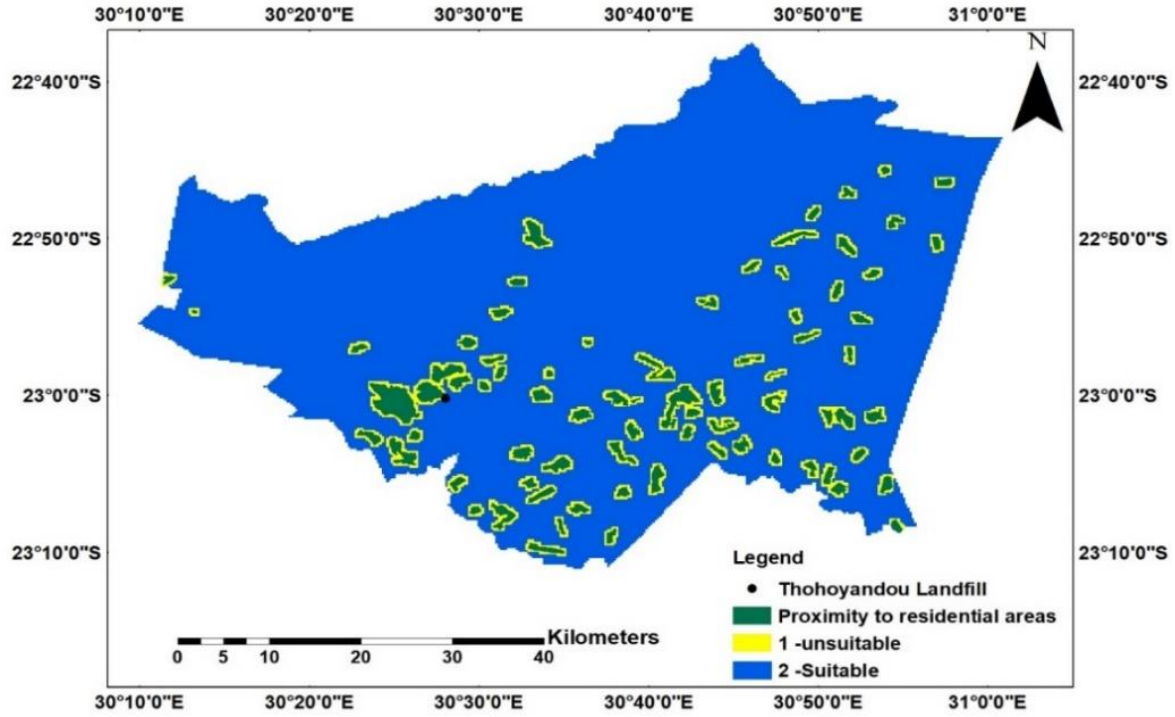


Figure 6:7: Reclassified distance to residential areas map

The map shown on figure 6.8 was attached to show how close the hotel and the residential areas are to the Thohoyandou Landfill. From the map it is evident that the Hotel and the residential areas are very close to the landfill. From the study the researcher found that the people who lived within 50m from the landfill experience socio-economic impacts. The major impact that was experienced by the residents was traffic congestion caused by the landfill trucks, noise pollution caused during landfill operations, unpleasant odour, insect and animal attraction (especially mosquitoes), air pollution in the form of dust which is caused by the covering of the landfill with soil. The residents also indicated that the area did not look attractive. Through field observation, the researcher also observed the unattractiveness of the area.

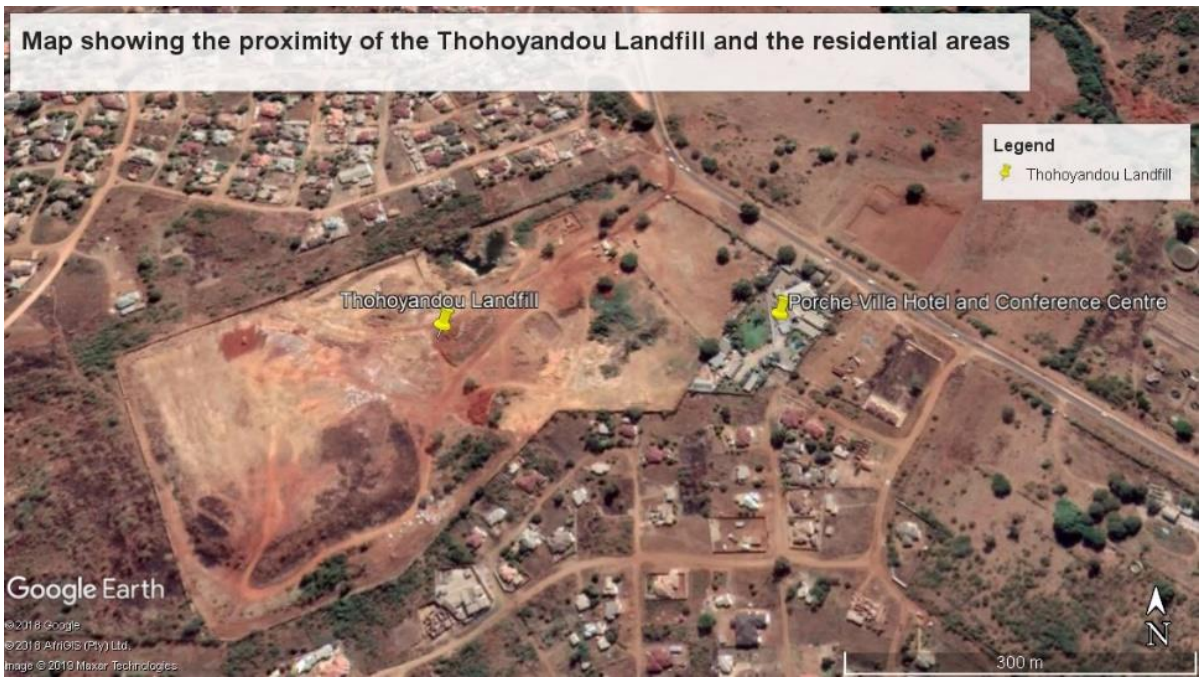


Figure 6:8 The proximity of the Thohoyandou Landfill to the residential areas (Sourced from: Google Earth, 2019)

6.2.6 Proximity to water sources

Figure 6.9 presents the reclassified distance to water sources map which is an environmental factor. The map shows that the Thohoyandou Landfill is situated less than 400m from the water source which is regarded as very unsuitable. According Kontos *et al.,* (2015) the international practice is that landfills should be at least 500m away from the water sources. Karimi *et al.,* (2018) indicated that landfills should be located at least 750m away from the water sources. This means the risk of water contamination is very high due to the leachates that leak and could have a negative effect on organisms because organisms depend on water. (Karimi *et al*., 2018).

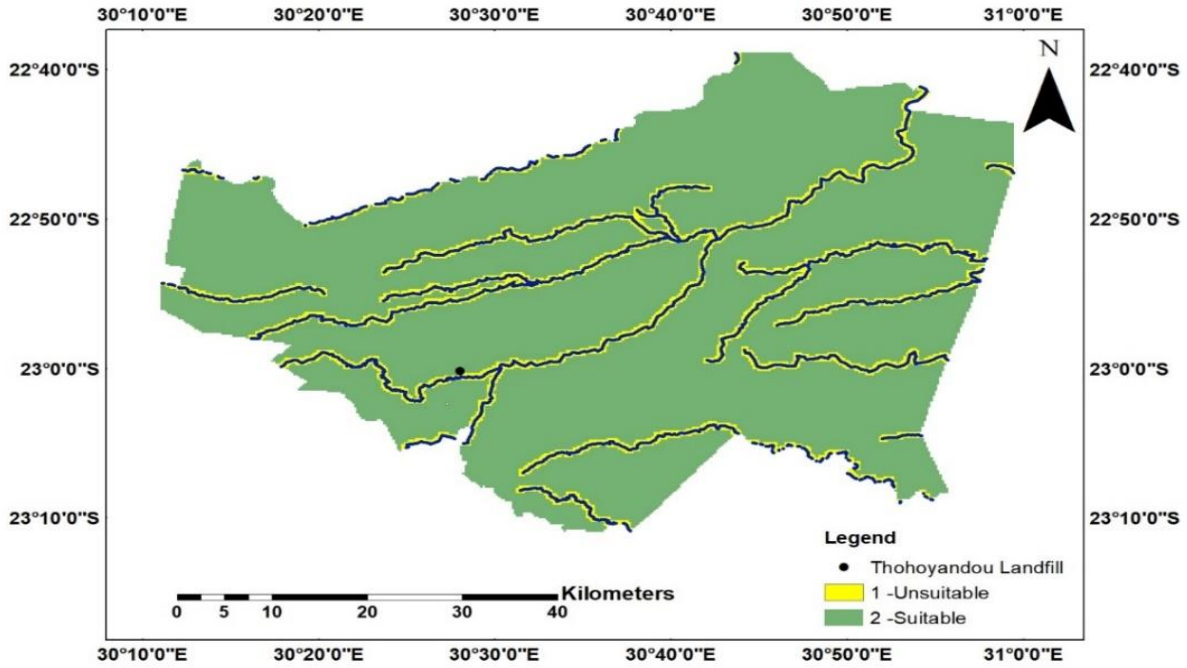


Figure 6:9: Reclassified distance to water sources map

6.2.7 Proximity to town

Landfills should be located at least 500m away from towns. Landfills that are located less than 500m from the town would contribute to health problems due to the dust and bad odour that is caused during landfill operations. The other problem that will be faced is dust. The map showing the proximity of Thohoyandou Landfill to town is represented on figure 6.10.

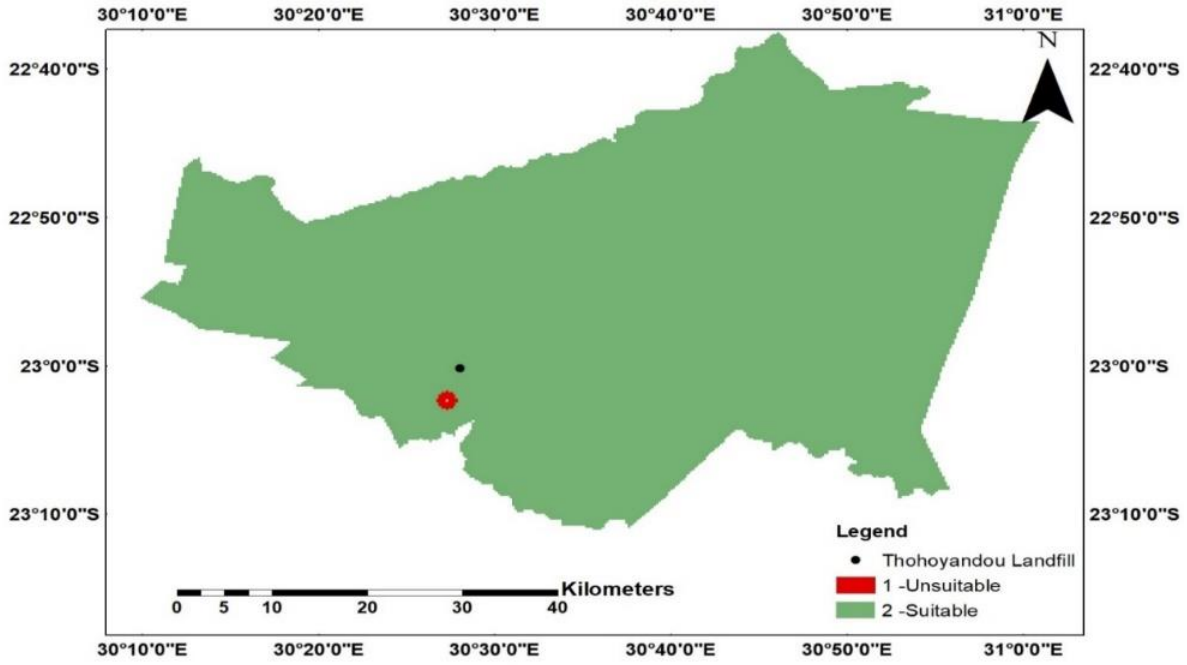


Figure 6:10: Reclassified distance to town map

6.2.8 Final Suitability (Composite) Map

The final suitability map also known as the composite map is presented in Figure 6.11. According to the final suitability map, the Thohoyandou Landfill is situated in an unsuitable location. The landfill is very likely to have negative environmental, and social impacts.

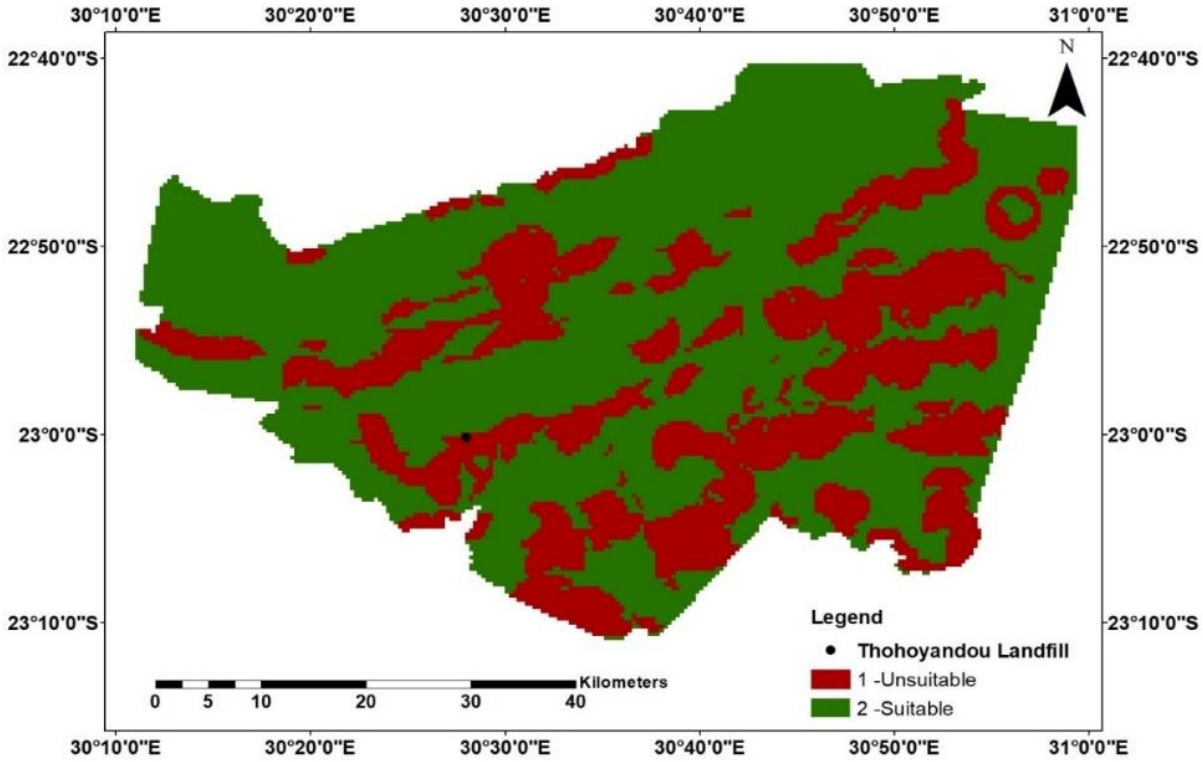


Figure 6:11 Final suitability map

Table 6-6: different criteria and suitability value

Suitability of solid waste landfill in Thohoyandou and its environs	
Criteria	**The suitability value of landfill**
Slope	Unsuitable
Proximity to roads	Unsuitable
Proximity to residential areas	Unsuitable
Proximity to cultivated areas	Unsuitable
Proximity to towns	Suitable
Proximity to fragile ecosystems	Suitable
Proximity to water sources	Unsuitable

6.3 Chapter summary

The chapter presented and discussed the results of the locational suitability of Thohoyandou Landfill. Proximity to roads, slope, proximity to residential areas, proximity to cultivated land, proximity to town, proximity to fragile ecosystems, proximity to water sources and slope were used to evaluate the locational suitability of the landfill. The study found that the landfill was not suitably located due to its proximity to roads, slope, proximity to residential areas, proximity to cultivated land, and proximity to water sources. However, the landfill was suitably located in terms of the proximity to fragile ecosystems and town. In terms of the overall locational suitability of the landfill, the study found that the landfill was located in an unsuitable location. The next chapter presents and discusses the results of the GIS database prototype that was constructed.

CHAPER 7: GIS DATABASE PROTOTYPE FOR SOLID WASTE MANAGEMENT IN THOHOYANDOU AND ITS ENVIRONS

7.1 Introduction

This chapter focuses on the physical design and the final product of the GIS data base. The entity relationship diagram (also known as the database schema diagram) was constructed using Microsoft Access. The conceptual design of the GIS database was used as a guide. The GIS database constructed to store data on the solid waste generators, which focused on the amount of waste that is generated from the households(residential areas), commercial (business establishments), and the institutions; the available solid waste management facilities such as recycling and landfill facilities, which looked at the amount of solid waste that enters landfill or recycling facilities; the locational suitability which looked at the different criteria such as proximity to water sources, residential areas, town, road, fragile ecosystems, cultivated area and slope. The GIS database also contained information on the compliance of the landfill with the environmental, health and safety regulations.

7.2 GIS database prototype

The physical design of the GIS database is shown of figure 7.1. A relational database was constructed on Microsoft Access. The data was entered in tables. Seven (7) tables were constructed for waste generated, town and its environs, solid waste facilities, locational suitability, land uses, compliance- health and safety regulations; compliance- environmental regulations. The relationship was established.

Table 7.1 shows the data type used when inputting data on compliance-health and safety regulations. The primary key was compliance-health and safety regulations ID which was given the data type- “AutoNumber”. The building structure, equipment and safety equipment, first aid, fire safety, environmental responsibility, and the overall compliance are known as the foreign key and the data type used is “short text” and a lookup wizard was used and the values the researcher made were “compliant”, “partial compliant’, and “non- compliant”.

Table 7-1:Field name and data type used when inputting data on compliance- health and safety regulations

Field Name	Data Type
Compliance- Health and safety regulations ID	AutoNumber
Building structure	Short Text
Equipment and safety information	Short Text
First Aid	Short Text
Fire safety	Short Text
Environmental Responsibility	Short Text
overall compliance	Short Text

Table 7.2: shows the data type used when inputting data on compliance- environmental regulations. The primary Key was compliance- environmental regulations ID, and the data type used is “AutoNumber”, while the rest of the field names are foreign keys and the data type used is “short text”. A lookup wizard was used and the values the researcher made were “compliant”, “partial compliant’, and “non- compliant”.

Table 7-2: Field name and data type used when inputting data on compliance- environmental regulations

Field Name	Data Type
Compliance- Environmental regulations ID	AutoNumber
Signposting	Short Text
Road access	Short Text
Waste acceptance procedures	Short Text
Fencing	Short Text
Control of vehicle access	Short Text
Operating plan	Short Text
Services	Short Text
Weighbridge	Short Text
Adequate plant and equipment	Short Text
Staff	Short Text
Compaction of waste	Short Text
Wet weather cell	Short Text
Leachates	Short Text
Excavation for cover	Short Text
Drainage	Short Text
Waste reclamation	Short Text

Table 7.3 shows the field name and data type used when inputting data on land use. The land use ID was the primary key and the data type used is “AutoNumber”. The rest of the field name were foreign keys and the data type used was short text except for the town ID which used “Number” as the data type.

Table 7-3: Field name and data type used when inputting data on land use

Field Name	Data Type
Land Use ID	AutoNumber
Land Use Type	Short Text
Land Use Classification	Short Text
Land Use Latitude	Short Text
Land Use Longitude	Short Text
Town ID	Number

Table 7.4 shows the field name and data type used when inputting data on locational suitability. The locational suitability ID used AutoNumber as the data type. The rest of the field name which is the foreign key used short-text and a lookup wizard. The values the researcher made were “suitable” and “unsuitable”.

Table 7-4: Field name and data type used when inputting data on locational suitability

Field Name	Data Type
Locational suitability ID	AutoNumber
Proximity to roads	Short Text
Proximity to rivers	Short Text
Proximity to cultivated areas	Short Text
Proximity to residential areas	Short Text
Proximity to towns	Short Text
Slope	Short Text
Proximity to fragile ecosystems	Short Text
Overall locational suitability	Short Text

Table 7.5 shows the field name and data type used when inputting data on solid waste facility Sites. The site ID had a primary key and the data type used was “AutoNumber”. The rest of the field name used “short text”, except for waste generated ID, locational suitability ID, Town

ID, compliance- environmental regulations ID, and compliance-health and safety regulations ID which used “Number” as the data type.

Table 7-5: Field name and data type used when inputting data on solid waste facility Sites

Field Name	Data Type
Site Type	Short Text
Site Name	Short Text
GPS (Latitude)	Short Text
GPS (Longitude)	Short Text
Years in operation (years)	Short Text
Waste Class	Short Text
Area (Km2)	Short Text
parameter (Km)	Short Text
Dominant waste accepted	Short Text
Fixed route for the collections of solid waste	Yes/No
Quantity of waste accepted at the landfill per week (Tons/Week)	Short Text
Compliance- Environmental regualtion ID	Number
Compliance- health and safety ID	Number
Town ID	Number

Table 7.6 shows the field name and data type used when inputting data on waste generated. The field name of waste generated ID was the primary key and the data type used was “AutoNumber”. Waste weight generated per week (kg) was represented by “short text”. While the land-use ID was represented by data type “Number”.

Table 7-6: Field name and data type used when inputting data on waste generated

Field Name	Data Type
Waste generated ID	AutoNumber
waste weight generated per week (Kg)	Short Text
Land use ID	Number

Table 7.7 shows the field name and data type used when inputting data on town. The field name Town ID was the primary key and the data type used was “AutoNumber”. The rest of the field names were foreign keys. The town name and town area were represented by “Short text” as the data type, while “Number” was used as the data type.

Table 7-7: Field name and data type used when inputting data on town

Field Name	Data Type
Town ID	AutoNumber
Town Name	Short Text
Town Latitude	Number
Town Longitude	Number
Town Area	Short Text
Land use	Number
Solid waste facilities ID	Number

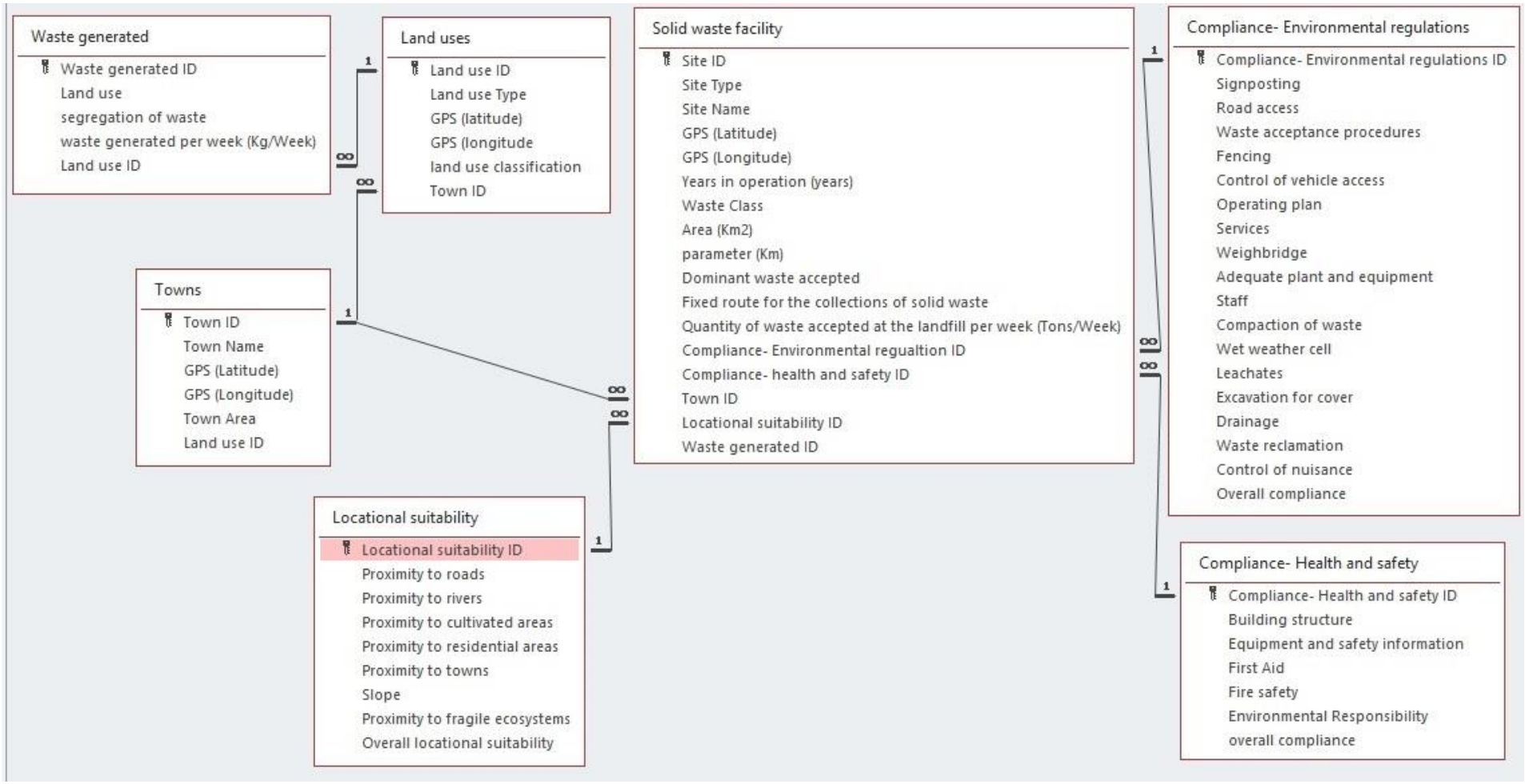


Figure 7:1: Physical Design of the entity relationship (ER) diagram that was constructed using Microsoft Access

The data was uploaded onto Caspio software where a code was copied and pasted on the Wix application which is used to create a website. To access the website, one needs to enter a password for security reasons. Figure 7.1 shows the user login details needed to access the database.

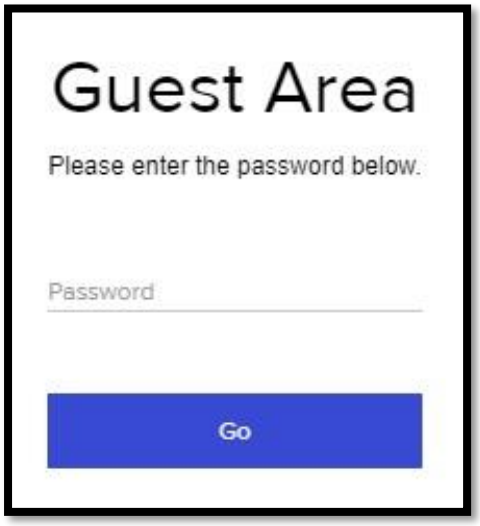


Figure 7:2: User login details required to access the database

7.2.1 Home page of the database

Figure 7.3 is the home page of the website. The home page shows the menu, which shows the “home” tab which is the home page, “solid waste generators” tab, “land uses” tab, and “town” tab and more tab which shows additional tabs which are the “Locational suitability” tab, “compliance -environmental regulations” tab, and the “Compliance with the health and safety regulations”.

7.2.2 Solid waste generators tab

The tab contains data on the solid waste generators, the amount of waste generated per kg per week. Querying of the data is possible. The data can be queried according to the generator type, which is household, institutions, and commercial. The data can further be queried according to whether segregation of solid waste is performed or not.

7.2.3 Land uses tab

Figure 7.4 is the land use tab. Land use tab contains data on the type of land use and the land use classification, the GPS co-ordinates (latitude; longitude). Querying of the data is possible as one can query data according to the land use time and the land use classification.

7.2.4 Town tab

The town tab shows data on the 3 different towns which were Shayandima, Thohoyandou, and Muledane. The GPS co-ordinates (latitude; longitude) of the town area are included in the database. Query can be performed where one can search according to the town name.

7.2.5 Locational suitability tab

Locational suitability tab shows the locational suitability of Thohoyandou Landfill. The criteria used were the proximity to the following: roads, rivers, cultivated land, fragile ecosystems, towns and slope, and the overall compliance was considered.

7.2.6 Compliance -environmental regulations tab

Figure 7.7 is the Compliance -environmental regulations tab which contains data on the extent to which the Thohoyandou Landfill complies with the environmental regulations which contain information on the signposting, road access, fencing, waste acceptance, control of vehicle access, services, operating plan, weighbridge, adequate staff, compaction of waste, wet weather cell, leachates, excavation for cover, drainage, waste reclamation, control of nuisance, and overall compliance.

7.2.7 Compliance with the health and safety regulations tab

Compliance with the health and safety regulations tab shows data on the building structure, equipment and safety information, first aid, fire safety, environmental responsibility and the overall compliance.

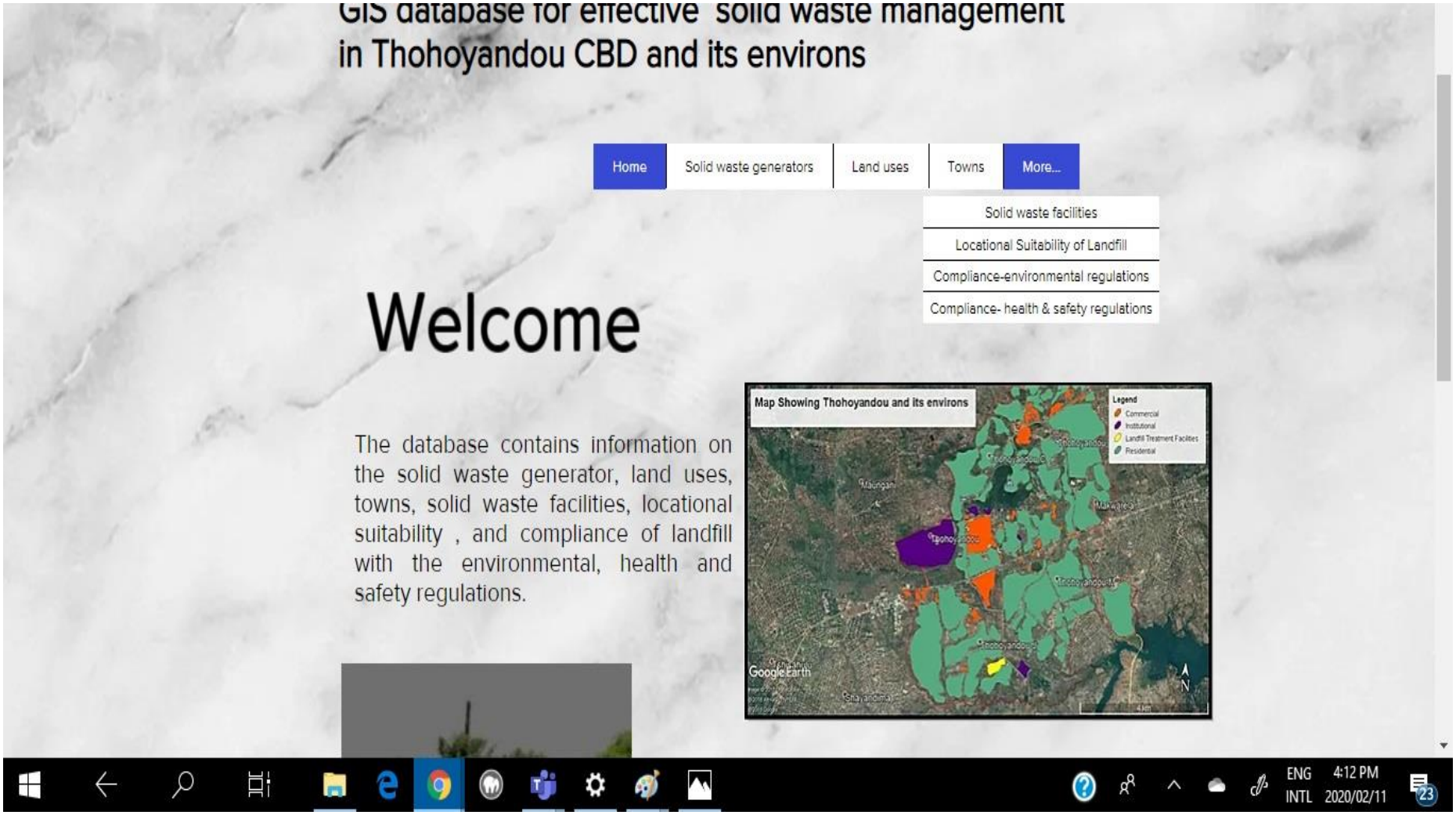


Figure 7:3: Home page of the database

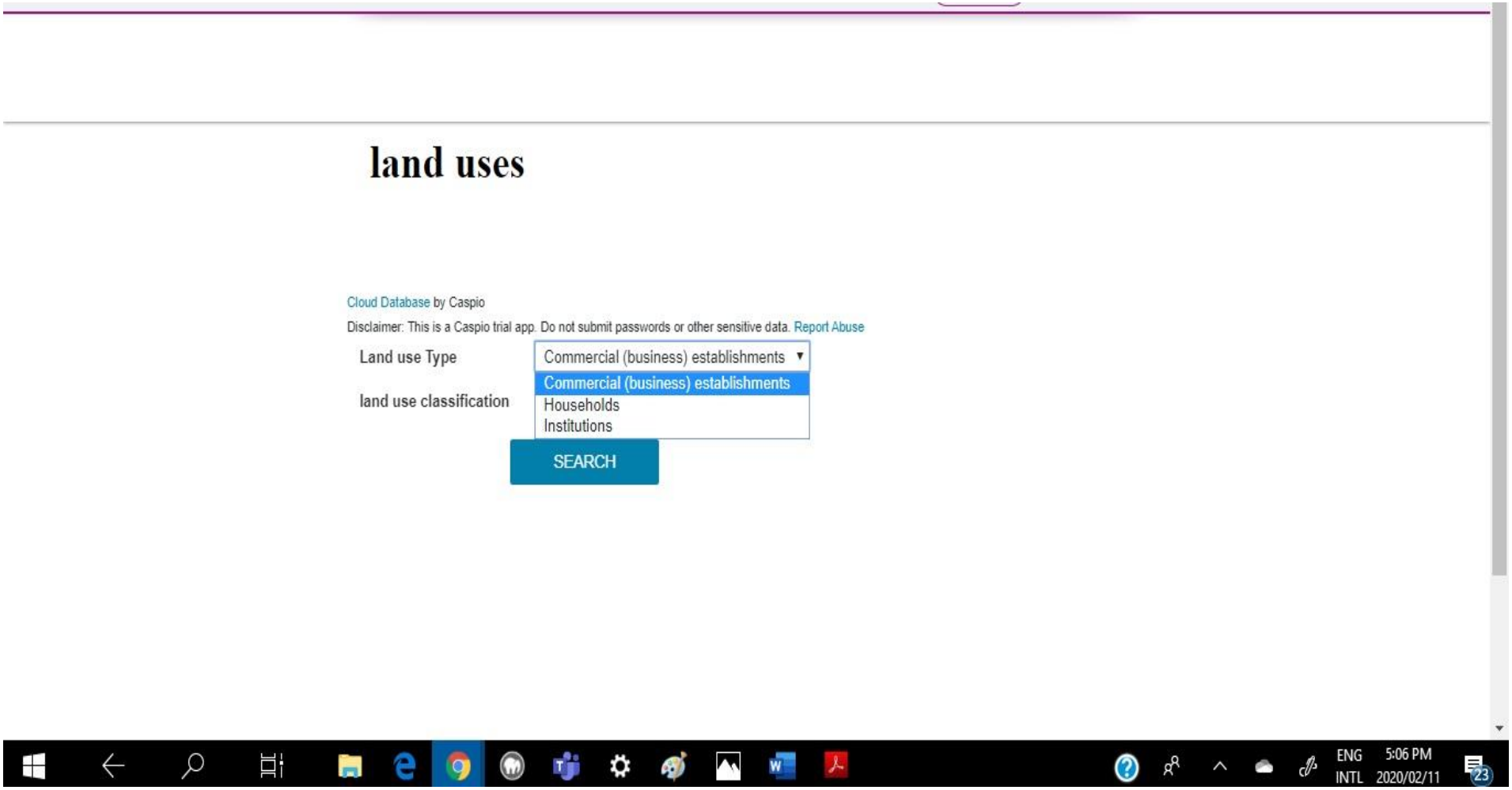
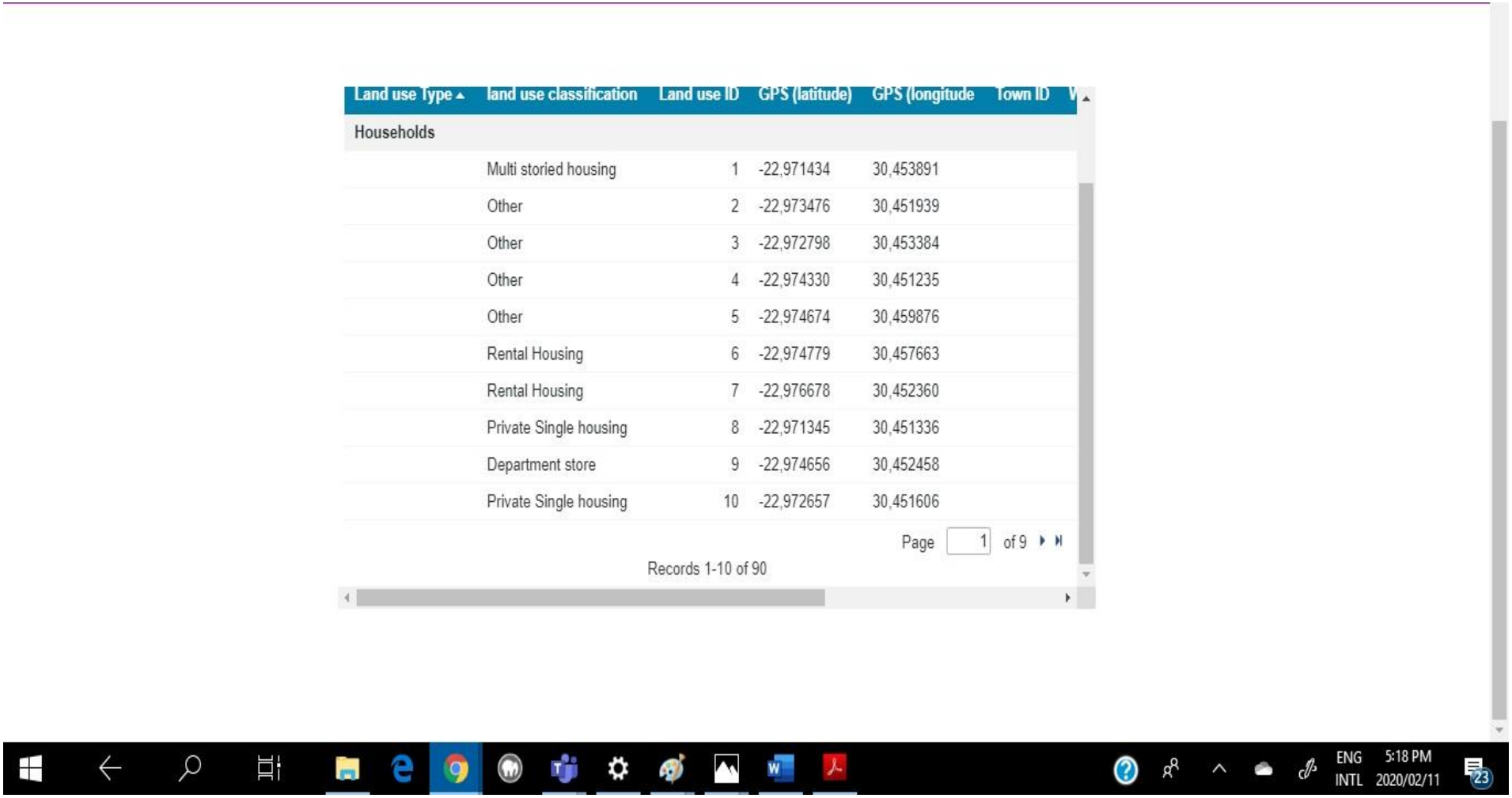


Figure 7:4: querying of the data based on land use type and classification



Land use Type	land use classification	Land use ID	GPS (latitude)	GPS (longitude	Town ID
Households					
	Multi storied housing	1	-22,971434	30,453891	
	Other	2	-22,973476	30,451939	
	Other	3	-22,972798	30,453384	
	Other	4	-22,974330	30,451235	
	Other	5	-22,974674	30,459876	
	Rental Housing	6	-22,974779	30,457663	
	Rental Housing	7	-22,976678	30,452360	
	Private Single housing	8	-22,971345	30,451336	
	Department store	9	-22,974656	30,452458	
	Private Single housing	10	-22,972657	30,451606	

Page 1 of 9

Records 1-10 of 90

Figure 7:5: Data on the waste generators which contains information on the amount of waste generated.

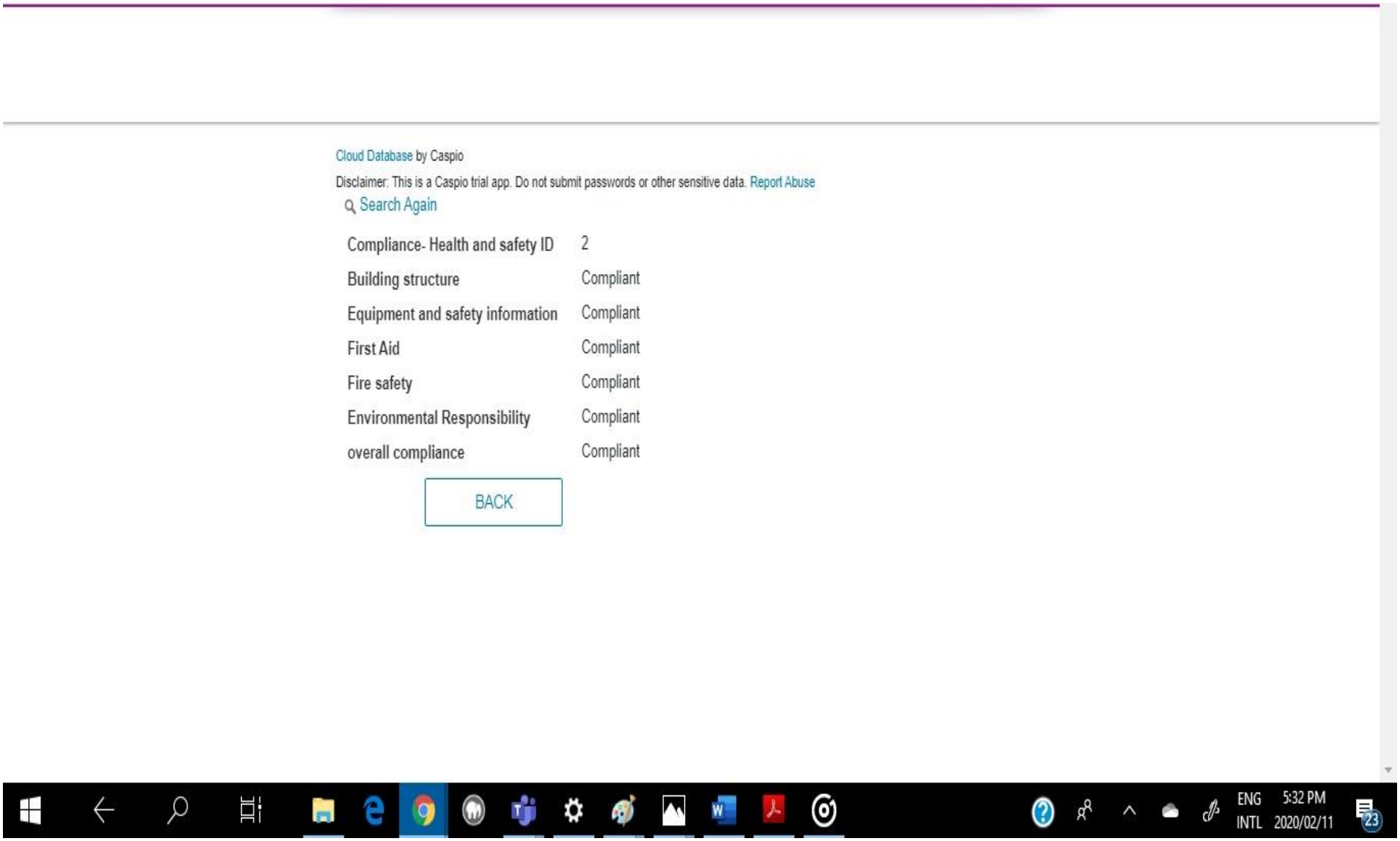


Figure 7:6: Data on the compliance of landfill compliance with the health and safety regulations.

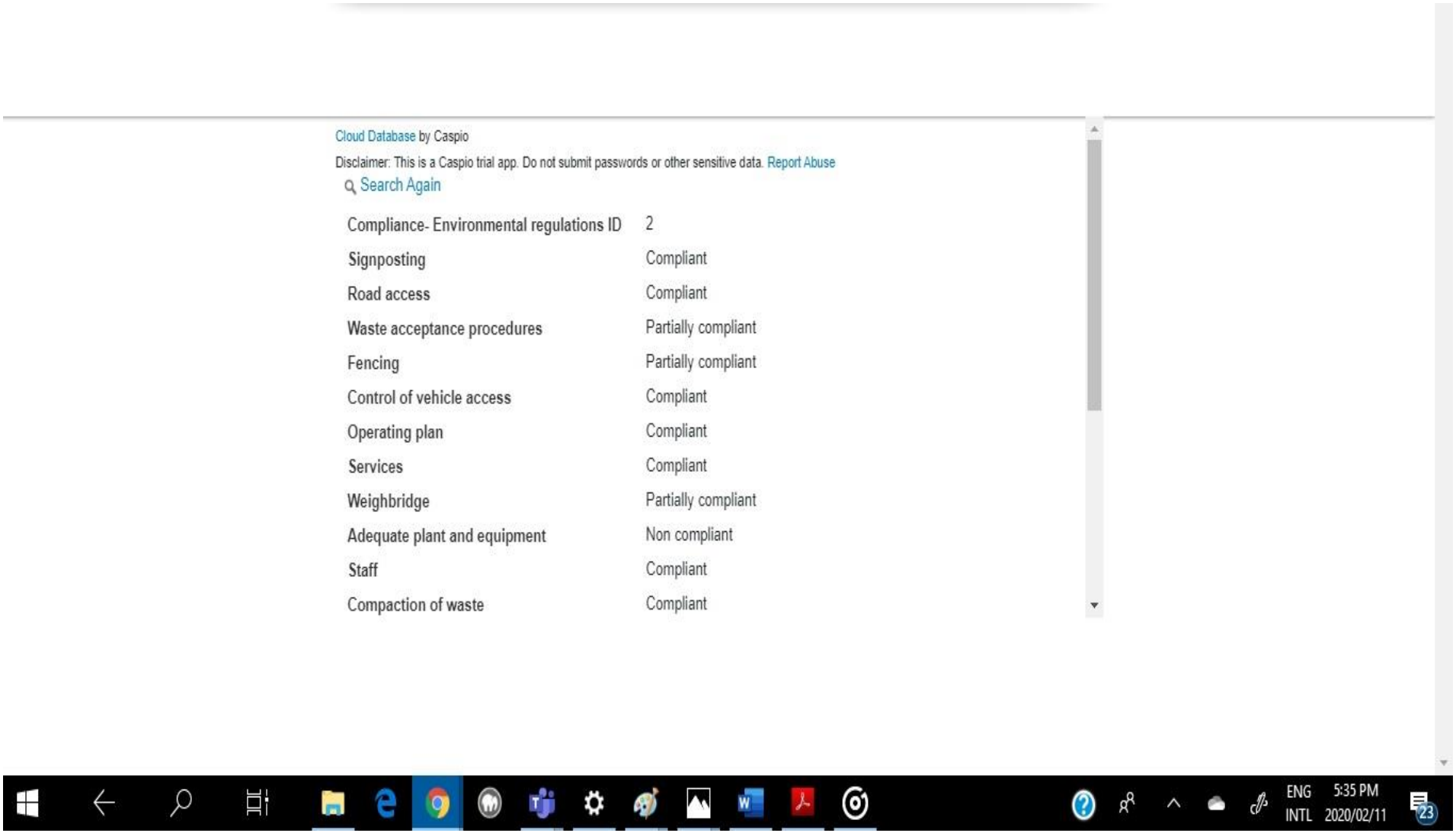


Figure 7:7: Data on the compliance of landfill compliance with the environmental regulations.

7.3 Chapter summary

The chapter presented and discussed the results of the database that was constructed. The database has a home page which shows the menu which shows the following: “home” tab (which is the home page), “solid waste generators” tab, “land uses” tab, and “town” tab and more tab which shows additional tabs which are the “Locational suitability” tab, “compliance -environmental regulations” tab, and the “Compliance with the health and safety regulations”. Querying of the database is possible.

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

This chapter focused on the conclusion that were drawn from the research findings. The chapter also provides recommendations that would improve the compliance of Thohoyandou Landfill with the environmental, and health and safety regulations; these recommendations promote waste diversion which would result in waste minimisation and environmental sustainability.

8.2 Conclusions

The main aim of the study was to develop a GIS database for solid waste management in Thohoyandou. The specific objectives of the study were to identify and determine the solid waste generators in Thohoyandou and its environs; identify and assess the types of solid waste that were accepted at the waste facilities; Establish the extent to which the Thohoyandou Landfill complies with the environmental, and health and safety regulation; evaluate the locational suitability using GIS and AHP methodology. The study found that the composition of the household waste is different from that of the commercial (business establishments), and the institutions. The waste from the households contained more organic waste compared to the waste from the commercial and the institutions which contained more paper and cardboard and plastic. The study also found that waste from the household was handled differently from that of the institutions and business establishments as it was not segregated from source while that from the business and institution was segregated.

The study found that the overall compliance in terms of landfill facility was 90%, control was 77, 78%, landfill resources was 66, 67%, and landfill operation was 60%. In terms of health and safety, the overall was 97, 44%. In terms of the locational suitability, the study found that the landfill was located in an unsuitable location which indicates that there is high risk of social, environmental and economic implications.

8.3 Recommendations

From the findings the researcher came up with the following recommendations:

8.3.1 Solid waste generators, nature, and the estimate amount of waste generated

- The researcher found that there was no segregation for household waste. During an informal interview with respondents, the researcher asked why they didn't segregate

the waste at source, and most respondents indicated that it was the responsibility of the municipality to segregate the waste. The researcher recommends more research to be done to change people's perception, values, and attitudes towards waste. Changing the individual's perception, attitude and value toward waste would contribute to efficient waste management because people would have a lower footprint. People would avoid buying plastic bags when shopping and move towards the reuse and recycling of waste. People need to be informed about responsible citizenship (role) to bring about environmental sustainability and that it is not just the role of municipalities. There should be waste segregation campaigns.

8.3.2 The solid waste facilities in Thohoyandou and its environs

- The researcher found that there was a shortage of recycling facilities, by-back centres in Thohoyandou area. As a result, the researcher recommends that more facilities that help divert recyclable waste from entering the landfill should be established. The recycling process should be done in Thohoyandou Town. The waste should not have to be stored, transferred and recycled away from the Thohoyandou.

- The researcher recommends that there should be awareness campaigns on promoting innovative ways of handling waste and changing waste to other useful products. This would generate money by creating jobs for the unemployed as unemployment is very high in South Africa. Waste such as tyres which was not accepted at the landfill or recycling facilities is dumped illegally because people do not know what to do with the waste, so, eco-solutions need to be introduced to reduce open dumps in the area.

8.3.3 The locational suitability of the solid waste facilities

- An alternative location for the landfill should be considered due to its proximity to the residential areas, water sources, road, cultivated areas, and slope which is too flat.

8.3.4 Compliance with the environmental, health and safety regulations

- A weighbridge has to be erected at the Thohoyandou landfill so that the exact amount of waste that enters and exits the landfill is recorded. Obtaining the exact amounts of waste increases reliability and dependability of the data. Subsequently, this would help in determining the life span of the landfill.
- Recycling structures need to be established within the Thohoyandou Landfill to avoid compromising the safety of the reclaimers. Waste diversion should be promoted to reduce the amount of recyclable waste getting into the landfill.

- All the equipment needs to be regularly inspected and maintained to ensure safety at work.

- During field work, the researcher found that the financial problem was the biggest challenge faced by the landfill. This resulted in inadequate equipment (equipment that frequently breaks down), so, the researcher recommends each household should pay a monthly levy for the collection of waste. When each household pays a monthly fee, the landfill would be generating money which could help to repair the equipment. For this to be successful, regulations should be enforced. The gas produced from the landfill should be used as a source of energy. As a result, money will be generated from the gas and would help buy more equipment.

- The fence should be repaired to restrict access to the landfill of people who want to dump waste illegally in the landfill. When the fence is fixed animals such as dogs and cows will not be able to enter the landfill. To avoid vandalism of the landfill fences, there should be tight security and monitoring.

8.4 Recommendations for future studies

- A seasonal analysis of waste generation to establish weather different seasons influence the quantity and composition of the waste.

- Changing people's perception with regards to the handling of solid waste.

- To establish the quantity, composition, and handling of waste generated from health care centres. The results obtained could be included in the GIS database prototype.

- To incorporate data in the GIS database prototype on the quantities of illegal dumps in Thohoyandou and its environs, waste composition and estimated quantities of solid waste discarded at the illegal dumps, and the locational suitability of the illegal dumps using GIS and AHP.

REFERENCES

Abd-El Monsef, H and Smith, SE. 2019. Integrating remote sensing, geographic information system, and analytical hierarchy process for hazardous waste landfill site selection. *Arabian Journal of Geosciences,* 12 (5): 155.

Achankeng, E, 2003. *G*lobalization, Urbanization and Municipal Solid Waste Management in Africa*.* In *Preceedings of the African Studies Association of Australasia and the Pacific 26th annual conference* pp. 1-22.

Agouris, P., Carswell, J. and Stefanidis, A., 1999. An environment for content-based image retrieval from large spatial databases. *ISPRS Journal of Photogrammetry and Remote Sensing,* 54(4): 263-272.

Ahsan, N., 1999. Solid waste management plan for Indian megacities. *Indian Journal of Environmental Protection,* 19(2): 90-95.

Ajzen, I., 1991. The theory of planned behavior. *Organ. Behav. Hum. Decis. Process.,* 50: 179–211.

Akbari, V., Rajabi, M. A., Chavoshi, S. H. and Shams, R., 2008. Landfill Site Selection by Combining GIS and Fuzzy Multi Criteria Decision Analysis, Case Study: Bandar Abbas, Iran. *World Applied Sciences Journal,* 3: 39-47.

Alam , R., Cgowdgury, M.A., Hasan, G.M., Karanjit, B. and Shestha, LR., 2008. Generation, storage, collection and transportation of Municipal solid waste- A case study inthe city of Kathmandu, Captial of Napal. *Waste management,* 28: 1088-1097.

Alam, P. and Ahmade, K., 2013. Impacts of Solid Waste on health and environment. *International Journal of Sustainable Development and Green Economics (IJSDGE),* 2(1): 165-168.

Al-Anbari, M. A., Thameer, M. Y. and Al-Ansari, N., 2018. Landfill Site Selection by Weighted Overlay Technique: Case Study of Al-Kufa, Iraq. *sustainability,* 10 (4): 1-11.

Al-Anbari, M. A., Thameer, M. Y., Al-Ansari, N. and Knutsson, S., 2016. Estimation of domestic solid waste amount and Its required Landfill volume in Najaf Governorate- Iraq for the Period 2015-2035. *Engineering,* 8: 339-346.

Al-Khatib, I. A., Monou, M., Abu Zahra, A. S., Shaheen, H. Q. and Kassinos, D., 2010. Solid waste characterization, quantification and management practices in developing countries. A case study: Nablus district – Palestine. *Journal of Environmental Management,* 91: 1131–1138.

Alqader, A. A. and Hamad, J., 2012. Municipal solid waste composition determination supporting the integrated solid waste management in Gaza strip. *International Journal of Environmental Science and Development,* 3(1): 172.

Amirian , P., 2013. *Beginning ArcGIS for Desktop Development Using Net.* United Kingdom: John Wiley and Sons .

Awasthi, M. K., Mahar, A., Wang, A. A. and Zhang, Z., 2016. Component Technologies for Municipal Solid Waste Management. In: *Municipal Solid Waste Management in Developing Countries.* New York: CRC Press Taylor and Francis Group.

Ayoade, J. O., 2000. Climatic Factors Affecting Pollution in Waste Disposal Sites in Developing Countries in Rogers W'o Oku-Uma *et al* (ed): *Pollution Control and Waste Management in Developing Countries.* The Commonwealth Secretariat, London.

Baban, S. M. and Flannagan, J., 1998. Developing and implementing GIS-assisted constraints criteria for planning landfill sites in the UK. *Planning Practice and Research,* 13(2): 139-151.

Babbie, E. and Mouton, J., 2001. *The practice of social science research.* Wadsworth: Belmon.

Barik , D., ed., 2019. *Energy from Toxic Organic Waste for Heat and Power Generation.* United Kingdom : Woodhead Publishing .

Barr, S., 2017. *Household waste in social perspective: values, attitudes, situation and behaviour.* Routledge.

Barr, S., Gilg, A. W. and Ford, N. J., 2001. A conceptual framework for understanding and analysing attitudes towards household-waste management. *Environment and Planning,* 33(11): 2025-2048.

Batool, S. A. and Ch, M. N., 2009. Municipal solid waste management in Lahore city. *Waste Management,* 29: 1971–1981.

Bdour, A., Altrabsheh, B., Hadadin, N. and Al-Shareif, M., 2007. Assessment of medical wastes management practice: a case study of the northern part of Jordan. *Waste management,* 27(6): 746-759.

Bilitewski, B., Härdtle, G. and Marek, K., 1997. *Waste Disposal. In Waste Management.* Berlin, Heidelberg: Springer.

Blessing, L. T. and Chakrabarti, A., 2009. *DRM: A Design Reseach Methodology.* London: Springer.

Butler, J. A., 2008. *Designing geodatabases for transportation.* ESRI, Inc..

Butt, T. E., Javadi, A. A., Nunns, M. A. and Beal, C. D., 2016. Development of a conceptual framework of holistic risk assessment - landfill as a particular type of contaminated land. *Sci. Total Environ.,* 569: 815-829.

Capelli, L. et al., 2011. Olfacto-metric approach for the evaluation of citizens' exposure to industrial emissions in the city of Terni. *Sci. Total Environ.,* 595: 409.

Chakhar, S. and Mousseau, V., 2008. Multicriteria decision making, spatial. In: *n Encyclopedia of GIS.* Boston: Springer,

Chandrappa, R. and Das, D. B., 2012. *Solid waste management: Principles and practice.* New York: Springer Science and Business Media.

Chang, N. B. and Davila, E., 2008. Municipal solid waste characterizations and management strategies for the Lower Rio Grande Valley, Texas. *Waste Management,* 28(5): 776-794.

Cheremisinoff, N. P., 2003. *Handbook of solid waste management and waste minimization technologies.* New York: Butterworth-Heinemann.

Christensen, T., ed., 2011. *Solid waste technology and management.* United Kingdom: John Wiley and Sons.

Cooper, C., 2017. *Mastering ArcGIS Enterprise Administration: install, configure, and manage ArcGIS Enterprise to Publish, optimize and secure GIS Services.* United Kingdom: Packt.

Demesouka, O. E., Vavatsikos, A. P. and Anagnostopoulos, K. P., 2014. GIS-based multicriteria municipal solid waste landfill suitability analysis: A review of the methodologies performed and criteria implemented. *Waste Management and Research,* 32(4): 270-296.

Dennis, B., 2000. Environment and Health Implications of Waste Management in Developing Countries. In: Okot-uma, R. W., Ekosse, G. E., Bogatsu, Y. G., Darkoh, K. and Totolo, O. eds. *Pollution Control and Waste Management in Developing Countries.* London: Commonwealth Secretariat and SFI Publishing.

Dhokhikah, Y. and Trihadiningrum, Y., 2012. Solid Waste Management in Asian Developing Countries: Challenges and Opportunities. *Journal of Applied Environmental and Biological Sciences,* 2(7): 329-335.

Dikgang, J., Leiman, A. and Visser, M., 2012. Analysis of the plastic-bag levy in South Africa. *Resources, Conservation and Recycling,* 66: 59– 65.

Donevska, K. R., Gorsevski , P. V., Jovanovski , M. and Pesevski, I., 2012. Regional non-hazardous landfill site selection by integrating fuzzy logic. AHP and geographic information systems. *Environ. Earth Sci.,* 67: 121–131.

DWAF , 1998. *Minimum Requirements for Waste Disposal by Landfills: Waste Management Series.* 2nd ed. Pretoria: Department of Water Affairs & Forestry.

Edokpayi, J. N., Durowoju, O. S. and Odiyo, J. O., 2018. Assessment of Heavy Metals in Landfill Leachate: A Case Study of Thohoyandou Landfill, Limpopo Province, South Africa. *Heavy Met .*

Effat, H. A. and Hegazy, M. N., 2012. Mapping potential landfill sites for North. *Egypt J Remote Sens. Space Sci.,* 15(2): 125–133.

El-Salam, M. M. and Abu-Zuid, G. I., 2015. Impact of landfill leachate on the groundwater quality: A case study in Egypt. *Journal of advanced research,* 6(4): 579-586.

Eskandari, M., Homaee, M. and Mahmodi, S., 2012. An integrated multi criteria approach for landfill siting in a conflicting environmental, economical and socio-cultural area. *Waste Management,* 32: 1528–1538.

Eskandari, M., Homaee, M., Mahmoodi, S., Pazira, E. and Van Genuchten, M. T., 2015. Optimizing landfill site selection by using using land classification maps. *Environmental Science and Pollution,* 22(10): 7754–7765.

ESRI, 2016. *Understanding Euclidean distance analysis.* [Online] Available at: desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/understanding-euclidean-distance-analysis.htm [Accessed 13 September 2018].

Farzadkia, M., Moradi, A., Mohammadi, M. S. and Jorfi,, S., 2009. Hospital waste management status in Iran: a case study in the teaching hospitals of Iran University of Medical Sciences. *Waste Management and Research,* 27(4): 384-389.

Ghobadi, M. H., Babazadeh, R. and Bagheri, V., 2013. Sitting MSW landfills by combining AHP with GIS in Hamedan province, Western Iran. *Environ. Earth Sci.,* 70(4): 1823–1840.

Giusti, L., 2009. A Review of Waste Management Practices and their impact on human Health. *Waste Management,* 29(8): 2227–2239.

Godfrey, L. and Oelofse, S., 2017. Historical Review of Waste Management and Recycling in South Africa. *CSIR Natural Resources,* 6(57): 1-11.

Gorsevski, P. V., Donevska , K. R., Mitrovski, C. D. and Frizado, J. P., 2012. Intergrating Multi-Critera Evulation techiques with geographic Information Systems for Landfill Site Selection: A Case Study Using Ordered Weighted Averages. *Waste Management,* 32(2): 287-296.

Green Home , 2013. *The Plastic Bag Levy: What's Inhibiting its Success in South Africa?.* [Online]
Available at: https://greenhome.co.za/south-africans-and-the-plastic-bag/
[Accessed 23 October 2018].

Guerrero, L. A., Maas, G. and Hogland, G., 2013. Solid waste management challenges for cities in developing countries. *Waste Manag.,* 33: 220–232.

Guide, 2020. *Occupational Health and Safety Act (Act 85 of 1993.* [Online]
Available at: https://www.labourguide.co.za/health-and-safety/848-health-and-safety-downloads
[Accessed 13 February 2020].

Hamzeh, M., Abbaspour, R. A. and Davalou, R., 2015. Raster-based outranking method: a new approach for municipal solid waste landfill (MSW) siting. *Environmental Science and Pollution Research,* 22(16): 12 511 –12524.

Hayes, J. E., Stevenson, R. J. and Stuetz, R. M., 2014. The impact of malodour on communities: a review of assessment techniques. *Sci. Total Environ.,* 500: 395-407.

Hering, J. G., 2012. An end to waste?. *Science,* 337(6095): 1623-1623.

Heywood , I., Cornelius, S. and Carver, S., 2011. *An Introduction to Geographical Information Systems.* 4th ed. Toronto : Pearson Education Limited.

Irwan, D., Basri, N. E. and Watanbe, K., 2011. Interrelationship between affluence and. *J. Asian Sci. Res.,* 2: 747–785.

Jaramillo, J., 2003. *Guidelines for the design, construction and operation of manual.* Colombia: Universidad de Antioquia.

Jha, M. K., Sondhi, O. A. and Pansare, M., 2003. Solid waste management-a case study. *Indian Journal of Environmental Protection,* 23: 1153-1160.

Johnke, B., 2012. *Emissions from Waste Incineration. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.* [Online] Available at: http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/5_3_Waste_Incineration.pdf [Accessed 2 October 2018].

Kahraman, C., Cebi, S., Onar, S. C. and Oztaysi, B., 2018. A novel trapezoidal intuitionistic fuzzy information axiom approach: An application to multicriteria landfill site selection. *Engineering Applications of Artificial Intelligence,* 67: 157-172.

Karimi, H., Amiri, S., Huang, J. and KarimI, A., 2019. Integrating GIS and multi-criteria decision analysis for landfill site selection, case study: Javanrood County in Iran. *International Journal of Environmental Science and Technology,* 16(11): 7305-7318.

Karl , T. R., Melillo, J. M., Peterson , T. C. and Hassol, S. J. eds., 2009. *Global Climate Change Impacts in the United States.* Cambridge University Press.

Khan, M. M., Vaezi,, M. and Kumar, A., 2018. Optimal siting of solid waste-to-value-added. *Sci. Total Environ.,* 610: 1065–1075.

Khodaparast, M., Rajabi, A. and Edalat, A., 2018. Municipal solid waste landfill siting by using GIS and analytical hierarchy process (AHP): a case study in Qom city, Iran. *Environmental Earth Sciences,* 77(2).

Khoshand, A., Bafrani, A H., Zahedipour, M., Mirbagheri, S A. and Ehtehsami, M., 2018. Prevention of landfill pollution by multicriteria spatial decision support System (MC-SDSS): development, implementation, and case study. *Environmental Science and Pollution Research,* 25: 8415–8431.

Kingsley, E. N., Paschal, I. O. and Jude, E. O., 2016. Assessment of landfill sites for solid waste management in Delta state, Nigeria. *Journal of Environment and Waste Management,* 3(1): 116-122.

Kirimi, F. K. and Waithaka, E. H., 2014. Determination of suitable a site using geospatial techniques and multi-critera decision analysis: a case study of Nakuru, Kenya. *International Journal of Science and Research (IJSR),* 3(11): 2319-7064.

Klinghoffer, N. B. and Castaldi, M. J. eds., 2013. *Waste to energy conversion technology.* Elsevier.

Kontos, T. D., Komilis, D. P. and Halvadakis, C. P., 2015. Siting MSW landfills with a spatial multiple criteria analysis methodology. *Waste Management,* 25(8): 818-832.

Kordi, M. N., Collins, L. B., O'Leary, M. and Stevens, A., 2016. ReefKIM: An integrated geodatabase for sustainable management of the Kimberley Reefs, North West Australia. *Ocean and Coastal Management,* 119: 234-243.

Krčmar, D., Tenodi, S., Grba, N., Kerkez, D., Watson, M., Rončević, S. and Dalmacija, B., 2018. Preremedial assessment of themunicipal landfill pollution impact on soil and shallow groundwater in Subotica, Serbia. *Science of the Total Environment,* 615: 1341–1354.

Kumar , R., 2011. *Research Methodology: A Step-by-Step Guide for Begineers.* 3rd ed. London: Sage.

Kumar, S., 2016. *Municipal Solid Waste Management in Developing Countries.* New York : CRC Press.

Lagerkvist, A., Ecke, H. and Christensen, T. H., 2011. *Waste Characterization: Approaches and Methods. in Solid Waste Technology and Management.* West Sussex: Wiley.

Leedy, P. D. and Ormrod, J. E., 2015. *Practical Research: Planning and Design.* 11th ed. England : Pearson .

Letcher, T. M. and Vallero, D. eds., 2019. *Waste: A handbook for management.* Academic Press.

Lin, H. Y. and Kao, J. J., 1999. Enhanced spatial model for landfill siting analysis. *Journal of environmental engineering,* 125(9): 845-851.

Liu,, Y. et al., 2016. Health risk impacts analysis of fugitive aromatic compounds emissions from the working face of a municipal solid waste landfill in China. *Environ. Int.,* 97: 15-27.

Li, Y., Park, S. Y. and Zhu, J., 2011. Solid-state anaerobic digestion for methane production from organic waste. *Renewable and sustainable energy reviews,* 15(1): 821-826.

Longley, P. A., Goodchild, M. F., Maguire, D. J. and Rhind, D. W., 2015. *Geographic Information Science and Systems.* 4th ed. New JerseY: John Wiley and Sons.

Manaf, L. A., Samah, M. A. and Zukki, N. I., 2009. Municipal solid waste management in. *Waste management,* 29(11): 2902-2906.

Manoiu, V., Fontanine, I., Costache, R., Pravalie, R. and Mitof, I., 2013. Using GIS Techniques for Assessing Waste Landfill Placement Suitability. Case Study: Prahova County, Romania. *Geographia Technica,* 8(2): 47- 56.

Matsie, R. and Palamuleni, L. G., 2017. *Developing an Institutional GIS Database of Waste Management in the North West Province, South Africa.* Unpublished MSc dissertation. North-West University.

McDougall, F. R., White, P. R., Franke, M. and Hindle, P., 2008. *Integrated solid waste management: a life cycle inventory.* John Wiley and Sons.

Medina, M., 1997. The effect of income on municipal solid waste generation rates for countries of varying levels of economic development: a model. *J. Resour. Manag. Technol.,* 24: 149-155.

Minghua, Z., Xiumin, F., Rovetta, A., Qichang, H., Vicentini, F., Bingka, L., Giusti, A. and Yi, L., 2009. Municipal solid waste management in Pudong New Area, China. *Journal of Waste Management,* 29: 1227–1233.

Moeinaddini, M., Khorasani, N., Danehkar, A., Darvishsefat, A. A. and zienalyan, M., 2010. Siting MSW landfill using weighted linear combination and analytical hierarchy

process (AHP) methodology in GIS environment (case study: Karaj). *Waste Management,* 30: 912–920.

Mohee, R. and Simelane, T. eds., 2015. *Future directions of municipal solid waste management in Africa.* Africa Institute of South Africa.

Monavari, S. M., Hoasami, P., Tajziehchi, S. and Khorramichokami, N., 2012. Study of Solid Waste Landfill Suitability using Regional Screening Method and AHP in Rasht City. *World Academy of Science. Engineering and Technology,* 62: 820-825.

Mu, E. and Pereyra-Rojas, M., 2016. *Practical Decision Making: An Introduction to the Analytic Hierarchy Process (AHP) Using Super Decisions* (Vol.2). Springer.

Mustafa, M. F., Liu, Y., Duan, Z., Guo, H., Xu, S., Wang, H. and Lu, W., 2017. Volatile compounds emission and health risk assessment during composting of organic fraction of municipal solid waste. *J. Hazard Mater,* 327: 35-43.

Nas, B., Cay, T., Iscan, F. and Berktay, A., 2010. Selection of MSW landfill site for Konya, Turkey using GIS and multi-criteria evaluation. *Environmental monitoring and assessment,,* 160(1-4): 491.

Nefale, A., 2018. *An evaluation of strategic management of landfill sites: A case study of Thohoyandou Block J. landfill site, Vhembe District Municipality, Limpopo Province.*[Online] Available at: http://univendspace.univen.ac.za/bitstream/handle/11602/1080/Dissertation%20-%20Nefale%2c%20a.-.pdf?sequence=1andisAllowed=y [Accessed 01 12 2019].

Ngumom, T. M. and Terseer, H. W., 2017. Site Suitability Analysis for Solid Waste Disposal using Geospatial Technology: A Case Study of Katsina-Ala Township, Katsina-Ala, Benue State. *International Journal of Science and Research (IJSR),* 6(3): 980-985.

Nilanthi, J. G., Patrick, J. A., Wirasinghe, S. C. and Sumit, P., 2006. Relation of waste generation and composition to socio-economic factors: a case study. *Environ. Monit.,* 135: 31-39.

Novara, A., Gristina, L., Saladino, S.S., Santoro, A. and Cerdà, A., 2011. Soil erosion assessment on tillage and alternative soil managements in a Sicilian vineyard. *Soil Till Res.,* 117: 140–147.

Obiri-Danso, K., Kádár, Z., Fei-Baffoe, B. and Mensah, M., 2015. Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. *Waste Management,* 46: 15–27.

Ogola , J. S., Chimuka, L. and Tshivhase, S., 2011. Management of municipal solid wastes: A case study in Limpopo Province, South Africa. *In Integrated Waste Management,* 1: 91-112.

Ramachandra, T. V., Bharath, H. A., Kulkarni, G. and Han, S. S., 2018. Municipal solid waste: Generation, composition and GHG emissions in Bangalore, India. *Renewable and Sustainable Energy Reviews,* 82: 1122–1136.

Rao, M. N., Sultana , R. and Kota , S. H., 2017. *Solid and Hazardous Waste Management: Science and Engineering.* United Kingdom : Elsevier Inc .

Rathore, S., Ahmad, S. R. and Shirazi, S. A., 2016. Use of the Suitability Model to Identify Landfill Sites in Lahore-Pakistan. *Journal of Basic and Applied Sciences,* 12: 103-108.

Reddy, P. J., 2016. *Energy Recovery from Municipal Solid Waste by Thermal Conversion Technologies.* CRC Press.

Republic of South Africa, 2000. White Paper on Integrated Pollution and Waste Management for South Africa. A Policy on Pollution Prevention, Waste Minimisation, Impact Management and Remediation.. 417(20978).

Rhyner, C. R., Schwartz, L. J., Wenger, R. B. and Kohrell, M. G., 2017. *Waste management and resource recovery.* CRC Press..

Rogoff, M. J., 2013. *Solid waste recycling and processing: planning of solid waste recycling facilities and programs.* Elsevier.

Saft, R. J. and Elsinga, W., 2006. Source separation, composting a win for greenhouse gas reduction. *BioCycle,* 47(8): 50-53.

Sakawi, Z., Mastura, S., Jaafar, O. and Mahmud, M., 2011. Community perception of odour pollution from landfills. *Malaysian Journal of Society and Space,* 7(3): 18 - 23.

Samadder, S. R., Prabhakar, R., Khan, D., Kishan, D. and Chauhan, M. S., 2017. Analysis of the contaminants released from municipal solid waste landfill site: a case study. *Sci. Total Environ.,* 580: 593–601.

Saral, A., Demir, S. and Yıldız, S., 2009. Assessment of odorous VOCs released from a main MSW landfill site in Istanbul-Turkey via a modelling approac. *Journal of Hazardous Materials,* 168(1): 338-345.

Sasikumar, K. and Krishna, S. G., 2009. *Solid waste management.* PHI Learning Pvt. Ltd.

Scott, B. F. and Jobber, D., 2000. Environmentally responsible purchase behaviour: a test of a consumer model. *European Journal of Marketing,* 34(5/6): 723-746.

Şener, B., Süzen, M. L. and Doyuran, V., 2006. Landfill site selection by using geographic information systems. *Environmental geology,* 49(3): 376-388.

Şener, S., Şener, E., Nas , B. and Karagüzel, R., 2010. Combining AHP with GIS for landfill site selection: a case study in the Lake Beyşehir catchment area (Konya, Turkey). *Waste management,* 30(11): 2037-2046.

Shaikh, Z. A., 2018. Towards Sustainable Development: A Review of Green Technologies. *Trends in Renewable Energy,* 4(1).

Sharholy, M., Ahmad, K., Mahmood, G. and Trivedi, R. C., 2008. Municipal solid waste management in Indian cities–A review. *Waste management,* 28(2): 459-467.

Sharifi, M., Hadidi, M., Vessali, E., Mosstafakhani, P., Taheri, K., Shahoie, S. and Khodamoradpour, M., 2009. *Integrating multi-criteria decision analysis for a GIS-based hazardous waste Landfill Sitting in Kurdistan Province, Western Iran.* 29 ed. Iran: Elsevier.

Sigua, G. C., 2018. Recycled agricultural waste: Biochars Multifunctional Role un Agricultural and Environment. *Journal of Ecosystem and Ecography,* Volume 8: 38.

Singh, J., Laurenti, R., Sinha, R. and Frostell, B., 2014. Progress and challenges to the global waste management system. *Waste Management and Research,* 32(9): 800–812.

Soncuya, R. T. and Viloria,, L. A., 1992. Solid waste study of Mandaluyong and San Juan.. *Prepared for the MEIP Project in Metro Manila on Integrated Waste Resource Recovery and Reuse.*

Soroudi, M., Omrani, G., Moataar, F. and Jozi, S. A., 2018. Modelling an Integrated Fuzzy Logic and Multi-Criteria Approach for Land Capability Assessment for Optimized Municipal Solid Waste Landfi ll Siting Yeast. *Pol. J. Environ. Stud.,* 27(1): 313-323.

South Africa, 2008. *National Environmental Management: Waste Act No. 59 of.* Pretoria: Government Printer.

Struwig, M., Struwig, F. W. and Stead, G. B., 2001. *Planning, reporting and designing research.* South Africa: Pearson.

Sumathi, V. R., Natesan, U. and Sarkar, C., 2008. GIS-based approach for optimized siting of municipal solid waste landfill. *Waste management,* 28(11): 2146-2160.

Tan, S. T., Ho, W. S., Hashim, H., Lee, C. T., Taib, M. R. and Ho, C. S ., 2015. Energy, economic and environmental (3E) analysis of waste-to-energy (WTE) strategies for municipal solid waste (MSW) management in Malaysia. *Energy Conversion and Management,* 102: 111–120.

Teorey , t., Lightstone , S., Nadeau, T. and Jagadish, H. V., 2011. *Database Modelling and Design: Logical Design.* 5th ed. New York: Elsevier.

Uyan, M., 2014. MSW landfill site selection by combining AHP with GIS for Konya, Turkey'. *Environmental Earth Sciences,* 71(4): 1629-1639.

Visser , M. and Theron, J., 2009. *Waste not: Externalisation and management of waste in Cape Town.* Institute of Poverty, Land and Agrarian Studies (PLAAS) Working Paper 12.

Wu, C., Liu, J., Liu, S., Li, W., Yan, L., Shu, M., Zhao, P., Zhou, P. and Cao, W., 2018. Assessment of the health risks and odor concentration of volatile compounds from a municipal solid waste landfill in China. *Chemosphere,* 202: 1-8.

Yildrim, U. and Guler, C., 2016. Identification of suitable future municipal solid waste disposal sites for the metropolitan Mersin (SE Turkey) using AHP and GIS techniques. *Environ. Earth Sci.,* 75(2): 101.

Young, G. C., 2010. *Municipal solid waste to energy conversion processes: economic, technical, and renewable comparisons.* John Wiley and Sons.

Žaltauskaitė, J. and Vaitonytė, I., 2016. Toxicological Assessment of Closed Municipal Solid-waste Landfill Impact on the Environment. *Environmental Research, Engineering and Management,* 72(2): 8-16.

Zeiss, C. and Lefsrud, L., 1995. Analytical framework for waste-facility siting. *Journal of urban planning and development,* 121(4): 115-145.

Zhang,D.Q., Tan, S. K. and Gersberg, M., 2010. Municipal Solid waste Management in china: status, problems and challenges. *Journal of Environmental Management*, 91: 1623

APPENDICES

Appendix A: Questionnaire cover letter

PARTICIPANT INFORMATION LETTER

Dear Participant

My name is Murendeni Netshaulu. I am a Master of Environmental Science student in the Department of Geography and geo-information sciences at the University of Venda with student number: 14014230. My research supervisor is Dr N.S Nethengwe (PhD). I am conducting research titled: *The Development of GIS Database for Solid Waste Management in Thohoyandou and its Environs.*

The biggest environmental challenge affecting developing countries is the rapid growth of solid waste and its consequent poor management. This is attributed to rapid population growth due to the uncontrolled and unplanned urbanisation that characterises population dynamics of developing countries. More importantly, it is attributed to the individual attitudes and value systems as they relate to waste management. In addition, the rapid economic growth is also responsible for the increase in the solid waste generated (Seo, *et al.,* 2004; Guerrero, *et al.,* 2013). Poor management is attributed to the capitalist economy which promotes mass consumerisation. Management of waste requires data from different entities associated with solid waste and GIS has the capability of integrating data from different sources. There is a lack of knowledge and data concerning waste attributes due to the inability of municipalities manage data from different sources. This often contributes to the poor management of solid waste. Therefore, this study aims/ purpose is to develop a GIS database prototype for the efficient management of solid waste.

Outline of procedures

The participants are responsible for filling in the questionnaire and to answer the questions asked during the interview. The informal interview will be conducted in the language that the participants understand. The questionnaire and the informal interviews will be conducted in the solid waste treatment facilities which is the Thohoyandou Landfill and the recycling facility that is situated in Shayandima. This is done to determine the type of solid waste that is disposed/ recycled. Some questionnaires will be distributed at the solid waste generators such as institutions, commercial areas, industrial sites. This is done to determine the type and the estimated quantity of solid waste that is produced. The people who will be interviewed or given questionnaire will be those who handle waste. The time that will be required of participants is approximately 30min. The participants are expected to be fill in questionnaires and answer interview questions truthfully. Purposive sampling will be used to get the participants. The

respondents will be visited and will be given the same questionnaires to make sure that the data is valid, dependable and reliable

Risks, discomfort to the participants: There will be no foreseeable risks or discomfort to the participants. There will not be research-related injury or adverse reaction. Therefore, there will be compensation given to the participants. The researcher will ensure that there is no emotional nor physical harm to the respondents. There is no right nor right answers.

Benefits from the research study: The researcher will publish the research in journal articles in the future. The benefit is that the participants will gain more information or better understanding on about the management of solid waste in Thohoyandou and its environs.

Consent: Be knowledgeable that the participation in this study is voluntary. You are free to withdraw from participating at any time without any penalty and you are not in any obligation to take part in this study. If you decide to continue with the participation, you will be treated fairly

Reasons why participants may be withdrawn or may withdraw themselves from the study: There is no reason participants may want to withdraw, but if they choose to withdraw there will be no adverse consequences.

Remuneration of participants: The participant should not expect to receive any monetary or other types of remuneration, but your participation will be highly appreciated.

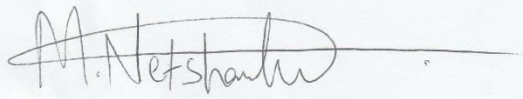
Costs of the study to the participant: The participant will not be expected to cover any costs towards the study.

Confidentiality: All participants are entitled to privacy about their thoughts and beliefs. Respondents/ participants will remain anonymous. Participant's name, or ID number will not be required when doing interviews or when filling in the questionnaire. No personal particulars will be revealed in public, information collected from the study will be kept confidential and will not be disseminated to other parties without your permission

For any queries or event of any problems, please feel free to contact the researcher (Ms. M. Netshaulu, 0766369413) or my supervisor (Dr. N.S Nethengwe, PhD, 015 962 893)

Yours Sincerely

Murendeni Netshaulu



PARTICIPANT INFORMATION LETTER

I hereby confirm that I have been informed by Murendeni Netshaulu of student number 14014230, about nature the of the study. I read the researchers participant letter. I am aware of the purpose of the study, procedures on how the data collection process will be conducted.

I am also aware that there are no risks or discomfort involved should I participate in the study. I know what the researcher and I will benefit from the study. I know that I should not expect monetary or other types of remuneration. I am aware that I am not expected to cover any costs for the study. I am also aware that confidentiality will be ensured and that my personal details such as my name, and date of birth will be anonymously processed into the study report.

I am aware that the participation in this study is voluntary and that I may at any stage, without prejudice, withdraw my consent and participation in the study. I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study. I also understand that significant new findings developed during the research may relate to the participant will be made available to me.

Participants signature ..... Date ..... Time.....

Murendeni Netshaulu herewith confirm that the above participant has been fully informed about the nature, conduct and the risks of the above study.

Researcher's signature..... Date.....

Appendix B: Questionnaire for the solid waste generators

The purpose of the questionnaire is to elicit data concerning the nature of the solid waste generators at Thohoyandou and its environs. Your time and patience in answering this questionnaire is appreciated. Your responses will be treated with confidentiality. Please answer each question truthfully.

Inquiries: Netshaulu Murendeni

Cell phone Number: 0766369413

Email Address: netshaulum@gmail.com

PLEASE CROSS (X) OR WRITE YOUR ANSWER WHERE APPLICABLE

Date: ……

Site GPS Co-ordinates

Latitude ……..

longitude ……

Occupation of the respondent: ……

1. **Source of solid waste generation**

a.		**Household/ residential/domestic**	
b.		**Commercial**	
	Type of commercial	Departmental store	
		Hotel	
		Restaurant	
c.		**Institutional**	
	Type of institution	Government office	
		Religious place Church	
		Community hall	
		School	
d.		I**ndustrial**	

If household:

2. **Type of Housing**

a.	Private Single housing	
b.	Rental housing	
c.	Multi storied housing	

d.	Other (please specify) ……	

3. What type of solid waste are you generating?

a.	Paper/cardboard boxed	
b.	Metals	
c.	Plastic	
d.	Glass	
e.	Organic waste	
f.	Other (Please specify)……	

4. Do you segregate the solid waste at source?

a.	Yes	
b.	No	

5. What type of containers are you using to store the solid waste?

a.	Bin (metal or plastic)	
b.	Refuse plastic bags	
c.	Other. Please specify……	

6. Who transports the solid waste to the waste facilities?

a.	Generator	
b.	Municipality	
c.	Private Sector	

7. What type of vehicles are used to collect the solid waste at source?

a.	Small Truck	
b.	Medium Truck	
c.	Truck with Tractor	
d.	Tractor	
e.	Other. Please Specify……	

8. What is the mode of solid waste collection?

a.	House-to-house	
b.	Community Bin	
c.	Curb side Pick-up	
d.	Self- delivered	
e.	Contracted or delegated services	

9. Is there a fixed schedule for the collection of solid waste?

a.	Yes	
b.	No	

10. Collection of waste each week

a.	Once a week	
b.	everyday	
c.	Not collected at all	

11. What is the quantity of waste produced by week?

……

**********THE END. THANK YOU FOR YOUR RESPONSE**********

Appendix C: Questionnaire for the solid waste facilities

The purpose of the questionnaire is to elicit data concerning the types of solid waste treatment facilities and the type of waste accepted at the facility. Your time and patience answering questionnaire is appreciated. Your responses will be treated with confidentiality. Please answer each question truthfully.

Inquiries: Netshaulu Murendeni

Cell phone Number: 0766369413

Email Address: netshaulum@gmail.com

PLEASE CROSS (X) OR WRITE YOUR ANSWER WHERE APPLICABLE

Date: ……

Site GPS Co-ordinates

Latitude ……

longitude ……

Occupation of the respondent: ……

1. **Name of the solid waste facility**

……

2. **The Area of the solid waste facility**

……

3. **The parameter of the solid waste facility?**

……

4. **How long has the solid waste facility been on operation?**

……

5. **Type of solid waste facility**

a.	Landfill	
b.	Buy-back- centres	
c.	Recycling sites	

6. If landfill, what type of landfill is it?

a.	Open dumping	
b.	Controlled	
c.	Sanitary	

7. Dominant type of waste that is disposed/ accepted at the solid waste facilities?

a.	Paper/cardboard boxed	
b.	Metals	
c.	Plastic	
d.	Glass	
e.	Organic waste	
f.	Other (please Specify) ……	

8. Method of solid waste recovery or treatment

a.	recycling	
b.	Thermal treatment	
c.	Biological	
d.	Landfill gas recovery	

9. What is the waste class accepted at the solid waste facilities?

a.	General	
b.	Hazardous	
c.	Both General and hazardous	

10. Where does the waste in the facility come from?

a.	Household/ residential	
b.	Commercial	
c.	Institutional	
d.	Industrial	
e.	Other. Please Specify ……...	

11. The quantity of solid waste that enters the solid waste facility per day.

……

12. Type of storage containers used to store the waste.

……

13. Where do you send the waste?

……

14. Do you collect the waste from the solid waste generator?

a.	Yes	
b.	No	

If yes

15. Is there a fixed route for the transportation of the solid waste to the facilities?

c.	Yes	
d.	No	

********************THE END. THANK YOU FOR YOUR RESPONSE***************************

Appendix D: Checklist for compliance with the environmental regulations

COMPLIANCE WITH THE ENVIRONMENTAL REGULATIONS CHECKLIST

REF.	
	4 Department of Water Affairs and Forestry, Second Edition, 1998. Waste Management Series. Minimum Requirements for Waste Disposal by Landfill - Section 10 "Landfill Operation
	5 National Environmental Management: Waste Act 59 of 2008- National Norms and Standards for Disposal of Waste to Landfill (GNR636 of 2013)

C **Fully Compliant [score: 1]**

PC **Partial compliance [score: 0,5]**

NC **Non-compliant [score: 0]**

Site GPS

Latitude (y)…… S

Longitude (x) …… E

Site type: ……

Site Name: ……

	Requirements	Compliance C/NC/ PC	Observation/ Comment	Score
	Permit to operate the facility			
	A FACILITY			
1	**Signposting**			

1.1	Signs in appropriate official languages indicating Route and distance to the landfill site from nearest main road			
1.2	Sign at entrance indicating in appropriate official languages			
1.3	Contact details of Permit holder and Responsible person			
1.4	Hours of operation			
1.5	Emergency telephone number			
1.6	Class of landfill			
1.7	Types of permissible and non-permissible waste			
1.8	Disposal of non-permissible waste is illegal and can lead to prosecution			
2	**Roads Access**			
2.1	Road access maintained to accommodate vehicles that normally utilise the facility			
2.2	Roads to be surfaced, enabling waste disposal in all weather conditions			
2.3	Two-way traffic possible in all weather conditions			
2.4	Roads watered in aid of dust control, with no mud formation			
B CONTROLS				
1	**Waste acceptance procedures**			
1.1	Waste inspected prior to acceptance by qualified staff			
1.2	Hazardous waste diverted to appropriate landfill site			
1.3	Waste disposal tariffs displayed on notice board			
2	**Fencing**			

2.1	Fences - 1.8m high with an overhang			
2.2	Site boundary adequately fenced and clearly marked			
3	**Control of vehicle access**			
3.1	Single vehicle-controlled entrance			
3.2	Security staff at gate			
3.3	Lockable gate, manned during operating hours			
4	**Operating plan**			
C RESOURCES				
1	**Services**			
1.1	Water			
1.2	Sewerage			
1.3	Electricity			
1.4	Telephone services			
1.5	Site office			
2	**Weighbridge**			
2.1	Signpost: Waste disposal tariffs			
2.2	Collection of Waste disposal tariffs			
3	**Adequate plant and equipment**			
3.1	Purpose-built landfill compactors, bulldozer and front-end loader			
3.2	Vehicle to transport cover material			
3.3	Storage facilities			

3.4	Back-up equipment and operating staff			
3.5	Equipment in good repair, not causing noise and air pollution			
4	**Staff**			
4.1	Responsible/ managerial person on duty			
4.2	Support staff			
4.3	Suitably qualified			
4.4	Back-up staff			
4.5	Occupational Health and Safety measures in place			
4.6	Protective clothing (PPE)			
D LANDFILL OPERATION				
1	**Compaction of the waste**			
1.1	Purpose built compactor in use- Compaction is best achieved if the waste is spread in thin layers and compacted by a purpose-built landfill compactor.			
1.2	Waste should be fully covered at the end of each working day (A minimum thickness equivalent to the effective covering of 150mm of compacted soil is required).			
1.3	Two-week cell capacity			
1.4	Three days cover stockpile available, close to working face			
1.5	Protection of unsafe excavations			
2	**Wet weather cell**			
2.1	Location close to entrance and all-weather roads			

2.2	One-week capacity			
3	**Leachates**			
3.1	Limit leachate generation to 200 mm/year over the area of the waste body, or to a figure for which the leachate treatment capacity may be designed, which will ensure socially and environmentally acceptable conditions. It may only be exceeded if it can be shown that the overall design of the landfill, the leachate management system and the leachate treatment system can easily accommodate this flow.			
3.2	Sporadic leachate reporting			
3.3	Co-disposal (Solid and liquid waste)- Co-disposal of solid and liquid waste must only occur at sites with a leachate management system which can contain, extract and preferably treat the resultant leachate flow.			
3.4	Cells appropriately lined			
3.5	Leachate management system to collect and drain leachate to a point where it can be extracted for treatment.			
4	**Excavation for cover**			
4.1	Excavation floor sufficiently separated from the wet season high elevation of ground water			
5	**Drainage**			

5.1	Run-off and storm water diverted around waste body			
5.2	Contaminated water and leachate contained on site			
5.3	Contaminated water and leachate contained stored in retention sump or dam			
5.4	0.5-meter freeboard for contaminated water impoundments and drainage trenches.			
5.5	Final covered areas promote run-off with minimum erosion and/ or ponding of water.			
5.6	Uncontaminated water to flow into natural drainage system			
6	**Waste reclamation**			
6.1	Waste reclamation prohibited (licence condition)			
6.2	Any reclamation operation formalised in Operating plan			
7	**Control of nuisances**			
7.1	Waste burning prohibited			
7.2	Litter fences present and cleaned daily			
7.3	Malodorous waste covered immediately			
7.4	Equipment to comply with local authority by-laws on noise levels.			
7.5	Vermin management measures in place			
7.6	Dust kept to a minimum (watering)			

Appendix E: Checklist for compliance with the Health and safety regulations

COMPLIANCE WITH HEALTH AND SAFETY REGULATIONS CHECKLIST

REF.	Occupational Health and Safety Act (85 of 1993)

Site GPS

Latitude (y)…… S

Longitude (x) …… E

Site type: ……

Site Name: ……

	Requirements	Compliance C/NC/ PC	Observation/ comments	Score
1	**Building structure and facilities**			
1.1	Building: any visible safety hazards/risks?			
1.2	Floors: clean and free of obstructions, damage, holes, etc, to cause slipping/tripping?			
1.4	Facilities and hygiene: are all areas and toilets etc clean and hygienic? Ventilation adequate? Lighting sufficient and maintained?			
2	**Equipment and safety info:**			
2.1	**Machinery and equipment**: a. All equipment kept on record? B. Stored safely? C. Regularly inspected and maintained to ensure safe working order? D. Any defective items removed from facility?			

2.2	**Lifting equipment**: a. Weights secured safely with clips? B. Weight lifting waist belts provided? C. Stacked safely when not in use?			
2.3	**Safe working procedures**: *printed* instructions on correct and safe use are present and visible? Do staff receive safety training?			
2.4	**Safety signs and notices**: all cautionary, danger, and warning signage present and visible?			
2.5	**Access control**: a. Occupancy load certificate (with max. Number allowed in facility at any time) visible? B. Access control procedures enforced? Inspection of incoming load loads			
2.6	**PPE**: A. All personnel trained in how to protect themselves from hazards identified in the solid waste treatment facility. B. Personal protective clothing and equipment used as required?			
2.7	**Supervision**: a. Properly trained personnel present to supervise safe use of equipment at all times during opening hours?			
2.8	**Universal precautions**: safe procedures in place to clean contaminated surfaces and dispose of items containing bodily fluids?			
2.9	**Safety discussed**: safety, health and environmental concerns discussed in regular staff meetings?			
2.10	**Reporting procedures**: A. Staff know how to report any unsafe/unhealthy conditions or accidents? B. Any incidents reported this term, and if so, were concerns attended to?			
2.11	**Emergency contacts**: info present and visible?			
3	**First aid:**			
3.1	First aid box: a. Present? B. Staff told where it is? C. Contents up to date?			
3.2	First aiders: *visible* contact details of health care centre + closest ru first aiders* readily available?			
4	**Fire safety:**			

4.1	**Fire drills**: please provide details of recent fire drill - include a. Date and time of day; b. Evacuated in __min __sec; c. Number of persons present / total); d. Comments and corrective action.			
4.2	**Emergency evacuation plan**: a. Is a detailed plan of action for emergency evacuation in place? “emergency evacuation plan of action generic b. Is the plan well displayed? C. System in place to monitor presence and identity of all individuals who enter and exit facility?			
4.3	**Prohibition of smoking on site and prohibit deliberate burning**			
4.4	**Maintenance of adequate water supply**			
4.5	**Fire safety guidelines and talks**: a. Fire safety info on display? B. When was a fire safety talk/demo held for all occupants?			
4.6	**Maintenance of Firefighting equipment**: a. Extinguishers and/or fire hoses in place and accessible - also to people with disabilities? B. Signage present to indicates their position? C. Seals unbroken? D. Last service date?			
4.7	**Emergency exits** a. Clearly marked (signage)? B. Kept clear of obstructions at all times? C. Can be opened in a single movement, not deadlocked?			
4.8	**Exit routes**: a. Clearly marked and kept clear at all times? B. Emergency lights present and in working order?			
4.9	**Fire alarm**: a. What device/method is used to warn occupants to evacuate (automatic alarm/break glass/ whistle/hand bell/other)? B. If automatic: when was last signal test arranged with cpu? C. *Visible* instructions on how to activate alarm or warn others in an emergency?			
4.10	**Potential fire hazards**: have you given careful thought to things that might be a fire hazard (e.g. Faulty electrics, piles of boxes/papers, flammable oil, heater left on under desk, etc)? Take action to sort it out!			
5	**Environmental responsibility:**			

5.1	**Environmental sustainability policy**: a. Staff made aware of policy? B. In your work area are there visible efforts to save water and electricity, reduce waste, etc? C. Water restrictions implemented when called for?			
5.2	**Safety education and Training**: (A) Are staff made aware of the location and content of the safety manual. (B) protective measures employees should take to avoid exposure or injury. (C) physical, chemical, biological, laser and radiation hazards in the work area, including the signs and symptoms of exposure and allowable exposure limits. (D) procedures for responding to emergencies such as fire, chemical spills, and severe weather) as outlined in the emergency action plan. (E) proper recordkeeping. (F) proper waste management and disposal procedures. (G) procedures for obtaining medical care in the event of exposure/ injury. (H) Methods to detect the presence of contamination or the release of chemical, biological and radioactive materials.			

Appendix F: Ethics Clearance Certificate

RESEARCH AND INNOVATION
OFFICE OF THE DIRECTOR

NAME OF RESEARCHER/INVESTIGATOR:
Ms M Netshaulu

Student No:
14014230

PROJECT TITLE: **Development of a GIS database for solid waste management in Thohoyandou and its environs, Limpopo Province.**

PROJECT NO: **SES/19/GGIS/08/3105**

SUPERVISORS/ CO-RESEARCHERS/ CO-INVESTIGATORS

NAME	INSTITUTION & DEPARTMENT	ROLE
Dr NS Nethengwe	University of Venda	Supervisor
Dr NV Mudau	University of Venda	Co - Supervisor
Ms M Netshaulu	University of Venda	Investigator – Student

ISSUED BY:
UNIVERSITY OF VENDA, RESEARCH ETHICS COMMITTEE

Date Considered: May 2019
Decision by Ethical Clearance Committee Granted
Signature of Chairperson of the Committee: .....
Name of the Chairperson of the Committee: Senior Prof. G.E. Ekosse

UNIVERSITY OF VENDA
DIRECTOR
RESEARCH AND INNOVATION
2019 -06- 04
Private Bag X5050
Thohoyandou 0950

University of Venda
PRIVATE BAG X5050, THOHOYANDOU, 0950λ LIMPOPO PROVINCEλ SOUTH AFRICA
TELEPHONE (015) 962 8504/8313 **FAX** (015) 962 9060
"A quality driven financially sustainable, rural-based Comprehensive University"

Appendix G: Permission letter for Thulamela Local Municipality to collect data from the Thohoyandou Landfill

THULAMELA MUNICIPALITY
RECEIVED
2019 -07- 15
REGISTRY
PRIVATE BAG X5066 THOHOANDOU 0950
LIMPOPO PROVINCE

SCHOOL OF ENVIRONMENTAL SCIENCES

Department of Geography & Geo-Information Sciences

08 July 2019

TO WHOM IT MAY CONCERN

This is to certify that Ms. Netshaulu Murendeni, student number, 14014230 is a registered student doing Master of Environmental Sciences in the School of Environmental Sciences. Her research dissertation is entitled, *"The development of a GIS database for solid waste management in Thohoyandou and its environs".*

The student's proposal is approved and registered by the University Higher Degree and ethical clearance provided by the University Clearance Committee. Hence, the student can conduct field work. The student, therefore, requests permission to collect data in your area/organisation which are aligned to the research objectives. Such data will include *interalia:* sources/generators of solid waste; nature/type of solid waste and waste treatment compliance. The student will then use GIS to perform locational suitability analysis and develop a GIS database for solid waste management in the study area. In my capacity as the supervisor, I humbly request that you accord Ms. Netshaulu the support that she needs during this stage of her research. Furthermore, I would also like to confirm that data collected will be used for academic purposes to inform the development of a sustainable strategy for managing solid waste in the area.

Kind Regards,

Dr. N.S. Nethengwe
HOD: Department of Geography & Geo-Information Sciences
Deputy Dean: School of Environmental Sciences

University of Venda
Geography and Geo-information Sciences
11 -07- 2019
Private Bag X5050
Thohoyandou 0950

University of Venda

PRIVATE BAG X5050 THOHOYANDOU 0950 SOUTH AFRICA
TEL: +27 15 962 8593; Fax: +27 15 962 8597/4749 E-mail: nthaduleni.nethengwe2@univen.ac.za

Appendix H: Permission letter from Thulamela Local Municipality

Private Bag X5066
Thohoyandou
0950
Limpopo Province
Tel: 015 962 7500
Fax: 015 962 4020

THULAMELA MUNICIPALITY

Ref : 14/9/1
Enq : Ravele V
Tel : 0824191775
E-mail: ravelev@thulamela.gov.za
Date: 10 Sep 2019

TO: NETSHAULU MURENDENI

RE: REQUEST FOR INFORMATION FOR THE PURPOSE OF CONDUCTING A RESEARCH ON: THE DEVELOPMENT OF A GIS DATABASE FOR SOLID WASTE MANAGEMENT AND ITS ENVIRONS.

1. The above matter refers.
2. You are hereby granted permission to come and conduct research within Thulamela Local Municipality provided you abide by the Municipal rules and regulations (Municipal By-Laws). You are also requested to furnish us with a copy of the desiccation after finalizing the research.
3. Hoping that you will find the above matters in order.

Municipal Manger 2019.10.10 **Date**