ASSESSING GEOGRAPHICAL INFORMATION SYSTEM INTEGRATION IN SOLID WASTE MANAGEMENT IN LILONGWE CITY

MSc THESIS (GEOGRAPHICAL INFORMATION SYSTEM)

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Assessing Geographical Information System Integration in Solid Waste Management in Lilongwe City

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A THESIS SUBMITTED TO THE FACULTY OF ENVIRONMENTAL SCIENCES, DEPARTMENT OF THE BUILT ENVIRONMENT IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE (MSc) IN GEOGRAPHICAL INFORMATION SYSTEM AT MZUZU UNIVERSITY

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DECLARATION

I hereby declare that this thesis titled, "**Assessing Geographical Information System Integration in Solid Waste Management in Lilongwe City** " has been written by me and is a record of my research work. All citations, references, and borrowed ideas have been duly acknowledged. It is being submitted in fulfillment of the requirements for the award of the degree of Master of Science in Geographical Information System of Mzuzu University. None of the present work has been submitted previously for any degree or examination in any other university.

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Students name Date

CERTIFICATE OF APPROVAL

We, the undersigned, certify that this thesis is a result of the author's work and that to the best of my knowledge, it has not been submitted for any other academic qualification within the Mzuzu University or elsewhere. The thesis is acceptable in form and content, and satisfactory knowledge of the field covered herein was demonstrated by the candidate through an oral examination held on 1st December, 2023.

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ABSTRACT

Solid Waste Management involves several stages that include, generation, solid waste collection, segregation, and transferring and dumping. Rapid urbanisation has caused the volume of solid waste produced by cities to increase. In Malawi, city councils are responsible for solid waste management. The process of solid waste management is location-based and requires spatial information to be integrated through a Geographical Information System (GIS). Lilongwe City Council does not integrate solid waste management into its process. Using a conceptual framework adapted from Tembo (2003), this study assessed the integration of the Geographical Information System in the Solid Waste Management (SWM) process in Lilongwe City. Interviews were done with key informants working in the waste management section of the Lilongwe City Council. The study employed a mixed methods approach; 398 interviews were conducted with Lilongwe residents in Area 23, Area 1, Area 19, Area 29, and Area 43 based on their land uses and volume of waste generation. Usage of quantitative data analysis for the Lilongwe City Council was performed in trying to understand the comparison of wastes generated in the five areas of the city. For comparison between continuous and categorical variables, t-tests were used if the variable in comparison has two groups only while ANOVA tests were used if the variable in comparison has more than two groups. A chi-square test was used for a comparison between categorical variables spatial analysis models in QGIS were used to analyse data and generate maps. Results show that there is a spatial information gap in solid waste management processes used by Lilongwe City Council. The study recommends that the Lilongwe City solid waste management process should integrate the Geographical Information System to improve its efficiency on both waste management and solid waste spatial data.

DEDICATION

I dedicate this research work to my dear wife Falles Kamwiyo for the support and encouragement she gave me throughout my course, my late father Mr. George Timothy Kamwiyo, and my late mother Mrs. Violet Kamwiyo. They should have been here to witness this success that they implanted in their son so many years ago.

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ACRONYMS

ADL	Airport Development Limited
DHSS	Department of Health and Social Services
DPD	Department of Planning and Development
GHG	Green House Gas
GPS	Global Positioning System
GIS	Geographical Information System
JICA	Japanese International Cooperation Agency
MHC	Malawi Housing Cooperation
MoLHUD	Ministry of Lands Housing and Urban Development
PPP	Private Partnership Program
QGIS	Quantum Geographical Information System
LLC	Lilongwe City Council
NSO	National Statistical Office
SW	Solid Waste
SWD	Storm Water Drain
SWM	Solid Waste Management
SWMP	Solid Waste Management Process
SWTS	Solid Waste Transfer Station

UN HABITAT	United Nations Habitat
UN	United Nations
WB	World Bank

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CHAPTER 1: INTRODUCTION

1.1. STUDY BACKGROUND

A global review of Solid Waste Management (SWM) indicates that managing solid waste (SW) is one of the costliest urban services, typically absorbing up to 20 to 40 per cent of municipal revenues in low-income countries (Hoornweg 2012). Currently, cities worldwide generate about 1.3 billion tonnes of SW per year. This volume is expected to increase to 2.2 billion tonnes by 2025 (Hoornweg 2012). Globally, Geographic Information System (GIS) has been widely used by cities in developed cities. The application of GIS in waste management can be evidenced in countries such as India, China, Malaysia, and Greece (Mani & Singh, 2015). In the African region, Kenya (Mombasa), Ghana (Accra City), and Tanzania (Dar es Salaam) are some of the countries using GIS in their waste management systems (Kyessi & Mwakalinga 2009).

In Malawi, SW is a major challenge faced by cities and towns due to rapid urbanisation. City and Town councils take the responsibility of managing the solid wastes that are generated from the urban population (JICA 2010).

Lilongwe City is managing over 273,750 tonnes of SW from plastic papers, kitchen waste, garden waste, electronic waste, and industrial waste among others. The waste is generated from both the formal and informal areas (LUP 2010).

The Lilongwe City Council (LCC) is responsible for SWM and is mandated by the Local Government Act of 1998 to manage all the solid waste generated in the city. The management of SW involves the collection, transportation, reprocessing, reuse, and dumping. LCC has a dedicated department that looks into all issues of waste in the city (UN-HABITAT 2011). The Council follows the standard SWM process that is backed by its city by-laws. The SWM department implements its activities in line with SDG number 11 which promotes safer, resilient, sustainable, and inclusive cities and human settlements.

According to JICA (2010), Lilongwe City produces about 0.75kg of SW per day per person. This converts to 273,750 tonnes per year. However, only 9 per cent of the generated SW is serviced by LCC. It is clear from this that solid waste management is inadequate, due to inadequate resources and equipment in the City Council (UN-HABITAT 2011).

The current SWM process involves several stages which include; solid waste generation, collection, transportation, segregation, reuse, reprocessing, and dumping.

The SWM process used by LCC responds to questions of where SW is generated and dumped, when it is collected, how it is collected and transferred to the dump site, what type of SW is generated according to areas, and who collects the waste. All questions show that SWs have both spatial and non-spatial elements (Achi 2012). Spatial and non-spatial data is needed at each stage that Lilongwe City engages in SWM to help respond to the questions of where, what, how, who, and when SW is managed.

The application of GIS in the process of SWM improves decision-making concerning where, when, and what SWs are generated in a specific area and maps the routes that are to be taken when transporting this waste (Lee 2015). Literature shows that spatial information is used along with non-spatial data. This data describes the type of SW, generating source, volume, and how the waste is transported from the point of generation to the disposal site, while spatial information is data that responds to where the waste is generated and dumped (Lee, 2015).

Literature has shown that spatial information is an important aspect that can help cities achieve effective SWM (Pichtel 2005). Therefore, this study analysed the whole process for SWM in

Lilongwe City to assess the spatial information gap that exists at each stage to integrate GIS into the process.geo

1.2. Problem Statement

Spatial information on municipal solid waste collection/dump sites is essential for SWM decision-making and the decisions include siting and collection route planning, and dumps cleanup (Abulai, et al. 2015). Integration of GIS and GPS presents a platform to capture, map, and analyse spatial municipal solid waste management issues.

Manda, (2009) did a study on Water and Sanitation in the cities of Lilongwe and Blantyre where he found that urban communities are not well served by city authorities as collection of solid waste is erratic or the service is not provided and the collection of SW for disposal is affected by administrative factors such as inadequate number of vehicles. Mkwambisi (2007) carried out a study on Urban Agriculture and found that solid waste in cities is a potential source of manure for Urban Agriculture Use. No study has been conducted on Geographical Information Systems concerning Solid Waste Management at Lilongwe City Council. The lack of GIS integration in SWM at Lilongwe City Council affects its services

1.3. Study Objectives

Table 1 presents the main objective and specific objectives of the study.

Table 1: Study Objectives and Research Questions

Main Objective: The main objective of the study was to assess GIS Integration in Solid Waste Management in Lilongwe City	
Specific Objectives **The specific objectives of the study were:**	**Research Questions**
1. To analyse the process of SWM at LCC.	1.1.What is the process of SWM at LCC?
2. To assess spatial information needs for the SWM process at LCC.	2.1 What are the spatial information needs existing in SWM at LCC?
3. To analyse sources of spatial information for solid waste management at LCC.	3.1. Does the available information meet the required spatial information needs for SWM at LCC?
4. To assess the Solid Waste Management challenges at LCC	4.1. What challenges affect Solid Waste Management at LCC?

1.5. Ethical consideration

To conduct this study, a letter of authorisation and ethical approval was obtained from the Research Council of Mzuzu University. Another letter of authorisation to conduct the research was also obtained from the LCC; this letter introduced the Researcher to all the people who were involved in the study. During data collection, the researcher treated all the respondents and their responses with privacy and confidentiality. All the data collection tools did not indicate the names of respondents.

1.4. Justification of the study

The study responds to the National Sanitation Policy (2008), which focuses on improved sanitation, hygiene promotion, and sustainable management of liquid and solid wastes to protect the environment. The study is aligned with the National Urban Policy, 2019 that promotes access to adequate waste management services by the urban population. The study responds to indicator 11.6.1 of SDG 11 which promotes the reduction of solid wastes by 2030.

Spatial information for solid waste is needed by Lilongwe City Council to enable it to improve the SWM process. This study will help LCC to consider the integration of GIS in the SWM process. The integration of GIS in the SWM process will generate SW spatial data that will help LCC to make effective location-based decisions in delivering SWM services and make sure that both areas settled by low and high-income people are treated equally.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter reviews literature on the integration of GIS in solid waste management and other related topics. This chapter has put most of its emphasis on how solid waste is managed at the local level and how data regarding SWM is handled from point of generation to point of disposal. The review of the literature aims to identify the spatial data gaps in solid waste management processes and check the theories that have been applied to integrate GIS in SWM.

2.2. Process of solid waste management

Municipal solid waste is an issue of shared concern across the globe. Many global and regional countries are mandated by the central or local Government to have a Solid Waste Management Plan (SWMP) outlining the region's unified effort to reduce the amount of municipal solid waste requiring disposal (Valley 2013). There are so many spatial information gaps in many solid waste management plans that governments have to close to improve solid waste management (Valley 2013).

Valley (2013) indicated that the SWMP does not cover all forms of waste management, nor is that the intent. The management of other forms of waste including, but not limited to, hazardous, agricultural, biomedical, and liquid waste, lies outside the purview of the plan in accordance with the Environmental Management Act. The plan acknowledges the importance of comprehensive planning for all waste categories and actively supports responsible waste management initiatives that benefit the regions (Valley 2013)

No theories have shown that GIS can help in SWM although considerable efforts are being made by many governments and other entities in tackling waste-related problems (Malakahmad 2013). Hayashi (2016)in his paper, indicated that studies have shown there are still major gaps to be filled in the area of SWM, especially the SW data handling. The World Bank report by Hoornweg (2012) estimates that in low-income countries, it is common for municipalities to spend 20-50 per cent of their available budget on solid waste management (open dumping with open burning is the norm), even though 30-60 per cent of all the urban solid wastes remain uncollected and less than 50 per cent of the population is served. According to a report by United Nations Environment Programme (2009), in low-income countries, collection alone drains up to 80-90 per cent of the municipal solid waste management budget. In mid-income countries, collection costs 50-80 per cent of the total budget. In high-income countries, collection only accounts for less than 10 per cent of the budget, which allows large funds to be allocated to waste treatment facilities. Upfront community participation in these advanced countries reduces the collection cost and facilitates waste recycling and recovery (UNEP, 2009)

2.2.1. Solid Waste Management Policies

UNEP (2009) indicated that it is recommended that countries should have SWM plans and strategies. When the national strategy is put in place, it has strong implications for waste management, since the government issues several policies and economic instruments to encourage recycling and recovery and this can be adopted and implemented at the local level (UNEP 2009).

Local social and economic development plan:

Solid wastes, especially Municipal Solid Waste and some waste streams such as e-waste and vehicle wastes have a close correlation with economic growth and living standards. Accelerated urbanisation and urban sprawl, have been continuously pressurizing municipal services including waste management (Mani & Singh 2015).

Local industrial development plan:

The industrial growth rate and the sectorial structure planned for the future have major impacts on the future generation and composition of industrial as well as hazardous wastes (UNEP 2009). The industrial development plan can also influence the potential and feasibility for industrial symbiosis, a more efficient way of utilizing resources and reducing wastes and other pollution (UNEP 2009)

In most of the low-income nations, due to the increase in population, solid waste management has become an issue (Hayashi 2016). The urban administration, municipals, and town corporations are facing huge challenges in managing municipal solid waste management hygienically (Hayashi 2016). To address that, various environmental audits are carried out by the government to solve these problems in solid waste management (UNEP 2009).

Ilangovan (2016) proposed linking the problem with information and communication technology by a system that assists the solid waste management and monitors the dump bins using GIS, and by monitoring the vehicles that collect the waste from the dump bins by using GPS. The aim of Ilangovan (2016) paper was to create an application (app) for the e-Governance for municipal solid waste management and make India one of the model nations in the world for converting waste into wealth by using an App on Android Mobile (Ilangovan 2016).

A major constraint in comparing solid waste management systems in different cities is that there are few consistent solid waste and recycling benchmarks anywhere in the world, not even the most common indicator; cost per tonne, is available for most cities. The most basic kinds of information are collected in very different ways in each city if indeed they are collected and recorded at all (Wilson et al. 2010). The 20 real cities presented in the book were chosen from six continents. They provide up-to-date and comparable data that is used to inform issues of waste policy: good and bad practices, management, governance, financing, etc. (Wilson et al., 2010). The focus is on processes and interactions among stakeholders as much as it is on technologies deployed (Wilson et al. 2010).

2.2.2. Spatial Data for Lilongwe SWM and Planning

The term 'spatial information' has been defined by different authors. Huisman and de By (2009) define spatial data as data that contains positional values, such as (x,y) coordinates. Folger, (2011) defines spatial information as geographically referenced information and some of the types of geospatial information include features like highway intersections, office buildings, rivers, the path of a tornado, solid waste areas, and congressional district boundaries among others. Folger (2009) describes spatial information as data referenced to a place, a set of geographic coordinates that can often be gathered, manipulated, and displayed in real-time on a map.

In Malawi, topics related to waste or waste management are embedded in three environmental documents. These documents include; the 1994 National Environmental Action Plan (NEAP), The Environmental Management Act (EMA) of 1996, and The National Environmental Policy

(NEP) approved in 1996 and amended in 2004. The NEAP (1994), focuses mainly on solid waste which is divided into three categories: **Inert** "Harmless (builder rubble, soil and spoil"), **general** "threat to human health and the environment when incorrectly managed (commercial wastes, domestic waste and garden refuse and industrial waste) and **hazardous** "corrosive, explosive, toxic, mutagen, carcinogen and eco-toxic, which pollute water and diminish public health safety when improperly managed".

According to a study by Mkwambisi (2010) a participatory municipal solid waste management was introduced in Malawi and used the approach called Nutrient-Budget Analysis. The approach assessed the potential of local sources of municipal solid waste to act as a source of the nutrients required by urban agriculture. The results showed that the integration of waste management and urban agriculture further yields positive results at the household level where solid wastes were used as nutrients for urban agriculture hence curbing the issue of city solid waste management (Mkwambisi 2010).

According to a study by Manda (2009), urban poor communities are not well served by city authorities as collection of solid waste is erratic, or the service is not provided. Where it is provided, it is by simply leaving a skip in the communal area for households to deposit their waste. City authorities may or may not come to collect the skip for disposal at landfill sites (Manda, 2009). The collection of skips for disposal is affected by administrative factors such as an inadequate number of vehicles. In Blantyre, there are only 15 lorries for this service. Inaccessibility to vehicles due to the congestion of houses poses another problem. The study found that many households (42.3%), in the study areas dispose of waste in waste pits dug within their plots, while 11.9% throw waste on the road-side, 9.1% throw waste on the river-side riverside and 9.1% use community/city skip sites. These results are not significantly different from those of the Integrated Household Survey of 2005 which found that 49% of the households in Malawi used rubbish/waste pits, while in urban areas 45% of the households used rubbish pits (Manda 2009)

The integrated household survey found that in urban areas, 25% of the population dump waste on public open spaces (NSO 2005a: 95). The low-level utilisation of city skips sites reflects the small number of skips placed and positioned very far apart in markets and residential areas and most of the times benefit the high-income people who reside in low and medium densities (NSO 2005a: 95). The garbage in these skips overflows because the skips remain uncollected for long periods due to vehicle shortage or neglect. Local residents may burn the waste in the skip to avoid overflows being blown to nearby homes (Manda 2009). During focus group discussions, it emerged that the collection of waste in the study areas is restricted to markets, where, as confirmed by huge pile-ups of waste, it is also erratic (Manda 2009).

The other causes of pollution in urban areas include the disposal of general and industrial waste into the rivers, sand mining, and farming along catchment areas as well as defecation along the river banks. The most affected are the poor people who use the stream waters for domestic uses in the cities and downstream while the lesser affected are urban dwellers who buy vegetables and other products grown and/or washed by this polluted water (Kumwenda et al. 2013). With such existing problems, it is expected that without overhauling the system and putting in place integrated pollution measures, there will be continued pollution of water resources. The current situation in Malawi is that almost all district and city councils do not have proper refuse disposal systems in place (Kumwenda et al. 2013).

Lilongwe City Council (LCC) is responsible for waste management in the City (Lilongwe City Council, 2013). The waste is collected by the LCC under the cleansing section and they are dumped at Area 38 dumpsite (Assa 2013). According to Assa (2013), solid waste generation in Lilongwe City has exceeded the current infrastructural capacity of the City Council and the effect has been the steady degeneration in the quality of solid waste management. Waste management services are readily available in high-income areas but low-income areas do not have access to these services. Commercial areas such as markets have their waste collected, albeit irregularly. The landfill in Lilongwe's Area 38/2 is estimated to receive about 20,754 tonnes of solid waste per month (UN-HABITAT 2011).

The Ministry of Natural Resources, Energy and Mining and Lilongwe City Council, with support from the Flemish International Cooperation Agency and through the United Nations Development Programme, commissioned two Waste Transfer Stations in a bid to help reduce solid waste disposed at dump sites in the City. The commissioned Waste Transfer Stations have been constructed under the Malawi Government's National Climate Change Programme as part of its Climate Change Adaptation and Mitigation Initiatives. It is envisaged that the two stations constructed in Areas 24 and 25 will help reduce the amount of solid waste disposed of at the dump sites and create opportunities through recycling and composting (UNDP 2018).

A study conducted by Assa (2013) proposed a solution to the problem of inadequate budget for improved solid waste management. Assa's (2013) study explored the possibility of cost-sharing by households in solid waste management which could provide a sustainable avenue for financing solid waste management in Lilongwe urban. The study employed a contingent valuation method which means to determine efficient prices for the management of municipal solid waste (Assa 2013). The study found that there are factors that significantly affect willingness to pay for household solid waste disposal including household income level, concern about waste management, education, and satisfaction with waste collection (Assa 2013).

The role of Lilongwe City Council is strictly restrained to the collecting of SW and transporting it to a safe and secure dump site (Barre 2014). People burn their waste to avoid waste accumulation and nauseous odours (Barre 2014). As for waste processing by the Lilongwe City Council, plastic bags and other inorganic refuse are mixed with organic waste such as food waste and leaves and there is a minimal attempt to separate these either at source or at intermediary disposal sites (UN-HABITAT 2011).

The method of collecting waste by the city council refuse freighters is door-to-door. With a limited number of refuse freighters, this service is only available to a few. According to the 2013 Lilongwe Urban Structure Plan, the Lilongwe City Council periodically collects waste through communal waste bins located in the high-density permanent housing areas. The majority of city residents living in low-income areas and informal settlements are rarely or not serviced at all by the city council due to the limited capacity of the city council, poor road infrastructure, and the unplanned nature of these areas (UN-HABITAT 2011).

2.2.3. Sources of Spatial Information for SWM at City Level

Upasna (2003) defined GIS as a system designed to allow users to collect, manage, analyse, and retrieve large volumes of spatially referenced data and associated attribute data collected from various sources. GIS assists in the recording of spatial data and the direct use of the data for analysis and cartographic representation (Chalkias & Lasaridi 2011).

Almost all factors related to SWM have both spatial and non-spatial components, thus, traditional ways of storing and analysing data keep data in an isolated form, which results in an inefficient management system (Ammar 2007).

Several studies reveal that GIS has been widely used in solid waste management. For example, appropriate landfill site selection (Ramuu & Kennedy 1994; Kao & Lin 1996; Haastrup et al. 1998; Leao et al. 2001; Ramasamy et al. 2002; Al-Jarrah & Abu-Qdais 2006), the location of recycling drop-off stations (Chang et al., 2000), the precise estimation of solid waste generation using the local population density and income group distribution (Vijay et al. 2005).

The Loudoun County Department of Natural Resources used GIS to find potential sites for new landfills (Mitchell, 1998 in Ammar 2007). Layers such as slope, soils, bedrock depth to groundwater ratios, historical areas, streets, and jurisdictions were combined to design the model (Mitchell 2007).

In 2016, Kibetu and Muchiri used GIS to select ideal sites for the Municipal Wastes Transfer Station. This study came from the understanding that in Kenya, many local authorities face uphill challenges in dealing with waste, especially volume reduction and proper disposal (Kibetu and Muchiri 2016). There is minimal solid waste segregation and recycling further compounding the problem of open dumping. The main objective of the study was to identify suitable areas to consider for the construction of a multi-purpose waste transfer and recovery facility within Embu municipality. The study by Kibetu and Muchiri, (2016) used a mixed approach design encompassing ground survey, interviews, questionnaires, data modeling and Analysis. Geographic Information System (GIS) was used to evaluate Population, land use and proximity to waste receptacles as impact factors influencing waste management in Embu Municipality (Kibetu & Muchiri 2016).

In 2013, Shoba and Rashappari conducted a study using the application of GIS to find out the waste generation rates in various wards of Coimbatore city in India (Shoba & Rashappari 2013). Solid waste generation data and population data were collected from each ward (the total number of wards is 72) and linked to the Coimbatore urban map through GIS (Shoba and Rashappari 2013). Analysis through maps was performed to identify the areas with increased solid waste generation in comparison with the local population. In the end, thematic maps showing population densities and waste generation rates of all 72 wards were produced (Shoba and Rashappari 2013). The study by Shoba and Rashappari (2013) concludes by recommending the use of GIS in solid waste management and improving the spatial data system of solid waste for proper monitoring and management.

Abdulai et al. (2015) conducted a study that applied GIS and GPS technologies to map the Municipal Solid Waste Collection System in Wa Town, Ghana. Wa Municipality waste collection system efficiency was analysed based on the spatial availability of communal containers. A GIS model was developed and used to analyse the proximity of the Municipal Solid Waste Collection System to boreholes' drinking water sources. A pollution risk map was also created to analyse the potential impact of indiscriminate dumps on hand-dug wells and surface water. The results revealed poor management in a significant number (about 67%) of Municipal Solid Waste Collection System sites. The study concluded by recommending the use of a similar approach in other developing nations with similar Municipal Solid Waste Management problems to enhance policy and management decision-making

Finding an environmentally sound landfill site is a challenging task (Sumathi, et al. 2007). With the rising population and the associated unsustainable practices, there has been an enormous increase in the quantum as well as the diversity of the solid waste being generated (Sumathi, et al. 2007). The problem of solid waste has assumed a significant dimension

especially in urban centres. Domestic, industrial and other wastes, whether these are of low or medium level, have become a perennial problem as they continue to cause environmental pollution and degradation, (Sumathi, et al. 2007).
Despite the increasing stress towards the waste reduction at the source, as well as recovery and recycling of solid waste, disposal of solid waste by landfilling remains the most commonly employed method (Palnitkar 2002). Landfill incorporates an engineered method of disposal of solid waste on land in a manner that minimises environmental hazards by spreading the solid waste in thin layers, compacting onto the solid waste to the smallest practical volume and applying a cover at the end of the operating day” (Muttiah Engel, & Jones, 2009).

However, with the increased population density and urban infrastructure in cities and urban areas, several key considerations are required to be taken into account to ensure its overall sustainability, especially those associated with its economics, optimised siting and operation, (Mujibor, Sultana, & Ahasa 2008). The development of a municipal solid waste landfill requires the acquisition of land and suitable siting in a pre-existing urban matrix comprised of diverse competing land uses, (Kamboj & Pandey 2017). Siting decisions are governed by the pre-existing land use dynamics of the urban area as well as the nature of potential interactions of the landfill with the pre-existing environmental, geologic, hydrological, and socio-economic parameters of the area. In the domain of the science of solid waste management, the identification of landfill sites for solid waste disposal remains a critical management issue wherein the selection should be based on several considerations (Sumathi, et al. 2007).

Siting a sanitary landfill requires an extensive evaluation process in order to identify the best available disposal location (Siddiqui, et al. 1996). The location of solid waste landfill must comply with the requirements of governmental regulations and at the same time must minimise economic, environmental, health and social costs (Valentina, 2013). The site selection procedure, however, should make maximum use of the available information and ensure that the outcome of the process is acceptable to most stakeholders and landfill siting generally requires the processing of a variety of spatial data (Valentina 2013).

The present study focuses on an optimised land use site selection based on multi-criteria decision analysis and geographic information system-based (GIS) overlay analysis. According to Ammar (2007), GIS provides a digital way of storing, retrieving, manipulating, analysing, and displaying geographically referenced data and has the potential to include ecological, biological, demographic, or economic information. GIS has become a valuable tool in the environmental and engineering sciences.

Amnar (2007) suggested that siting decisions including the pre-existing land use, location of sensitive sites, infiltration, water bodies, water supply sources, groundwater quality, air quality, fault line and geology are some of the elements that have to be checked when determining solid waste dumping sites. A study conducted in India by Siddiqui et al. (1996) found that GIS-based thematic maps of water sources, vegetative cover, land uses and built-up areas are used as criteria for selecting suitable sites for solid waste disposal. Subsequently, weightings are assigned to each criterion depending upon their relative importance, and ratings following the relative magnitude of impact (Siddiqui et al. 1996).

A GIS-based overlay analysis performed by Ammar (2007) was used to identify the optimum site for the landfill in India. According to Ammar (2007), the optimisation of the routing system for the collection and transport of municipal solid waste is a crucial factor of an environmentally friendly and cost-effective solid waste management system. The development of optimal routing scenarios is a very complex task, based on various selection criteria, most of which are spatial in nature, (Sumathi et al. 2007). The problem of vehicle routing is a common one, each vehicle must travel in the study area and visit all the waste bins, in a way that minimises the total travel cost. Most often defined based on distance or time but also fuel consumption, carbon dioxide (CO2) emissions, etc (Apaydin & Gonulu 2006).

Karadimas and Loumos (2008) proposed a method for the estimation of municipal solid waste generation, optimal waste collection and calculation of the optimal number of waste bins and their allocation. This method uses a spatial Geo-database, integrated into a GIS environment and was tested in a part of the municipality of Athens, Greece. After the reallocation of the waste bins, their total number was reduced by more than 30%. This reduction had a direct positive impact on collection time and distance. Chalkias and Lasaridi (2009) developed a model in ArcGIS Network Analyst to improve the efficiency of waste collection and transport in the Municipality of Nikea, Athens, Greece, via the reallocation of waste collection bins and the optimisation of vehicle routing in terms of distance and time traveled. The first results demonstrated that all the examined scenarios provided savings compared to the existing empirical collection organisation, in terms of both collection time (savings of 3.0% -17.0%) and travel distance (savings of 5.5% - 12.5%).

Apaydin and Gonullu (2006) developed an integrated system with a combination of GIS and GPS technology to optimise the routing of MSW collection in Trabzon City, northeast Turkey. The comparison of the proposed optimised routes with the existing ones revealed savings of 4–59% in terms of distance and 14-65% in terms of time, with a benefit of 24% in total cost.

(Muttiah, Engel, & Jones 2009), As the success of the decision-making process depends largely on the quantity and quality of information that is made available to the decision-makers, the use of GIS modeling as a support tool has grown in recent years, due to both technology maturation and the increase of the quantity and complexity of spatial information handled (Santos et al., 2008). In this context, several authors have investigated route optimisation, regarding both waste collection in urban and rural environments and transport minimization, through improved siting of transfer stations, landfills (Despotakis & Economopoulos, 2007) and treatment installations for integrated regional waste management (Zsigraiova et al. 2009).

The evaluation of a new waste disposal site is a complicated process as it requires considerable expertise in diverse social and environmental fields, such as soil science, engineering, hydrogeology, topography, land use, sociology, and economics (Sumathi, et al. 2007). Methods of evaluating new landfill sites take into consideration parameters such as distance to roads, habitation and key infrastructure elements. Therefore, the siting of a solid waste landfill must also involve processing a significant amount of spatial data, regulations and acceptance criteria, as well as an efficient correlation between them (Mujibo Sultana, & Ahasa 2008).

A study by Nash (2009) found that another important factor in SWM is the constraint parameterization indicating the areas of constraint in the given land use configuration where a landfill cannot be developed (Nash 2009). This is based on a set of buffer zones constituted based on some key influencing factors. The buffers were set in ArcGIS based on the existing scientific knowledge of the cause-impact relationship of a specific influencing factor upon a receptor. The next step involves the development of a GIS database for the above-mentioned governing criteria. Separate thematic maps characterising each sub-criterion are developed and the attribute data are associated (Kamboj & Pandey 2017).

In the study Kamboj and Pandey (2017) found that in identifying SW landfills, the land use map constitutes the base map and buffer maps are overlaid on the base map and the regions of constraint where a landfill cannot be constructed are identified. Subsequently, each of the thematic maps characterising a governing criterion is overlaid on the base map (Kamboj & Pandey, 2017). For each pixel of the base map, the cumulative suitability index (CSI) for landfill siting is evaluated through the aggregation of the sub-index values calculated from each of the overlaid thematic maps characterising a governing criterion (Sumathi, Natesan, & Sarkar, GIS-based approach for optimised siting of municipal solid waste landfill, 2007). The multi-criteria analysis was performed using the Spatial Modeler of ArcGIS. Thereafter, the algorithm performs a GIS-based constraint mapping technique to eliminate the potentially unsuitable sites. The algorithm thus ends with a final map indicating the best suitable sites for the development of a municipal solid waste landfill, based on a set of identified key criteria (Sumathi, et al. 2007). See Figure 1 below:

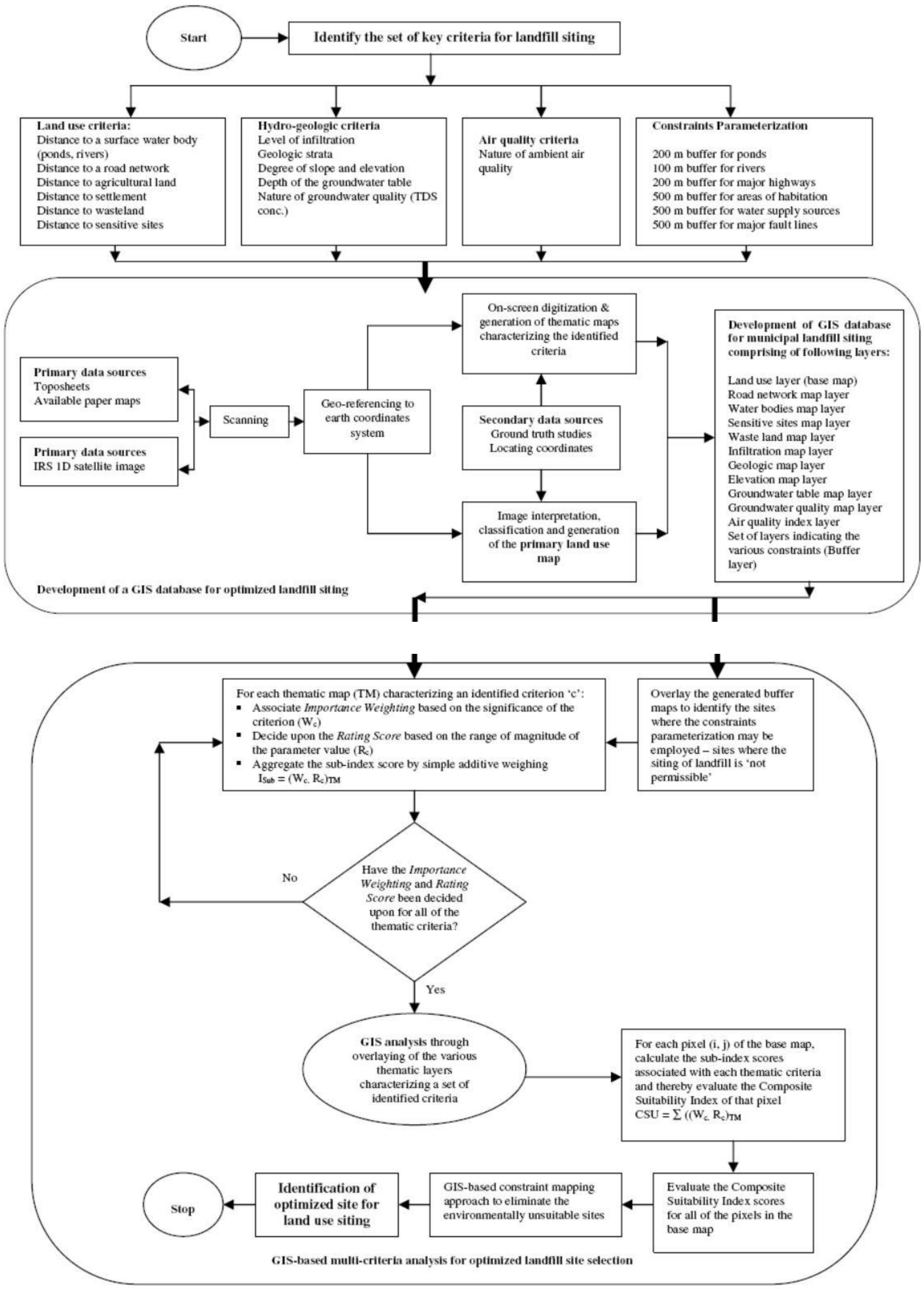


Figure 1: Example of GIS-based approach for optimised siting of municipal solid waste landfill (Sumathi, et al. 2007)

Figure 1, shows the workflow pattern of the proposed GIS model, which is designed to help reduce the waste management workload, and to solve some of the present situation problems

(Mujibor, Sultana, & Ahasa 2008). This model is divided into four components which are primary data, analysis, functions, and results.

The analysis processes include:

- **Inconvenience due to waste proximity**: this will eliminate waste bins within a buffer of 20 meters from sensitive land use. For the case of a building represented with a point feature a buffer of 10 meters will be applied in three layers, the first 10m will be considered as the building boundary, and the other two will form a buffer of 20m around it.
- **Proximity from environmentally sensitive areas:** a buffer of 15m will be applied on both sides of streams; all waste bins fall that in this buffer area will be relocated.
- **Recyclable bins for buildings:** such as cinema theaters, educational institutions, offices, and other buildings that generate recyclable waste. A multi-buffer will be applied around them to select the nearest location that could serve more than one building.
- **Recyclable bins for shops:** apply a query to identify shops that generate recyclable and mixed waste, then apply a multi-buffer around it to find the nearest place.

In recent years, GIS has emerged as a very important tool for land use suitability analysis. GIS can recognise, correlate and analyse the spatial relationship between mapped phenomena, thereby enabling policy-makers to link disparate sources of information, perform sophisticated analysis, visualise trends, and project outcomes and strategize long-term planning goals (Malczewski 2004).

With the evolution of GIS and the subsequent developments in the field of location science, considerable focus was placed on its potential application for optimised siting (Apaydin & Gonulu 2006). The earliest application of GIS in this direction included the analysis conducted in the 1970s. At about the same time, Apaydin and Gonulu (2006) generated models in Trabzon, Turkey to determine SW facility locations, capacities and expansion patterns. Several realistic solid waste management models were formulated by applying and refining various optimisation techniques.

2.2.4. Spatial Information use and SWM Challenges in Lilongwe city

Solid Waste Management (SWM) is one of the major environmental challenges in many low-income countries. Many efforts to reduce and recover the waste have been made, but still, land disposal of solid wastes is the most popular one. Malawi has 50.7% of its population living under the national poverty line and is one of the poorest countries in the world (World Bank, 2012b). Waste is a problem in urban areas. Public services struggle to collect all the waste produced which leads to inappropriate dumping and sanitary issues (Mkwambisi 2007).

In 2008, there were 13.1 million inhabitants in Malawi, among which 989,318 were living in Lilongwe, the capital located at the centre of the country. Like all fast-urbanising cities in the world, Lilongwe is challenged by the accumulation of waste due to the increase of its urban population and the limited resources of its public services. In 2010 the production of SW in Lilongwe was estimated at 4kg per capita per day, which is about six times more than the average production. However, the city is only able to collect 30% of this waste (Mkwambisi 2007).

Lilongwe City Council is struggling with its budget to offer appropriate waste management services (Mkwambisi 2007). However, alternative options like recycling, composting or any partnership with the private sector have not yet been taken into account (Mkwambisi 2007). Most governments do not consider waste management a priority. Attention and funds are more focused on food security and educational projects rather than SWM. Waste is considered an unnecessary waste of time and resources and is not seen as a potentially valuable resource (Mkwambisi 2007). Achankeng (2003) found that about 20 to 50% of Sub-Saharan cities' budgets go to waste management services while only 20 to 60% of the waste is successfully collected (Achankeng 2003).

According to Chalkias and Lasaridi (2011), detailed spatial information is required for effective management of municipal solid waste systems. This information is related to the geographical background of the area under investigation, as well as to spatial data related to the waste collection procedure.

Chalkias and Lasaridi (2011) went on to highlight some examples of spatial information that is useful in municipal solid waste management and these include Population density, Waste generation rate for mixed waste and specific waste streams; Number, type and positions of waste bins; Road network and the related traffic; Current routing system of the collection vehicles; Truck capacities and their characteristics; Geographic boarders and characteristics of the waste collection sectors. The table below shows some of the uses of spatial data in city administration:

Table 2: Uses of Spatial data

Inputs

Base Maps | Imagery | Demographics | Natural and Built Environment Data | Infrastructure/Network Data | Sensor Webs

Spatial Data Tools

Data integration | Information access | Visualisation | Spatial Analysis and Modelling | Spatial Planning

Service Delivery Using Spatial Data

Urban Design Planning codes Land zoning City-wide environmental plans Smart growth Sustainable neighbourhoods	**Utility Services** Telemetry SCADA Micro-tunnelling Asset management and inventory Disaster preparedness, response and recovery
Urban Management Development and building permits Electronic lodgement of applications Automated valuation/taxes	**Transport Planning** Trip analysis Scenarios Integrated public transport networks Real-time monitoring of movements
Environmental Justice Siting impacts Best use of land resources Placement of public facilities	**Economic Development** Find available and suitable land Workforce demographics
Community Involvement Scenario and impact analysis, option development 3D visualisation Fly-throughs	**Public Safety** Emergency response management Crime modelling Emergency dispatch and routing
Environmental Services Optimising waste collection networks Water storage, allocation and distribution Environmental monitoring	

Outcomes

Performance Monitoring, Evaluation and Reporting

Source: Chalkias and Lasaridi, (2011)

2.2.5. Spatial Data Gap Assessment

According to Tembo (2003), spatial data gaps are observed within the process of data management. Spatial data users always find data from different sources with different presentations of areas of concern which may contradict or not match exactly the user's semantic attributes of the same area and among all the wastes (solid, liquid and gas) are the most popular and most difficult to manage locally (Naibbi 2017). This is because solid waste does not flow, evaporate, diffuse, dissolve, or get absorbed into the surroundings, unlike liquid and gaseous wastes, but the spatial information about these solid wastes is captured within the management process and the management of solid waste including waste generation, on-site handling, storage and processing, collection, transport, sorting and recycling, treatment and reuse as well as disposal options (Naibbi 2017).

Abulai, et al. (2015) discovered that spatial information on municipal solid waste collection/dump sites is essential for SWM decision-making and the decisions include siting and collection route planning, and dumps cleanup. Integration of GIS and GPS presents a platform to capture, map, and analyse spatial municipal solid waste management issues. This was in the theory of the study but it was applied by introducing a GIS database that was used to capture SW data and monitor its movement from a point of source to a point of disposal. It was found that the GIS technique closed the gaps in SWM process (Abulai, et al. 2015)

The utilisation of GIS and GPS to capture and analyse spatial data is well known; it is growing in municipal solid waste management, for example, information on geographic locations of municipal solid waste collection/dump sites can help decision-making in municipal solid waste management, including collection route planning, dumps cleanup, and future siting of collection sites in order to enhance quality of water resources (Abdulai et al. 2015). If the solid waste management process does not generate spatial information on solids, there are spatial data gaps regarding solids hence, a problem to achieve effective SWM (Abdulai et al. 2015).

2.3. Study Conceptualisation

Figure 2 shows the study conceptualisation that was adopted and adapted from Tembo (2003). Tembo (2003) did a study in Tanzania where he assessed spatial information gaps by looking at a decentralised perspective on district natural resources management planning.

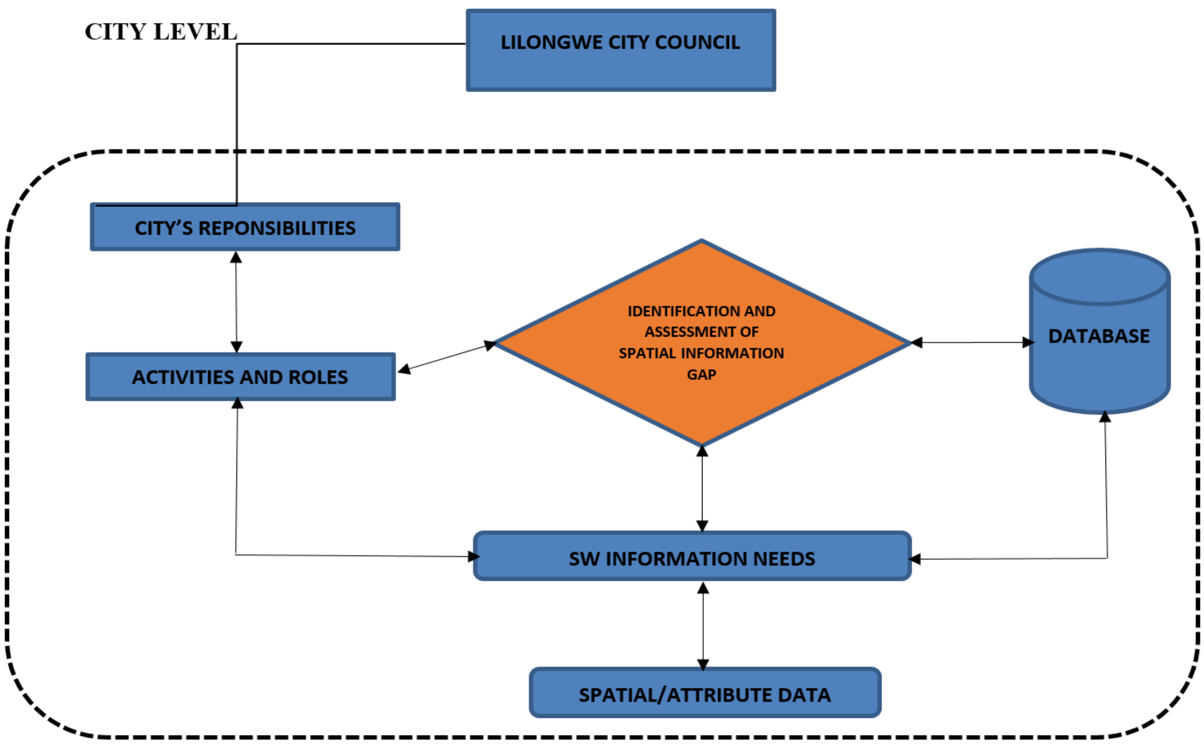


Figure 2**:** Study Concept, Source: Tembo (2003)

Some elements in the conceptual framework were adopted from Tembo (2003) who did a similar study in Tanzania where he was assessing the spatial information gaps; A decentralized perspectives on district natural resources planning management. The study by Tembo (2003) analysed the existing data sets in natural resources management which is a similar scenario as LCC when it is performing solid waste management services for the city.

The study conceptual framework helped to determine the levels at which spatial information is needed in connection with roles that are supposed to be played by each level in the SWM process.

This study assessed the SWM process to identify the spatial information gap and lay out a platform for the integration of GIS in the SWM process.

2.4. Chapter Summary

Spatial information technology supports the optimisation of municipal solid waste management as it provides an efficient context for data capture, analysis and presentation. In the first, GIS is used for the selection of waste disposal landfills, and to a smaller extent, other waste treatment facilities.

The implementation of GIS-based modeling for waste collection optimisation in many countries with different socio-economic conditions and technological backgrounds shows that significant savings could be achieved in most setups.

This chapter has reviewed literature and studies by different authors at global, regional and local levels. Globally, studies have found that the integration of GIS in SWM has been successful and improved the management of waste. Locally studies have indicated that many efforts have been made to solve the challenges of solid waste management. However, literature shows that there have been no attempts to integrate GIS in the management of solid waste. Therefore, there was a need for this study to assess the integration of GIS in solid waste management.

CHAPTER 3: MATERIALS AND METHODS

3.0. Introduction

This chapter highlights the materials and methods that were applied in the study in order to answer the specific objectives and research questions. The chapter also discusses the research design, site description, Lilongwe City land use and waste management, administrative description, sampling framework, data collection, Process of solid waste management at LCC, Identification of Spatial Information, Sources of spatial information for solid waste management, data utilisation, Data needs, Non-Spatial Data, Spatial Data, Spatial Data Gap Assessment and Solid Waste Management Challenges.

3.1. Study Area

3.1.1. Study Site Description

The study was conducted in Lilongwe City in Area 1, Area 19, Area 29 and Area 43. The areas were selected because of their land use status. According to the Lilongwe OZS, (1986), Area 1 was zoned for commercial and some residential uses, Area 19 was zoned for institutional, Area 23 was zoned for high-density traditional, Area 29 was zoned for Industrial and Area 43 was zoned for low-density residential. The following is the map for the study area:

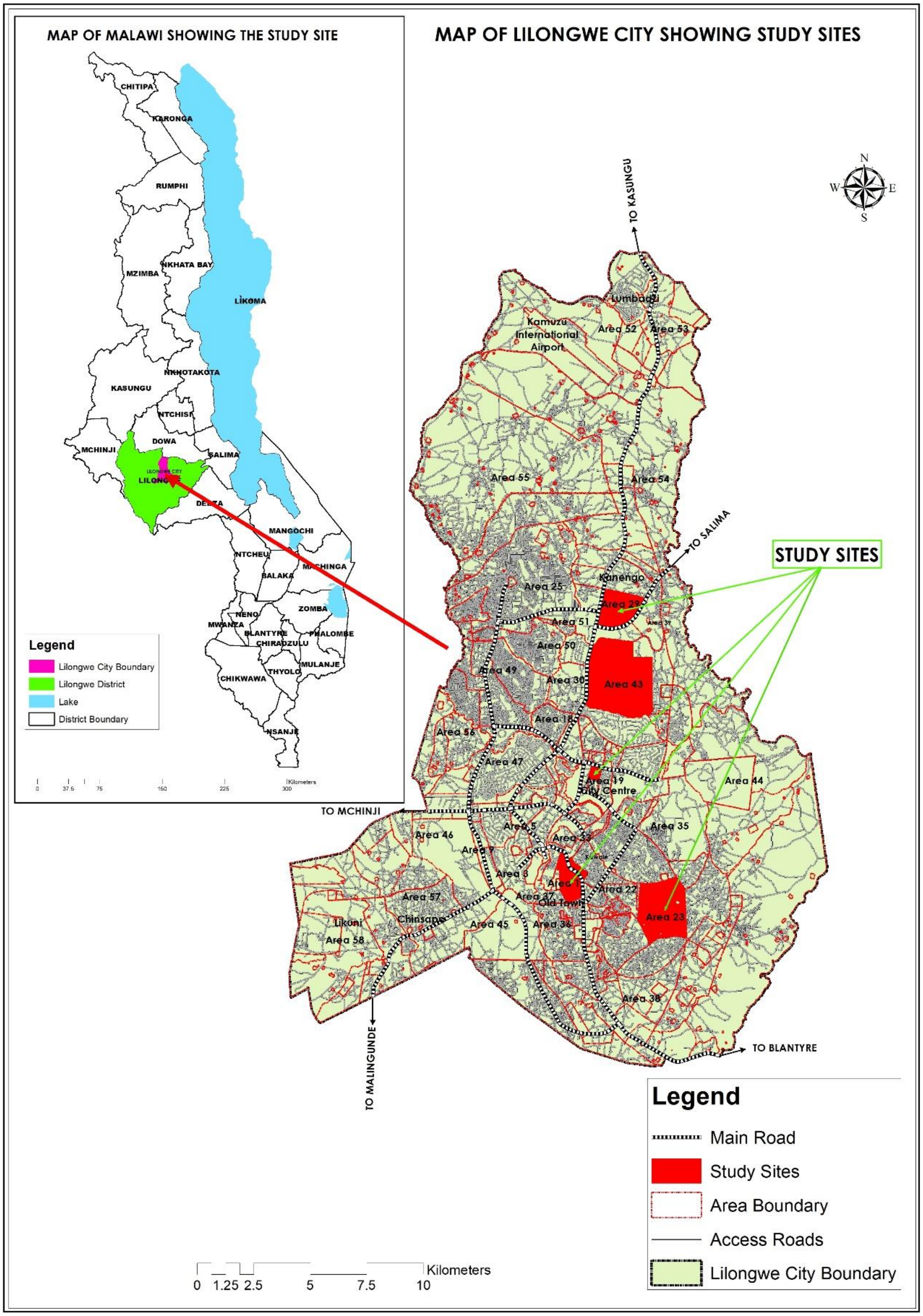


Figure 3: Map of Lilongwe City showing the study sites by Author (2019)

Lilongwe City was selected for this study because of the Capital City's status and the results will be used to draw out lessons that may be relevant to other Malawian cities. Lilongwe is advocating for keeping the City clean though the City is facing many SWM problems.

The Capital City location was shifted from Zomba to Lilongwe in 1975. Lilongwe City is zoned into 59 and each area has its zoned use. The City is managed by Lilongwe City Council in line with the 1998 Local Government Act. According to the National Statistics report of 2018, Lilongwe City has a population of about 989,318 which was projected to reach 1,324,314 by 2020 and it covers an area of about 8,007.39 square kilometers (Lilongwe City Council 2013).

3.1.3. Lilongwe City land use and waste management

The City is divided into areas and each area is zoned for its use. The major land owners in Lilongwe City are the Central Government through the Ministry of Lands, Malawi Housing Corporation (MHC), Lilongwe City Council, Airports Development Limited (ADL), and Press Properties. About 35% of the land area is designated for housing while the rest is planned for commerce, industry, government offices, institutions and agricultural uses. Lilongwe City has been mandated to develop and manage land for low-income housing including slum upgrading since 1992 (JICA, 2010). However, the City has inadequate resources for this role and has to rely on external support. Sixty per cent (60%) of the land is public while 30% is private land (freehold and leasehold) with customary land at 10%. Figure 4 shows proposed and existing land uses:

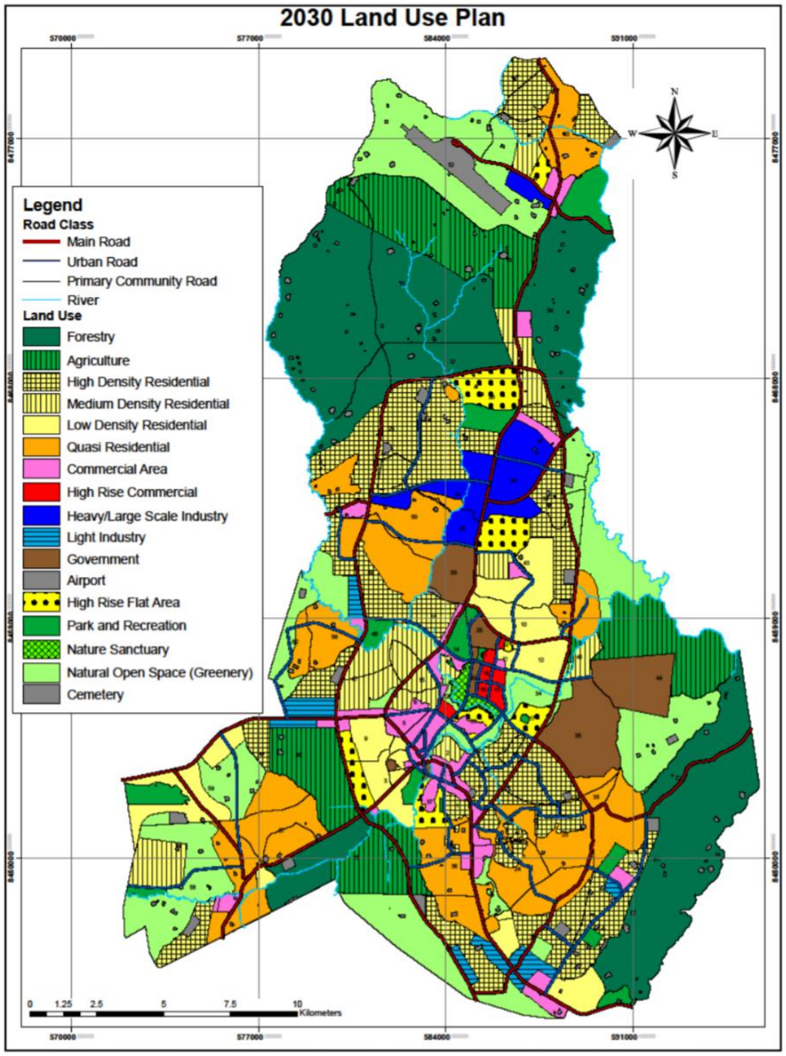


Figure 4: Lilongwe City Land Use Map (JICA, September 2010).

3.1.4. Administrative Description

The Local Government Act (1998), provides guidance on the management of Lilongwe City Council with elected councilors and a mayor elected from the councillors. The City is run through the following departments:

Table 3: Lilongwe City Council's Administrative Departments

	Department/Section	Sector
1	Administration	Local Governance & City Management
2	Finance	Financial Management
3	Internal Audit	Financial Accountability
4	Health and Social Services	Health and Social Services delivery
5	Public works	Infrastructure Provision
6	Agriculture, Environmental Affairs & Natural Resources	Public and open spaces and general environmental protection
7	Planning and Development	Urban planning, development control, housing and land administration services
8	Commerce & Industry	City marketing and managing city markets, bus stations
9	Education, Youth & Sport	Education services delivery, youth development and managing sports infrastructure

The City has an extensive infrastructure and is further benefitting significantly from its position as a national capital through additional and new infrastructure and service development.

However, infrastructure development in low-income areas suffers from inadequate funding as the city depends mostly on its own revenue generation and collection (Lilongwe City Council 2010).

3.1.5. Lilongwe City Solid Waste Management

Solid waste collection is poor, hindered by lack of adequate vehicles and poor access to informal settlements. Uncollected solid waste can be seen at markets, along streets and streams. Management of the only disposal facility at Area 38 is haphazard with threats of fire hazards (JICA 2010). Transportation of solid waste to the only dump site creates additional challenges due to cost and dropping of refuse (JICA 2010).

3.2. Research Design

The study used qualitative data and quantitative data for the description and definition of SW spatial elements. Informal interviews, observations, guided checklists, questionnaires and discussions were employed as data-gathering tools. The study focused on the existing LCC's SWM process and this was where much qualitative data was derived, for this reason, the targeted people to be interviewed were the team from the section of solid waste management and all institutions involved in solid waste management. The study also assessed the sources of spatial information and this was the area where quantitative data was obtained just for solid waste spatial elements description.

3.2.1. Descriptive Statistics: T-tests, Chi-square tests and ANOVA

Nonetheless, through the usage of quantitative data, an analysis for the Lilongwe City Council was performed in trying to understand the comparison of wastes generated in the foul areas of the city. For comparison between continuous and categorical variables, t-tests were used if the variable in comparison has two groups only while ANOVA tests were used if the variable in comparison has more than two groups. Chi-square tests were used for a comparison between categorical variables. (Gujarati 2009).

3.2.2. Inferential Statistics: Ordinary Least Square (OLS) regression model: Determinants of Waste Generation (Kg's/Day) by Households in Lilongwe City

Using the same quantitative data the study analysed the determinants of the waste following the average volume of waste per day in kilograms using an Ordinary Least Square (OLS) regression model. The model estimates the coefficients of a linear regression by describing the relationship between a continuous dependent variable and one or more independent variables (Wooldridge 2009). The model is presented as follows;

$$WG_i^* = \beta_0 + x_i\beta_i + \varepsilon_i$$

Where WG_i^* the average volume of waste per day in kilograms (KG), β_O is the intercept, β_1 is the estimated coefficient while x_i is a vector of the independent variable in the study; sex, age group, level of income, educational level, location, and house ownership. ε_i is the unobserved or excluded independent variables.

3.2.3. Probit Model: Factors Affecting Choice of Solid Waste Management by Households in Lilongwe City

After ascertaining determinants of waste generation, a quantitative analysis was made to assess whether the Lilongwe City Council, Private agencies and households should continue with their form of waste management. A Probit model was used to assess the effectiveness of the waste management. A Probit model is used to analyse a dependent variable with two responses in binary response coded as zero and one (Gujarati 2009). The probit model is presented as follows;

According to Wooldridge (2015), the Probit model is illustrated as;

$$WM_{ij}^{*} = x_i\beta_i + \varepsilon_i \tag{1}$$

$$: for \;\; j = 1,2,3$$

$$WM_{ij} = \begin{cases} 1 \; if \; WD_{ij}^{*} > 0 \\ 0 \; if \; WD_{ij}^{*} \leq 0 \end{cases} \tag{1.1}$$

Where WM_{ij}^{*} a latent variable for waste management option is: j represents the three waste management options, home, Lilongwe City Council and private agency. $x_i\beta_i$ are the independent variables which include; Location, level of education, level of income, type of waste and average volume of waste generated, awareness of SW management and house ownership. β_i Are the estimated coefficients which are transformed into marginal effects $\frac{dWM}{dx}$. Where ε_i is the unobserved or excluded independent variables.

3.3. Sampling framework

Informal interviews, observations and a checklist for guided discussions were employed. Key Informants from LCC dealing with solid waste management were specifically targeted for interviews. The sampling frame used in this study was the projected population of Area 1, Area 19, Area 23, Area 29, and Area 43.

Table 4: Sample size population Projection

AREA	POPULATION AS OF THE 2018 CENSUS	ANNUAL POPULATION INCREASE	3 YRS POP INCREASE	TOTAL PROJECTED POPULATION AS OF 2021
Area 1	9310	353.78	1061.34	10371.34
Area 19	3224	122.512	367.536	3591.536
Area 23	51691	1964.258	5892.774	57583.774
Area 29	670	25.46	76.38	746.38
Area 43	6208	235.904	707.712	6915.712
			TOTAL POPULATION	79208.742

The total population of the study sites was 71,103 and according to NSO, (2018), Lilongwe City's Annual growth rate is 3.8% and using this annual growth rate, the population used for the study was projected to be 79209. A confidence interval of 95% with a margin of error of 0.05 was used. Yamane's (1964) formula was used to calculate the sample size for this study as follows:

$$n=N/1+N(e)^2$$

Where **n** = corrected sample size, **N** = population size, **e**= margin of error, **e** = 0.05

Therefore, Sample size, n= 79209 /1+(79209 x $(0.05)^2$)

= 398

The sample was distributed in the study sites as follows:

Table 5: Sample size distribution

STUDY SITE	POPULATION	HOUSEHOLD	SAMPLE
Area 1	10371.34	2074.268	52.11268063
Area 19	3591.536	718.3072	18.04632463
Area 23	57583.774	11516.7548	289.3401261
Area 29	746.38	149.276	3.750321807
Area 43	6915.712	1383.1424	34.74925041
		Total Sample	397.9987036

The study used simple random sampling in selecting households in the study sites to give descriptive information on solid waste management at the household level, and a questionnaire was administered. The study wanted to compare the results from the five land uses and use them for spatial analysis and check which land use generates a large volume of SW. Therefore, the targeted areas included Area 23 (residential), Area 1 (Commercial & Residential), Area 19 (Institutional and Residential), Area 29 (Industrial and Residential) and Area 43 (Residential).

LCC has 9 departments and 18 key informants were interviewed. 2 key informants from each department were interviewed using an interview guide, questionnaire and observations. Representatives from each department were interviewed to provide qualitative data that was used in this study

3.4. Data Collection

The study used a multi-criteria approach in data collection. Primary data was sourced from interviews, discussions and observations with key informants and different sectors dealing with solid waste management. 400 household interviews were conducted in Area 23 (Residential), Area 1 (Commercial), Area 19 (Institutional) and Area 28 (Industrial). A simple random sampling method was adopted to identify research participants. LCC is divided into administration and technical sections. Representatives from these sections were interviewed to provide primary data that was used in this study. Only the sections involved in solid waste management were focused on and were used as sources of primary data. GPS was used to pick coordinates and provide primary spatial data on solid waste hot spots and the location of waste skips within Lilongwe City.

Secondary Data was sourced from the reports, documents, topographic maps, sketch maps, satellite images, online open spatial layer sources and other files from the Lilongwe City Council, Surveys Department and census reports from the National Statistical Office. The online open spatial layer data was calibrated and validated by transforming the spatial reference system from the World Coordinate system to Arc 1950 the local reference system. The data was then verified on the ground using Garmin handheld GPS using coordinates.

3.4.1. Process of solid waste management at the Lilongwe City Council

Data was collected through interviews and discussions with key informants dealing with the City's solid waste management at Lilongwe City Council. Thematic analysis was used to analyse qualitative data. The process that the Council uses for SWM was drawn and analysed by checking each stage within the process in order to find out the integration of GIS in all the stages.

3.4.2. Identification of Spatial information needs for solid waste management

Questionnaires and interviews were applied to collect information from Key informants dealing with SWM in Lilongwe City. The secondary data was sourced from the scanning of the available paper maps and plans and the use of the available solid waste data from the files and other documents as well as downloaded Google satellite images.

3.4.3. Sources of spatial information for solid waste management

A guided checklist was used to obtain data on the sources of spatial information and both secondary and primary data was used. Reports were used to generate data concerning solid wastes generated by residential and other land uses from within the City. Descriptive statistics was used to analyse and graphically present data collected from the household survey. Google satellite image was used to show existing dumping points. QGIS was used to conduct spatial analysis to identify and assess the integration of GIS in the process of solid waste management in Lilongwe City. The analyses that were run in QGIS included geo-processing of Google satellite images, computation of XY coordinates for SW hotspots, transformation of existing spatial layers, spatial data classification, and map generation. Figure 5 displays a detailed approach to spatial data analysis employed by this study.

3.5. Data Analysis

The study used a multi-criteria approach in analysing the collected data. Figure 5 illustrates the data analysis approach.

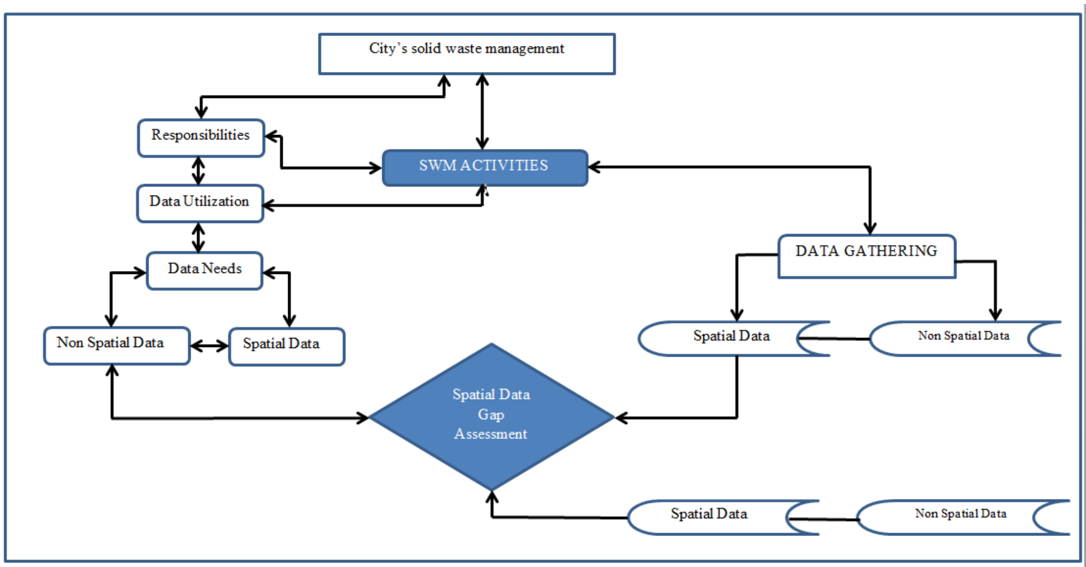


Figure 5: Data Analysis approach adapted from Tembo, (2003)

3.5.1. Lilongwe City's Solid Waste Management:

The Lilongwe City Council is responsible for keeping the City clean through solid waste management. All the solid waste generated in the city contributes to how the environment of the City is looked at. The SWM data was collected through key informants' interviews and the analysed in Excel sheets for the presentation of tables and graphs.

3.5.2. Responsibilities:

The City Council has a responsibility to manage solid wastes and this includes; solid waste collection, transporting, recycling and dumping. All the solid wastes generated from different locations within the city are supposed to be collected and the council is the one providing the service of making sure that all the solid waste is collected. The location where Lilongwe City

Council collects, transports, recycles and dumps SW were captured in XY data and analysed using Quantum GIS and presented in maps and tables.

3.5.3. Data Utilisation:

The City Council collects solid wastes from different locations and generates data in the form of reports and the data is used for planning, processing and implementation of action plans for solid waste management. Most of the data observed is attribute data or non-spatial. The data was collected using a GPS receiver, field observations and analysed using Quantum GIS.

3. 5.4. Data needs:

Data is needed for the planning and implementation of action plans and this data is supposed to be in two formats as follows:

- Spatial data
- Attribute data/ non spatial data

3.5.5. Non-Spatial Data:

This is data that describes the type of solid waste collected; for example, some wastes are biodegradable while some are not. Other waste can be recycled and reused. This data also gives information about quantities of solid waste generated and dumped. Non-spatial data is presented in the form of reports and tables, charts and figures. The Non-Spatial Data was collected through field observation and interviews with key informants. The data was analysed and presented in Microsoft Office Excel version 10.

3.5.6. Spatial Data:

This data shows the geographical locations of all the generated solid wastes from Lilongwe City. Spatial Data shows the exact positions where the solid waste is generated, collected, and moved from the source to the dump site. Spatial Data was used to indicate the routes that collection vehicles use when transporting the wastes to the dump site. The Spatial Data was used to show the land use and coverage of solid waste dumped in an area for situation analysis. However, to achieve proper Spatial Data utilisation a spatial analysis was applied and presented the data in the form of maps, drawings and models to help the institutions understand and make an institutional decision on Solid Waste Management in Lilongwe City. The spatial data was collected using handheld GPS that was used to pick the XY coordinates and digitization of secondary spatial data from existing maps and google satellite images and it was analysed using Quantum GIS.

3.5.7. Solid Waste Management Activities:

The study looked at all activities involved and who does what in the process of solid waste management and this information was collected using the check list and interviews with key informants from Lilongwe City Council and the data was analysed in excel.

3.5.8. Spatial Data Gap Assessment:

The existing data from LCC was analysed and quality checked and the non-spatial and spatial data were matched in order to determine the gap. The assessment of the data was performed in Quantum GIS based on a criteria of data availability, accuracy, readability, data format, preventability, data analysis and mode of analysis, data storage and cost attached in the generation of the data.

3.5.9. SWM Challenges

The key informant's interview was used to collect data concerning the challenges that are faced by Lilongwe City Council in performing solid waste management. The data was analysed using Microsoft office word version 10.

3.6. Chapter Summary

This chapter has highlighted the materials and methods that were used to achieve the results of the study. The study was aimed at assessing the integration of GIS in solid waste management in Lilongwe City. The study used a multi-criteria approach in both data collection and data analysis. The primary data was collected through interviews and the administering of a questionnaire to a sample of 398 population where simple random sampling was applied in a household survey. For categorical variables, t-tests were used if the variable in comparison had two groups only while the ANOVA test was used if the variable in comparison had more than two groups. A chi-square test was used for a comparison between categorical variables. The spatial data was collected using a GPS receiver where XY coordinates were picked. Secondary Data was collected from the literature and existing maps and reports obtained from Lilongwe City Council. All the collected data was analyse using Microsoft Excel and Quantum GIS.

CHAPTER 4: RESULTS

4.1. Introduction

This chapter presents the results of the study that was conducted in Lilongwe City to assess the integration of GIS in solid waste management. The chapter has the following sections: Lilongwe City Council Institutional Arrangement, SWM process in Lilongwe City Council, Solid Waste locations, Solid Waste collection, Lilongwe City Solid Waste Transfer Stations, Lilongwe City SW dump Site, Spatial Information need for SWM in Lilongwe City, Sources of spatial information for SWM in Lilongwe City, Lilongwe City rivers as dump sites, Lilongwe city roads as SW dump sites, Lilongwe City Built-up areas as source of spatial data, Lilongwe City Population and Locations as sources of spatial data SWM, Types of SW generated according to land uses as sources of spatial information, Local household methods of SWM and spatial information of SW disposal, Lilongwe topographic maps as sources of spatial data for SWM, Lilongwe City satellite maps as sources of spatial data for SWM and Routes used for SW transfer as sources of spatial information for SWM.

4.2. SWM Process used by Lilongwe City Council

The solid waste management is guided by a process in Figure 10. The study found that the process starts by determining the existence of solid waste in a specific area. The process starts with SW generation, transportation from a particular location, collection, dumping, and capturing of solid waste data at the dumping site. In Lilongwe City, the SWM process mainly targets city markets, city streets, and institutions.

The study analysis started by looking at the institutional arrangement for Lilongwe City Council in order to find out the departments that are directly responsible for SWM in Lilongwe

City. The study found that the Lilongwe City Council has about 9 departments and there are operational sections in each department. The following is the structure of the council:

LILONGWE CITY COUNCIL INSTITUTIONAL ARRANGEMENT

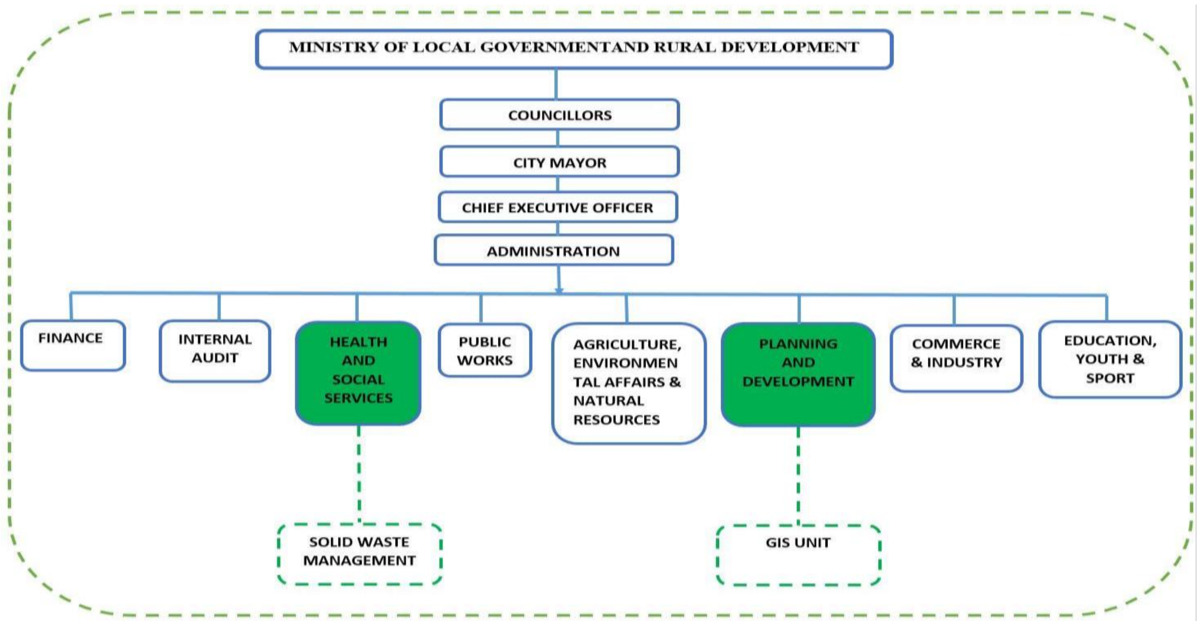


Figure 6: Lilongwe City Institutional Arrangement (Malawi Local Government Act 1998)

Results of the study showed that the Department of Health and Social Services (DHSS) and the Department of Planning and Development (DPD) are indirectly related. The SWM section under DHSS manages solid wastes that are generated in all the land use zones that the DPD plans, while the GIS Unit under the DPD generates spatial information on all developments for Lilongwe City. The section of Solid Waste Management is wholly responsible for managing the solid waste generated from all the land uses in Lilongwe City. Table 3 shows specific activities of the DHSS and DPD.

Table 6: Responsibilities of Departments involved in SWM in Lilongwe City

NAME OF DEPARTMENT	ACTIVITIES
Department of Health and Social Services	- Manage and control solid wastes that are generated from Lilongwe City - Ensuring sanitation of Lilongwe City at all times - Planning and deciding on SWM - Management of the Lilongwe City's dump site - Suitable site selection for positioning of SW collection skips and bins in Lilongwe City - Monitoring and Evaluation of health issues in Lilongwe City - Monitoring and Evaluation of Social amenities and services - Control of the Social welfare of the people in Lilongwe City
Department of Planning and Development	- Plan for land use zones for Lilongwe City - Inspection of development projects - Development control - Enforcement of city's development bylaws - Provision of plans for social and economic activities for Lilongwe City - Generation of spatial information for Lilongwe City

The study found that Lilongwe City Council uses the following SWM process in delivering SWM services in the city:

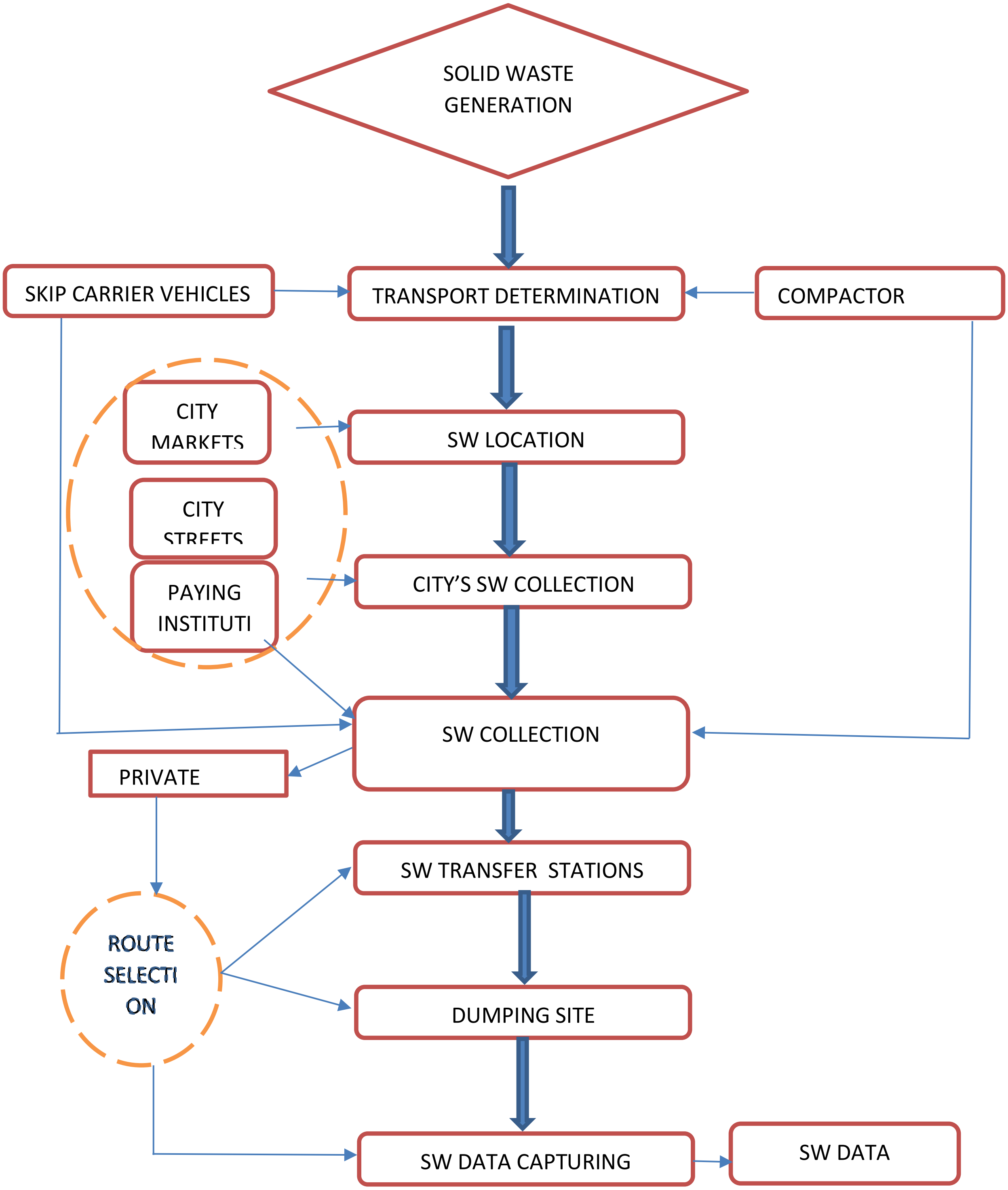


Figure 7: Lilongwe City Council's SWM process (Author's compilation 2019)

4.2.1. Solid Wastes Identification

In Figure 7, the study found that the identification of SW is the initial stage in the SWM Process followed by LCC. In this process, location data is gathered and used without reference to geographical coordinates. Space-related data and associated attributes were used to describe solid waste. Using this data, responsible personnel were able to describe what type or kind of solid waste was produced or generated within a specific area.

4.2.2. Transportation of Solid Waste

The study found that the transportation of SW is another stage in the SWM process. At this stage, the Council only determines what kind of vehicle to collect and transport the solid wastes. The results show that there was no specific determination of routes that vehicles use in transferring solid waste to the dumping site. It was found that spatial information was not used in the routing of trucks despite the availability of road network spatial data in the GIS Unit in Lilongwe City.

The SWM officers request transport from the Transport Officer who issue the transport in two forms. There are skip carriers and compactors. The Council's skip carriers can carry about 10 tonnes of solid waste per collection.

Figure 8: SW Skip Carrier Vehicles picture source: Field pictures at Lilongwe City Dump Site

The compactors carry about 5 tonnes per collection. When the SW collection vehicle is released from the transport officer, the Solid Waste Management Officers determine the locations within the city where the collection vehicles are deployed. The results found that the officers do not use maps to plan their routes for the collection of solid wastes.

Figure 9: SW Compactor Vehicle source: Pictures from field observation in Lilongwe City

4.2.3. Solid Waste Location

The SW accumulates in different locations in the city. The study found that the LCC uses experience to make decisions that are not informed by GIS analysis to locate the areas that require to be serviced. It was noted that at this stage the Council identifies which locations are to be serviced with a bin or a skip which streets are to be cleared and which locations need SW collection.

The study found that there is no SWM map or spatial information with regard to major waste generation hotspots in Lilongwe City. Figure 7, indicates that spatial information through maps and GIS could help the Council to visually monitor and evaluate areas that produce a lot of waste management waste and locations that generate solid waste management waste. By using maps, it was realised by the Council that it could easily determine points or locations that could be served with a bin or a skip.

4.2.4. Solid waste collection

The study found that SW collection is another stage in the SWM process as indicated in Figure 7, it was found that SW is collected from different collection points to the dump site. The study found that there are city council vehicles that collect SW. However, the study found that there is no GPS tracking system for the waste collection vehicles.

It was also found that the Council performs some patrols to track the vehicles that collect the waste although this exercise is not performed regularly. The solid Waste Management section does not use any map or any spatial information when deploying the collection vehicles to the solid waste locations. Instead, the Council uses experience to know which areas produce a lot of waste. It was noted that there is a schedule of solid waste collection for the city. The Council follows its own schedule of collecting solid waste. The study found that solid waste is collected once a week from the market areas while solid wastes from the streets are swept and cleaned from Mondays to Fridays.

The study found that LCC also recognises private companies that register SWM businesses with the council to collect the waste. This arrangement is made considering that the LCC does not have enough capacity to reach and service all areas within the city. The private collectors may use any schedule of collection and they mainly collect wastes from the residential areas and usually use open vehicles rather than the recommended SW collection vehicles.

Figure 10: Example of private vehicles carrying SW to the Dump Site Source: Picture from field observation

It has also been revealed that the LCC does not have any database showing which locations within the City where the private collectors perform their services. There is also no spatial data as to which routes the Council or the private SW collection companies use from the point of generation to the Dump Site.

Figure 11: Skip Positioned at Lilongwe and Mchesi Markets in Lilongwe City source: Pictures from field observation

The study found that LCC uses market and public places criteria in positioning bins and skips in Lilongwe City. There is no spatial information regarding the positioning and distribution of the bins and skips for Lilongwe City. There is no map to show which areas have been served with a bin or a skip. During data collection, the study collected xy coordinates for positions of skips within the City and Figure 12 shows the distribution of skips and markets that were served with a skip.

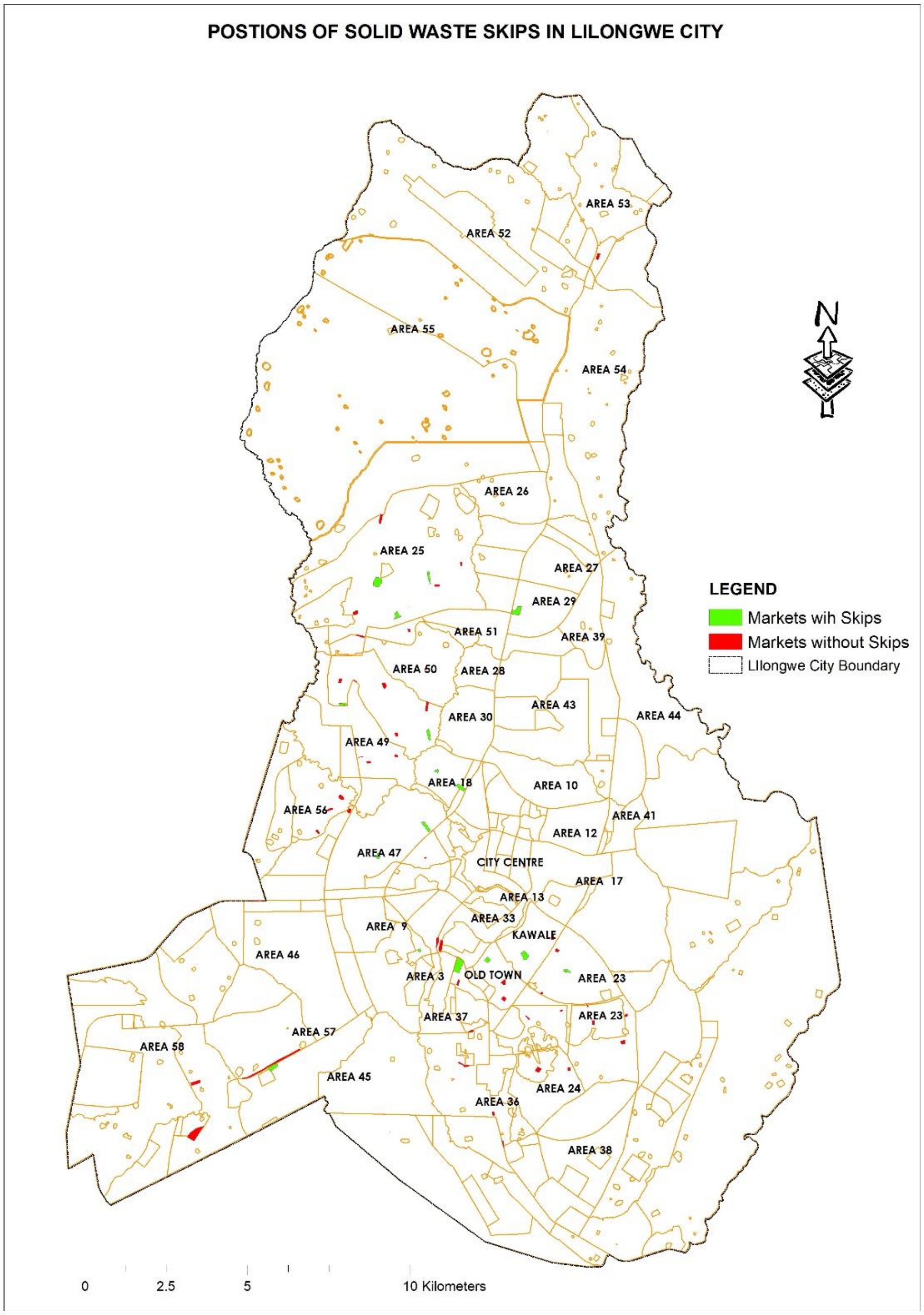


Figure 12: Map Showing markets served with SW Skips (Author 2019)

The study found that Lilongwe City has only provided 24 skips to markets and other institutions. Results from the spatial analysis found that there are about 61 official markets within the City as indicated in Figure 12 but Lilongwe City Council has managed to provide skips to only 17 markets.

4.2.6. Lilongwe City Solid Waste Transfer Stations (SWTS)

When SW is collected, it is supposed to be transferred to the facilities called the Solid Waste Transfer Stations. At these stations, the SW is sorted before it is transferred to the Dump Site. Figure 13 shows the positions of SWTS for Lilongwe City:

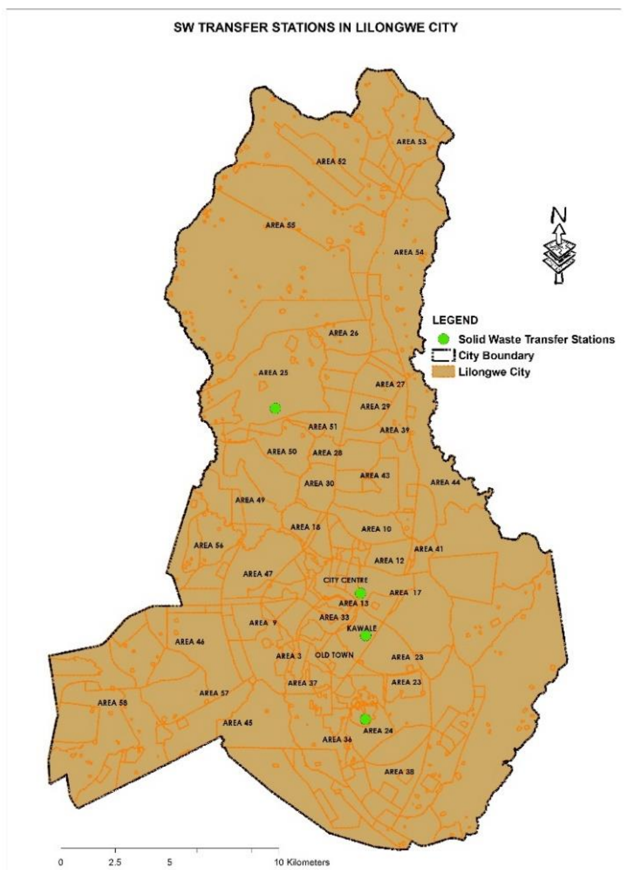


Figure 13: Map Showing markets served with SW Skips Source: Field Data

Spatial analysis results indicated that Lilongwe City has only four SWTSs as shown in figure 13. The stations are located in Areas 7, 13, 24, and area 25. The study found that the idea of constructing the transfer station facilities was to segregate the solid waste and categorise it for recycling and reuse before disposing of it at the dump site. However, the study found that the stations are not commissioned to start functioning.

4.2.7. Lilongwe City Solid Waste Dump Site

Lilongwe City has only one Dump Site. It was found that the site was established in the late 80s. The site was allocated about 26 hectares of land but only 25% of this land has been used. The area is located in Area 38 and this area was zoned for mixed-use that includes residential, Institutional and commercial. It was found that LCC has no spatial information or any map regarding its own dump site. The study results show that spatial information regarding the Dump Site would help the Council to monitor and evaluate the site in terms of its use, expansion, and compatibility issues with the surrounding users.

Figure 14: Lilongwe City Dump Site Source: Picture from field observation, (August 2021)

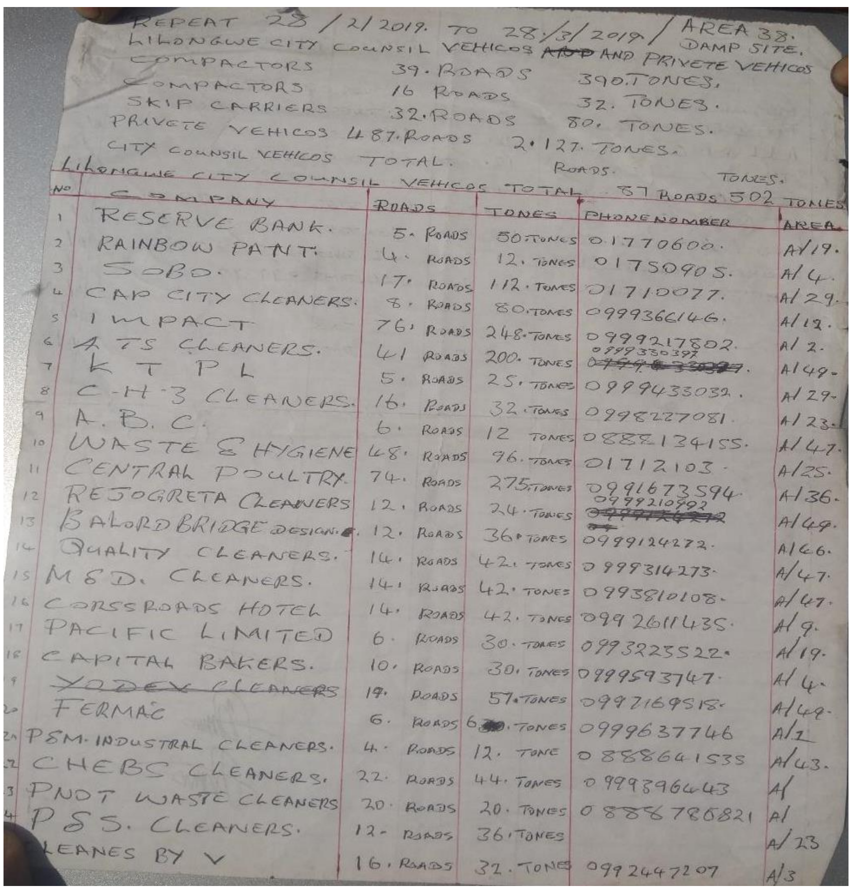
Figure 14 shows a picture captured during data collection. Field observation found that there is no buffer zone between the site and other uses. Figure 15 is a satellite map for the Dump Site downloaded using QGIS.

Figure 15: Satellite Image showing the position of Lilongwe City Dump Source (BING 2019)

Field observation found that the Lilongwe City Dump Site is now surrounded by mixed uses such as residential areas, institutional and commercial (Refer to Figure 15). A satellite image was downloaded in QGIS and a boundary for the dumpsite was plotted to create a new shape layer tool in QGIS through Spatial Analysis, the study found that the dump site is expanding outwards and records from LCC show that there is encroachment to the site by residential and agricultural uses. Due to this encroachment, the site is no longer a safe place especially for residents around it (JICA 2010).

4.3. Spatial information needs for SWM in Lilongwe City

The study found that secondary spatial information is available and mainly used for planning and development while primary spatial information is difficult to find. Referring to the existing Lilongwe City SWM process (See Figure 7), primary SW information is collected at the stage when solid waste is being deposited at the dump site. Lilongwe City has Dumpsite Attendants who collect data and supply the office to enter the information into the database. Figure 16 shows the information that is collected at the dump site.


REPEAT 28/2/2019. TO 28/3/2019 / AREA 38.
LILONGWE CITY COUNSIL VEHICOS ~~AND~~ AND PRIVETE VEHICOS DAMP SITE.
COMPACTORS 39. ROADS 390. TONES.
COMPACTORS 16 ROADS 32. TONES.
SKIP CARRIERS 32. ROADS 80. TONES.
PRIVETE VEHICOS 487. ROADS 2.127. TONES.
CITY COUNSIL VEHICOS TOTAL. ROADS. TONES.
LILONGWE CITY COUNSIL VEHICOS TOTAL 87 ROADS 502 TONES

NO	COMPANY	ROADS	TONES	PHONENOMBER	AREA
1	RESERVE BANK.	5. ROADS	50. TONES	01770600.	A/19.
2	RAINBOW PANT.	4. ROADS	12. TONES	01750905.	A/4.
3	SOBO.	17. ROADS	112. TONES	01710077.	A/29.
4	CAP CITY CLEANERS.	8. ROADS	80. TONES	0999366146.	A/12.
5	IMPACT	76. ROADS	248. TONES	0999217802.	A/2.
6	ATS CLEANERS.	41 ROADS	200. TONES	0999330397 ~~[illegible]~~	A/49.
7	K T P L	5. ROADS	25. TONES	0999433032.	A/29.
8	C-H-3 CLEANERS.	16. ROADS	32. TONES	0998227081.	A/23.
9	A. B. C.	6. ROADS	12 TONES	0888134155.	A/47.
10	WASTE & HYGIENE	48. ROADS	96. TONES	01712103.	A/25.
11	CENTRAL POULTRY.	74. ROADS	275. TONES	0991673594.	A/36.
12	REJOGRETA CLEANERS	12. ROADS	24. TONES	0999210992 ~~[illegible]~~	A/49.
13	BALORD BRIDGE DESIGN.	12. ROADS	36. TONES	0999124272.	A/66.
14	QUALITY CLEANERS.	14. ROADS	42. TONES	0999314273.	A/47.
15	M & D. CLEANERS.	14. ROADS	42. TONES	0993810108.	A/47.
16	CORSSROADS HOTEL	14. ROADS	42. TONES	0992611435.	A/9.
17	PACIFIC LIMITED	6. ROADS	30. TONES	0993223522.	A/19.
18	CAPITAL BAKERS.	10. ROADS	30. TONES	0999593747.	A/4.
19	~~YODEX CLEANERS~~	19. ROADS	57. TONES	0997169518.	A/49.
20	FERMAC	6. ROADS	6[illegible]. TONES	0999637746	A/2
21	PSM. INDUSTRAL CLEANERS.	4. ROADS	12. TONE	0888641535	A/43.
22	CHEBS CLEANERS.	22. ROADS	44. TONES	0999396643	A/
23	PNOT WASTE CLEANERS	20. ROADS	20. TONES	0888786821	A/
24	P S S. CLEANERS.	12. ROADS	36. TONES		A/23
	LEANES BY V	16. ROADS	32. TONES	0992447207	A/3

Figure 16: Data captured by Dump Site Attendants (LCC 2019)

A study through key informant interviews found that data is compiled in a book to keep a record of the tonnage/weight of SW that is generated and disposed of at the City’s dump site. The study found that data entered in the book include; the name of the company/institution responsible for the vehicle that is dumping the waste, total trips or loads per vehicle, tonnage, and contact details of the institution or company dumping the waste. The location or area where the solid wastes are coming from is also recorded.

The captured data is then compiled in the main Database that is managed by the SWM section at LCC. Assessment of the database indicated that only information regarding quantities of collected and dumped solid wastes is captured in the database.

Further analysis of the database showed that there is no spatial data regarding SW but only attribute data is available in the database. During an interview with the officers in the SWM section, it was found that the spatial database is not merged with the SW database that is already available in Lilongwe City.

Table 7 shows the information captured at the dump site per month in terms of the average weight of solid waste, trips made, the institution collecting the waste as well and the location where the solid waste originated:

Table 7: Average Monthly SW Collection in Lilongwe City

Source: Lilongwe City Dump Site (Attendants Report Book 2019)

COLLECTOR	TRIPS/MONTH	LOAD/TON	LAND USE
Lilongwe City Council	87	502	Commercial/Institutional
Private companies	333	1853	Residential
Industries	97	184	Industrial
Other institutions	57	90	Institutional/Industrial
TOTAL	**574**	**2629**	

The study found that on average 2,629 tonnes of solid waste are collected from Lilongwe City per month but a report by JICA, (2010) indicated that about 273,750 tonnes are produced in a year which is equal to 22,812.5 tonnes per month. The data in Table 4 is presented in the graphs below:

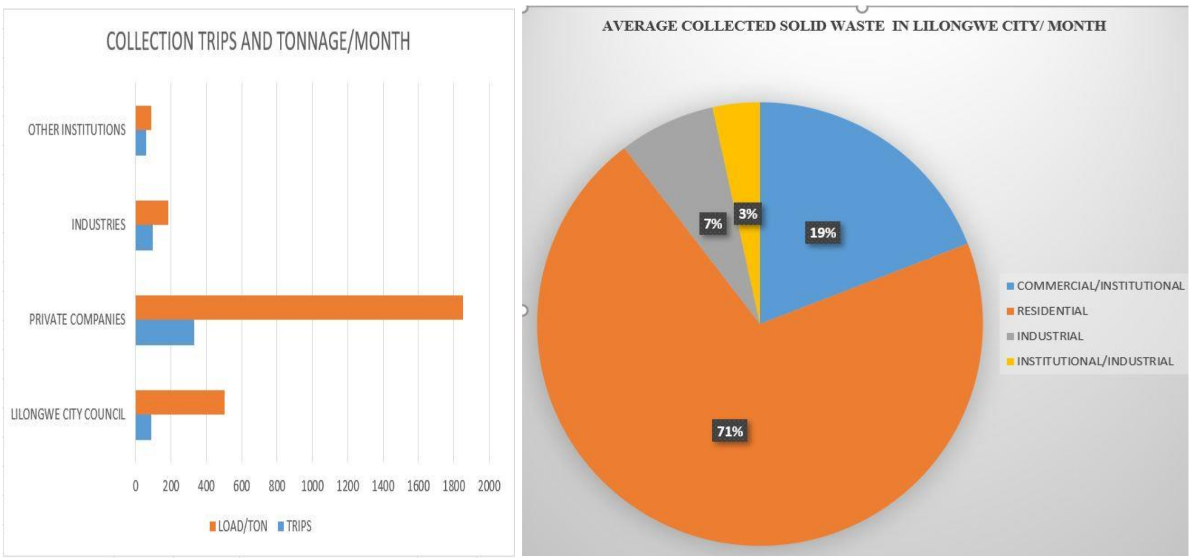


Figure 17: SW Trips, Tonnage and Average Collected SW in Lilongwe City

Figure 17 indicates that LCC only collects 19% of the total SW collected in a month. It is also indicated that the residential areas generate more SW about 71% than commercial/institutional areas which generate about 19%. Despite having a lot of industries in Lilongwe City only 7% of solid waste collected from industrial areas reaches the dump site. The assessment of the information showed that the monthly generated SW in Lilongwe City is not equal to the monthly collected solid waste which means that a lot of SW is left uncollected or is illegally dumped in undesignated sites. The study results found that the reasons for this situation include; a lack of enough capacity from the Lilongwe City Council to reach out to all locations within the City and there is no spatial information that guides and shows where to collect solid wastes.

4.3.1. SW Spatial Information Needs

The study found that LCC SWM needs spatial information for making institutional decisions on various solid waste issues in the city. Table 6 shows the needed spatial information for SWM in Lilongwe City.

Table 8: Solid Waste Spatial Information Needs for Lilongwe City

SPATIAL INFORMATION	SPATIAL INFORMATION NEEDS
Lilongwe City Boundary	• For determination of Lilongwe City Council working area
Area/ Land use	• To know the amount of solid waste generated from Lilongwe City land uses • To know the types of solid wastes generated from each city's land use • To know which areas to position skips in Lilongwe City
Hydrology	• To know which city rivers are affected by Solid Wastes that cause pollution
Road network	• To determine which roads are to be served with SW collection bins • To know which streets to be cleaned by Lilongwe City Council • To know which roads are affected by road SW dumping
Green Spaces	• To know which city spaces are used as an authorised SW dump site in Lilongwe City
Population	• Determination of the amount of SW generated in Lilongwe City
Buildings	• To know which buildings generate SW in Lilongwe City

Topographic	• Determination of solid waste dump sites • To know the terrain of Lilongwe City as an important factor for SWM
Satellite Images	• For SWM analysis • Source of Aerial photos for areas within Lilongwe City

Source: Lilongwe City Council

Table 8 shows the spatial needs for SWM in Lilongwe City. It was noted that spatial data is needed for Lilongwe City Council to make different decisions on the SWM for Lilongwe City. The Spatial information in Table 6 is available but it is not integrated into the SWM process. Spatial information on the Lilongwe city boundary is available in shapefiles and this information is needed in SWM to define the limits where Lilongwe City Council is supposed to provide SWM services. The study found that Lilongwe City Council has spatial information on the city's hydrology but it is not used in the SWM process to analyse which rivers are affected by the SW dumping. The Lilongwe City Council has spatial information on the road network, green spaces, population, and built-up areas and these are places where solid waste accumulates and remains unattended. The study also established that this information is not integrated into the SWM process to help the council make decisions for SW collection in time.

4.4. Sources of Spatial Information for Solid Waste Management in Lilongwe City

The study found that LCC has spatial data that can be used in SWM but the data is only used by the Department of Planning and Development for planning and development management purposes. Table 9 shows the available spatial data sources for Lilongwe City.

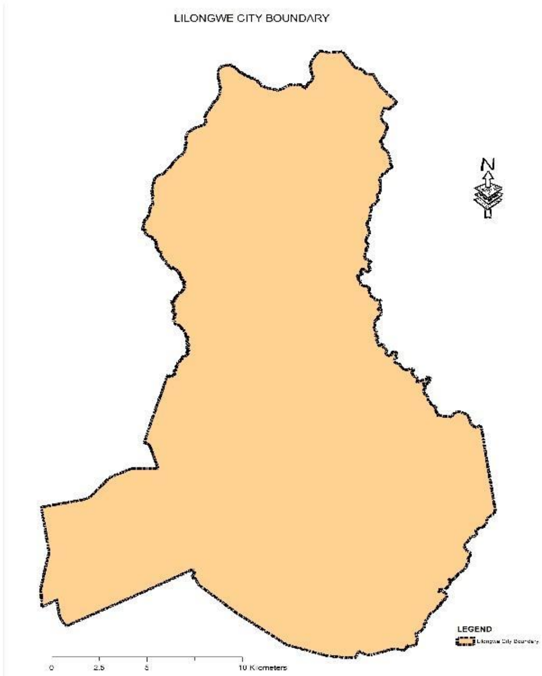
Table 9: Sources of Solid Waste Spatial Information for Lilongwe City

SOURCE	DATA TYPE	DATA FORMAT
Surveys Department	Lilongwe City Boundary	Shapefile and Analogue
Department of Planning and Development	Area/ Land use	Shapefile and Analogue
Surveys Department / Online Open Sources	Hydrology	Shapefile and Analogue
Surveys Department / Online Open Sources	Road network	Shapefile and Analogue
Surveys Department / Online Open Sources	Green Spaces	Shapefile and Analogue
National Statistical Office	Population	Analogue
Surveys Department / Online Open Sources	Buildings	Shapefile
Surveys Department / Online Open Sources	Topographic	Analogue
Surveys Department / Online Open Sources	Satellite Images	Raster

Source: Lilongwe City Council

The spatial data above is very crucial in the process of SWM but it is not utilized in the SWM process. The study found that this data can be utilized in SWM for example the Lilongwe City Boundary data defines the limits of Lilongwe City. It is within this boundary that the Council operates its services of SWM. It was noted that the City boundary covers up to 8007.386 square kilometers in size. Figure 18 shows the boundaries as one of the required spatial information for the City's SWM.

LILONGWE CITY LAND USE MAP



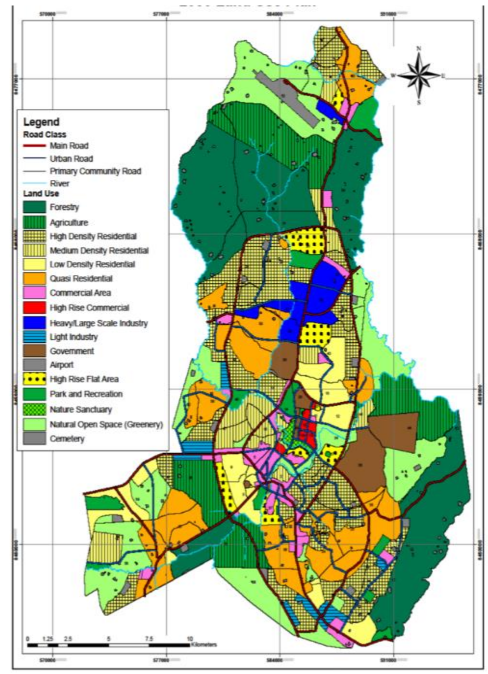


Figure 18: Maps showing Boundary and Land Use Zones for Lilongwe City (JICA 2010)

The study found that the spatial information in Figure 18 is available and it is important in solid waste management. The City is zoned into different land uses and these are the areas that generate solid wastes in Lilongwe City. The study further found that Lilongwe City Waste Management section can use this source of data to monitor and evaluate SWM and conduct studies on areas that generate large quantities of solid wastes compared to the others (JICA 2010).

4.4.1. Lilongwe City Rivers as Solid Waste Dump Sites

The study found that LCC has the spatial data for the hydrology of all rivers and wetlands in Lilongwe City. Using observations, spot checks on some rivers of Lilongwe City were conducted to find out illegal waste dumping practices. The rivers observed included: Lilongwe River, Lingadzi River, Mchesi River, Nankhaka River, and Namathanga River. The field observations showed that in these rivers, solid waste is dumped. Following a spatial analysis, the following map was generated to show some waste dumping hotspots in the rivers of Lilongwe City:

Figure 19: Map Showing Lilongwe Rivers and Wet Lands (Author's compilation 2019)

Figure 19 shows the hydrology spatial information that displays rivers that are affected by SW dumping. The study found that GIS displays spatial data and can help the Council monitor rivers, wetlands, and other blue spaces affected by solid waste within Lilongwe City.

4.4.2. Lilongwe City Roads as Solid Waste Dump Sites

The study found that most roads in Lilongwe City are used as dump sites for solid wastes. The study found that spatial information on road networks is available but not used for Lilongwe City's SWM. The Council employs people to sweep and remove the solid waste that is in streets and storm water drains. The Council needs spatial information on the road network since these are areas usually used by the public as they connect places within the City. Figure 20 shows a map of the road network for Lilongwe City and these are the roads that are affected by the accumulation of solid wastes:

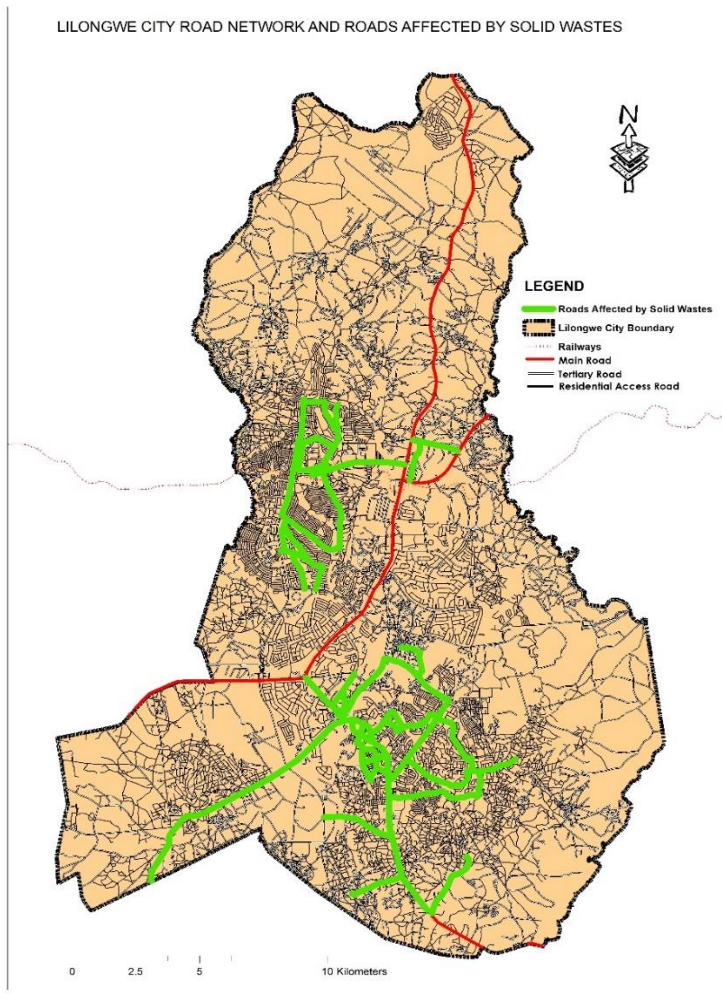


Figure 20: Map Showing Roads Affected by Solid Wastes (Author's Compilation 2019)

The study found that solid wastes accumulate quickly on most of the roads of Lilongwe City. The study through field visits found out that the roads highlighted in green on the map are the roads that are heavily affected by solid waste dumping in Lilongwe City. It was found that the spatial layers of the road network are available at Lilongwe City Council and if integrated into

SWM the data is used to monitor which roads are affected by solid waste within the City hence, making a proper institutional decision.

4.4.3. Lilongwe City Built-Up Areas as a Spatial Information Source for Solid Waste Generation

Using spatial analysis of Lilongwe City built-up areas, it was found that it is in these areas where SW is mostly generated. The following map shows all the built-up areas in Lilongwe City:

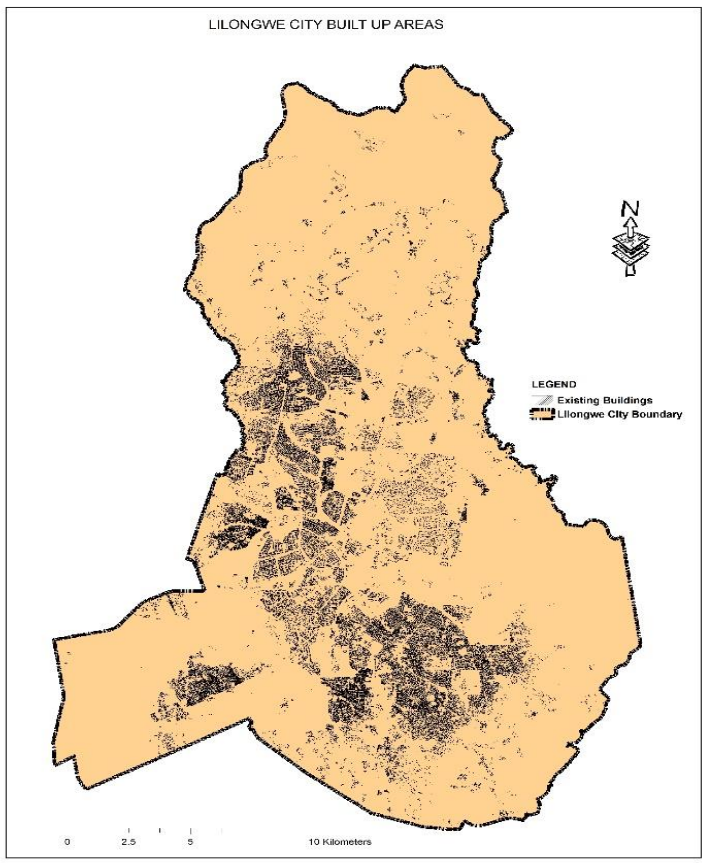


Figure 21: Map showing built-up areas as sources of SW generation in Lilongwe City (Author's compilation 2019)

Figure 21 shows that there are many built-up areas in Lilongwe City. It is from these built-up areas where most of the solid wastes are generated. The study established that this information is available and can help to estimate the amount of waste generated from the households and make proper planning to service the areas

4.4.4. Lilongwe City Population as Sources of SW Spatial Information Ration

This study found that population data is important information that compliments spatial information. It was observed that population data is important for SWM. The LCC uses census reports that are produced by the National Statistics Office. The population data is available in analogue and digital Excel formats as a secondary source of information. In the analysis of this study population data was used to estimate how much solid waste is generated in Lilongwe City just by using the population figures. Data that was captured from the SWM section indicates that an adult person produces about 0.75kgs of waste per day. Table 8 shows the Lilongwe City area's population and estimated solid waste produced per day.

The SW accumulates in different locations in the city. The study found that the LCC uses experience to make decisions that are not informed by GIS analysis to locate the areas that require to be serviced. In addition, through the quantitative analysis, the study found that the locations pertaining to the type of waste generated by the people in the four areas are highly significant in their differences highlighting the need for an imperative GIS analysis. It was also noted that at this stage the Council identifies which locations are to be serviced with a bin or a skip which streets are to be cleared and which locations are there to remove waste.

The study found that there is no SWM map or spatial information with regard to major waste generation hotspots in Lilongwe City. It was noted that the spatial information regarding solid waste locations would help to close the gap in the whole SWM process since SW generation is location-based. Figure 7, indicates that spatial information through maps and GIS can help the Council to visually monitor and evaluate which areas produce a lot of waste management waste and which locations and solid wastes management waste. With the use of maps, it was realised by the council that it can easily determine which points or locations can be served with a bin or a skip. Table 10 shows how different the locations are in terms of waste generated by the people highlighting major evidence for the need for spatial information through maps and GIS.

Table 10: SW generation by location per person per day

LOCATION	QUANTITY IN KGs (sum of average volume of waste/day)
Area 23	163.66
Area 1	25.84
Area 43	86.66
Area 19	7.50

Table 10 highlights differences in waste generated across the locations in Lilongwe City. However, the study excluded Area 29 due to data limitations. Furthermore, an ANOVA test was performed to analyse the variance among the areas and the study found highly significant differences among the groups with an F-statistic of 13.30 at a 1% level of significance. Therefore, from the table, below the results showed that residential areas generate more waste compared to institutional, commercial and industrial areas.

To corroborate these findings, a two-sample t-test was also performed to see the variance between residential areas with both high and low density compared to both institutional and commercial areas. The study found that the areas were statistically significant at a 5% level of significance with a t-value of 16.9629. Table 11 shows a summary of the t-test results.

Table 11: Summary of T-test results

Group	**Mean**	**t-value**	**p-value**
Residential Area	.8241206	16.9629	<0.001
Institutional & Commercial Area	.1758794		
Mean Difference	.6482412		

4.4.5. Choice of variables used in the two models

The table below provides an inclusive insight into various demographic and waste management variables across different locations (Area 23, Area 1, Area 43, and Area 19). For the study, one notable trend in the data is the gender distribution (Sex variable), with variations observed in the percentage of females and males across the areas. For instance, in Area 23, the percentage of females is higher at 57.1%, whereas in Area 1, males dominate at 55.8%. These differences highlight the need for a nuanced approach to waste management programmes that consider gender-specific preferences and behaviours. The educational background of respondents exhibits substantial disparities across locations. Notably, the prevalence of tertiary education is higher in Area 43 with 94.1% and 100.0% compared to other areas. Conversely, primary education is more prominent in Area 23 and Area 19. These variations highlight the importance of tailoring waste management educational initiatives to the educational levels prevalent in each location.

The distribution of income levels also showcases considerable differences. In particular, Area 23 demonstrates a stark contrast, with 98.6% of respondents falling into the low-income category. On the other hand, Area 1 has a more balanced distribution across income levels. Understanding these variations is crucial for designing waste management strategies that are accessible and affordable to residents based on their economic capacities. Lastly, the type of waste generated varies significantly across locations. For instance, the majority of respondents in Area 1 and Area 43 manage both kitchen and plastic waste (76.9% to 100.0%), whereas in Area 23, the prevalence of kitchen waste alone is notable (21.1%). These distinctions underscore the necessity of tailoring waste management infrastructure and awareness campaigns to the specific waste composition prevalent in each area, ensuring a targeted and effective approach to sustainability.

Table 12: Demographic and waste management variables across different locations

Choice of Variables	Location					Total Sample	P-value
	Area 23	Area 1	Area 43 Percentages	Area 23	Area 19		
Sex							0.684
Female	57.1	44.2	50.0	50.0	54.5		
Male	42.9	55.8	50.0	50.0	45.5		
Level of Education							0.000
Primary	10.2	5.8	0.0	0.0	8.3		
Secondary	69.7	73.1	5.9	0.0	61.6		
Tertiary	20.1	21.1	94.1	100.0	30.1		
Level of Income							0.000
Low	98.6	38.5	0.0	0.0	77.9		
Medium	0.0	61.5	0.0	0.0	8.0		
High	1.4	0.0	100.0	100.0	14.1		
Type of Waste							0.000
Kitchen waste	3.7	21.1	0.0	0.0	5.5		
Kitchen and Plastic	95.9	76.9	100.0	100.0	94.0		
Plastic	0.3	1.9	0.0	0.0	0.5		
SWM Knowledge							0.128
Aware	9.9	7.7	0.0	0.0	8.3		
Unaware	90.1	92.3	100.0	100.0	91.7		
Household Ownership							0.000
Rented	60.2	53.9	23.5	100.0	58.0		
Owner	39.8	46.1	76.5	0.0	42.0		
Age Group							0.000
20 to 24	13.3	5.8	5.9	11.1	11.6		
25 to 35	44.9	48.1	29.4	38.9	43.7		
36 to 40	25.9	34.6	32.4	22.2	27.4		
41 to 45	2.7	0.0	20.6	22.2	4.8		
46 plus	13.3	11.5	11.8	5.6	12.6		
SW Management							0.000
Home management	66.0	19.2	0.0	0.0	51.3		
Lilongwe City Council	16.7	71.2	2.9	100.0	26.4		
Private Agency	17.4	9.6	97.1	0.0	22.4		

4.4.6. Multiple Regression Model: Determinants of Waste Generation (Kg's/Day) by Households in Lilongwe City

Through the same quantitative analysis and in relation to the need for GIS, the study establishes the determinants of waste generation based on the average volume of waste in kilograms generated by the people in Lilongwe City. Most of the variables considered in the model are categorical hence during the discussion, the base category (reference point) in the age group is 20 -24, primary for education level, low for income levels and Area 23 for location.

The study found that at different levels of significance, 41 to 45 age group, high level of income, Area 43 and Area 19 determine the average volume of waste generated per day in kilograms.

At a 90% confidence level (5% level of significance), there is a 0.4 kg reduction in waste generation for household heads in the age category of 41 to 45. This is attributed to the household transitions in size and household member availability is mostly noticed within these age categories hence the reduction in waste generation at the household level.

At a 99% confidence level (1% level of significance), households with high levels of income generate 16 kg more waste per day than households with low income. High-income households tend to have more disposable income, which they use to purchase a greater quantity and variety of goods and services. This increased consumption leads to a higher volume of products and packaging materials, resulting in more waste generation. Lastly, the study also highlighted that households living in Area 43 and 19 generate less waste than households living in Area 23 by 13.9 Kg's and 16.1 Kg's, respectively.

Below is the table summarizing the determinant of the average volume of waste generated per day in kilograms by the people in Lilongwe City.

Table 13: Average volume of SW generated/day in kilograms by the people in Lilongwe City

Determinants	Quantity (Kg) of SW generated per day
	Coefficients
Sex	-0.058
	(0.051)
Age Groups	
25 to 35	-0.042
	(0.122)
36 to 40	0.036
	(0.130)
41 to 45	-0.354^{*}
	(0.211)
46 plus	-0.108
	(0.151)
Level of Education	
Secondary	0.045
	(0.137)
Tertiary	0.093
	(0.156)
Income Levels	
Medium	-0.040
	(0.211)
High	16.177^{***}
	(0.376)
Location	
Area 1	0.178
	(0.171)
Area 43	-13.931^{***}
	(0.396)
Area 19	-16.101^{***}
	(0.410)
House Ownership	-0.054
	(0.078)
Constant	0.369^{**}
	(0.165)
N	**398**

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4.4.7. Probit Model: Factors Affecting Choice of Solid Waste Management by Households in Lilongwe City

Having understood that the Lilongwe City Council, private agencies and households themselves manage waste. A second quantitative analysis was further done to assess whether factors affect one's choice in waste management, particularly the Lilongwe City Council. Below is a table showing the results.

The discussion will be done concurrently for all the choices. In terms of location which is significant at a 99% confidence level (1% level of significance), households in area 1 which is a commercial and a low dense area, are most likely to use Lilongwe City Council as a waste management agency by 53.8% compared to area 23. Commercial areas often have a higher profile and visibility compared to residential neighborhoods. As a result, any issues related to waste management, such as litter and improper disposal, can have a more significant impact on a City's public image.

City councils may prioritize waste management in commercial areas to comply with environmental regulations, improve the city's overall aesthetics, and maintain a positive reputation. The trade-off between the City Council and private agencies based on land use is further reflected under Home Management and Private Agency for Area 1, whereby there is a reduction in maximum likelihood for them in managing waste in Area 1 by 37.5% and 21.7% respectively compared to Area 23. Similarly, households living in Area 43, a residential area are most likely to use Private agency by 76.6% and reduced the maximum likelihood of waste management by the city council by 22.8% compared to Area 23.

Collectively, the private agencies are playing an active role in handling large quantities of waste generated whereby an increase in the quantity of waste generated has a negative effect on the usage of Lilongwe City Council waste management services by 9.6% at a 99% confidence level (1% level of significance). The emphasis is placed on the Lilongwe City Dump Site Attendants Report Book, 2019 whereby private agencies collected an average of 1853 metric tonnes, Lilongwe City Council collected an average of 502 metric tonnes. This shows limitations in the institutional capacity of Lilongwe City Council to confidently manage waste generated.

However, the type of waste and income level of households increase the likelihood of using Lilongwe City Council services by 16.3% and 70%, respectively. Commercial sites produce both kitchen and plastic waste compared to residential sites. Furthermore, a high level of income is influenced by commercial activities. On the same note, plastic and kitchen waste combined reduce the likelihood of using home management by 17.5% at a 90% confidence level. The medium level of income households are most likely to use private agencies by 65.3%.

Table 14: Marginal Effects for Choice for Solid Waste Management

Variables	Home management	Lilongwe City Council	Private Agency
Location			
Area 1	-0.375***	0.538***	-0.217***
	(0.112)	(0.088)	(0.022)
Area 43		-0.228***	0.766***
		(0.021)	(0.025)
Kg's of Waste	-0.193	-0.096***	0.034
	(0.159)	(0.035)	(0.023)
Level of Education			
Secondary	0.065	0.035	-0.059
	(0.090)	(0.063)	(0.070)
Tertiary	0.005	0.050	-0.003
	(0.103)	(0.073)	(0.080)
Income Levels			
Medium	-0.227	0.049	0.653***
	(0.156)	(0.117)	(0.019)
High		0.700***	-0.132***
		(0.024)	(0.033)
Type of waste			
Both Plastic and Kitchen	-0.175*	0.163***	-0.094
	(0.095)	(0.053)	(0.089)
Plastic		0.168	0.249
		(0.310)	(0.340)
Awareness of SW management	-0.069	0.006	0.049
	(0.088)	(0.065)	(0.062)
House Ownership	-0.014	-0.022	0.021
	(0.049)	(0.039)	(0.036)
Age Groups			
25 to 35	0.037	-0.012	-0.046
	(0.080)	(0.062)	(0.062)
36 to 40	0.102	-0.017	-0.086
	(0.084)	(0.066)	(0.064)
41 to 45	0.123		0.123
	(0.170)		(0.147)
46 plus	-0.006	-0.023	-0.005
	(0.100)	(0.075)	(0.076)
N	**340**	**365**	**380**

Standard errors in parentheses

$^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

4.4.8. Land uses as Sources of Spatial information for SWM in Lilongwe City

The study analysed the types of solid waste generated from different locations in Lilongwe City. Using the available land use spatial information, QGIS was used to analyse the data and the map in Figure 23 was prepared to show the kinds of SW generated from different locations in Lilongwe City

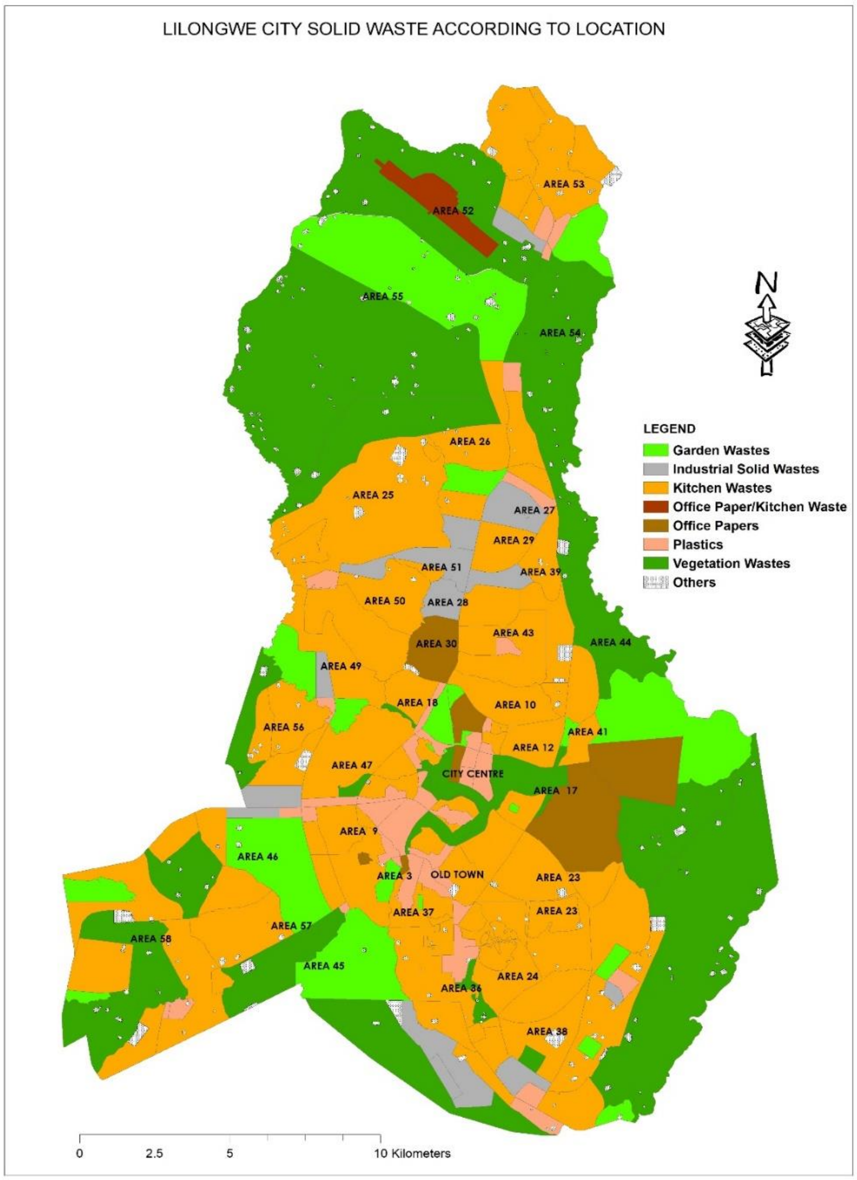


Figure 22: Map showing Types of SW generated from Areas in Lilongwe City (Author's compilation 2019)

Lilongwe City produces different types of solid wastes which include Kitchen leftovers, vegetable residues, plastic residues, paper, vegetation wastes and others. Figure 23 above shows the distribution of types of solid wastes generated in Lilongwe City. It is indicated that the City produces a lot of kitchen waste and this waste is generated from residential areas while the market areas produce a lot of plastics and vegetable leftovers. The industrial and institutional areas produce a lot of paper and other industrial solid wastes.

4.4.9. Local Methods of Solid Waste Management as Sources of Spatial Data for SWM in Lilongwe City

The study assessed the local knowledge of the people on SWM and mapped the locations that are used for SW dumping. Using the questionnaire that was administered in five study sites in the city it was observed that people especially in residential areas have their own local methods of managing wastes despite the LCC having its recommended methods. The following table shows the types of generated wastes and the local management methods used by residential areas versus the recommended methods.

Table 15: Types of SW, Household Local Methods of SWM

TYPE OF SOLID W	LOCAL METHOD OF DIDPOSAL							RECOMMENDED METHODS	
	Burning	Throw in Dug Pit	Throw in River	Throw in Road SWD	Throw on Open Space	Making Manure	Throw in Grave Yard	Reuse	Recycle
Plastics	Partly Used	Partly Used	Extremely Used	Extremely Used	Extremely Used	Not Used	Partly Used	Partly Used	Partly Used
Kitchen Waste	Not Used	Partly Used	Extremely Used	Extremely Used	Extremely Used	Partly Used	Partly Used	Not Used	Not Used
Children Pampers	Partly Used	Partly Used	Extremely Used	Extremely Used	Extremely Used	Not Used	Partly Used	Not Used	Not Used
Garden Wastes	Extremely Used	Partly Used	Extremely Used	Extremely Used	Extremely Used	Not Used	Partly Used	Not Used	Not Used

Key: Exetremely Used, Partly Used, Not Used

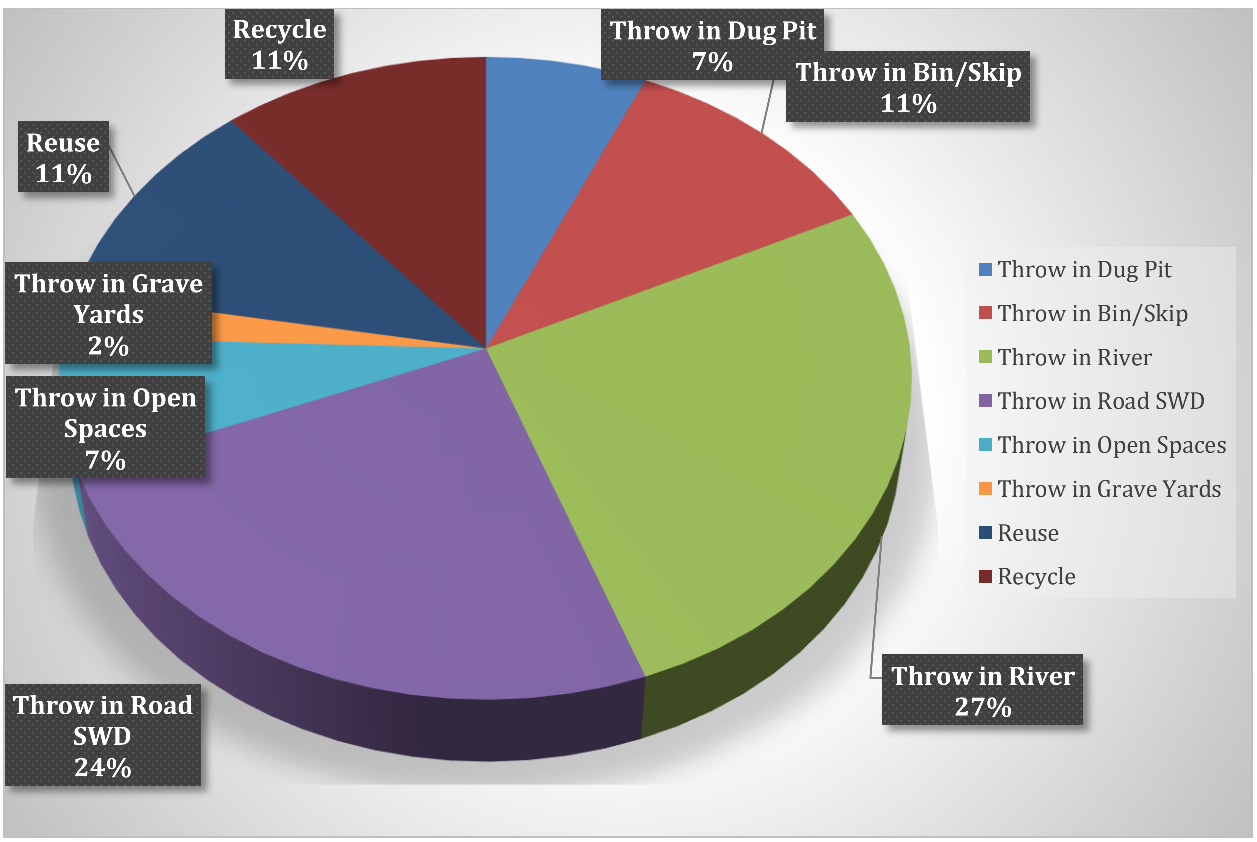


Figure 23: Local Methods of SW Dumping in Lilongwe City Source: (Author's Compilation 2019)

The results of the household survey from the study sites in Table 9 and the pie chart show that 27% of the households throw their SW in the rivers, 24% in road storm water drains, 18% in bins or skips, 11% of the SW from HHs is reused or recycled, 7% in open spaces or dug pits and 2% of the households throw their solid wastes into nearby graveyards. A few residents dig pits to throw the solid waste. The study found that some residents living close to graveyards tend to throw solid waste in the graveyards. A few people make kitchen and garden waste into manure. The LCC recommends recycling and reusing some of the waste but the table above shows that a few plastics are recycled and reused (Lilongwe City By-Law 2010).

4.4.10. Lilongwe City Topographic Data as Source of SW Spatial Information

The study found that Lilongwe City Council has topographic data as another important source of spatial information for solid waste management. The study assessed the 1:50000 topographic map for Lilongwe. The topographic maps are secondary spatial information sources for topographical information for Lilongwe City. The study found that the topographic map of Lilongwe is outdated though having some important information that can be used for SWM. These maps were prepared by the Surveys department and most of the maps were printed on hard copies. Figure 24 is a scanned topographic map of Lilongwe City:

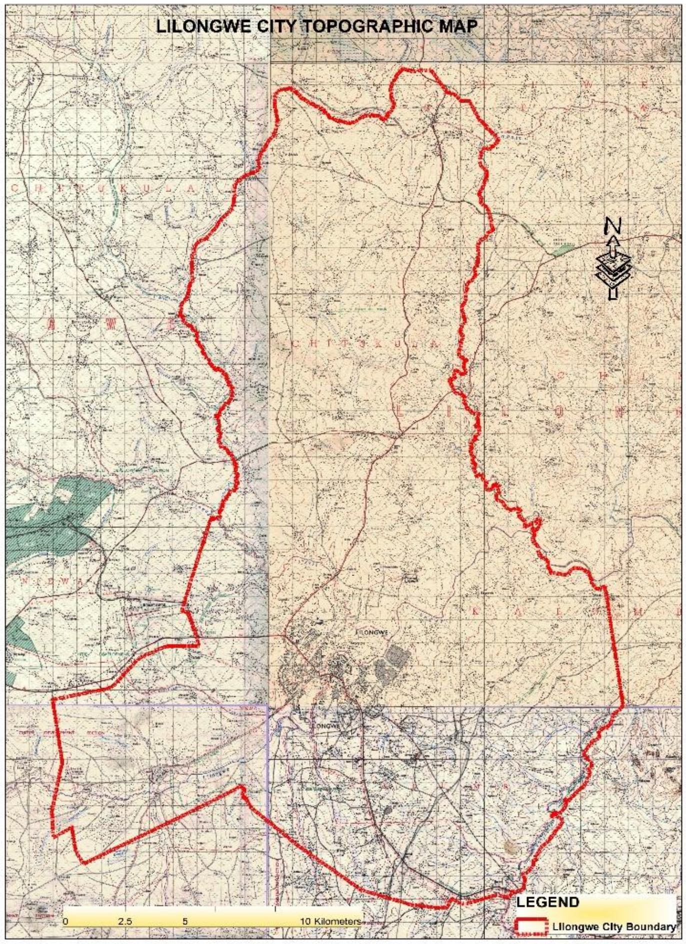


Figure 24: Topographic Map for Lilongwe City (Surveys Department 2000)

From the topographic map, the information is extracted for physical development that takes place within Lilongwe City. The study found that the topographic information is used by the DPD when planning for the physical development within the city. The study found that the SWM of Lilongwe City does not use or integrate any of the available spatial data in the whole process of SWM.

4.4.11. Lilongwe City Satellite Map Data

The Satellite map information is another kind of information that is available at Lilongwe City Council. It was noted that finding real-time satellite data information is expensive for the council to purchase. The other means of sourcing the satellite data is by downloading from

Google Maps and other online open sources. However, the downloaded satellite images are not up to date. Figure 25 is the 2018 satellite image for Lilongwe City that was downloaded using QGIS Open Layer Plug-ins:

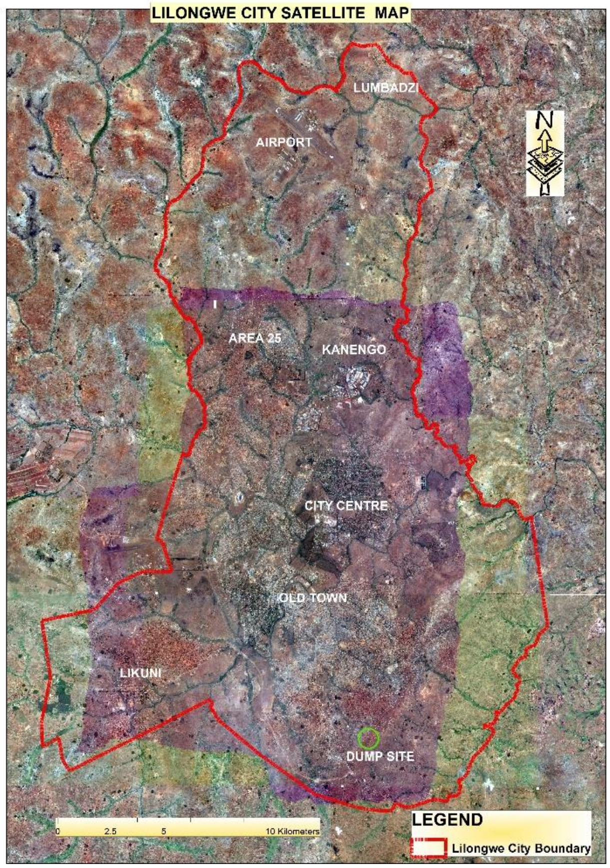


Figure 25: Satellite Map for Lilongwe City (Google 2019)

The study found that the satellite map is a source of spatial information for the Lilongwe City Council but does not use the information in the SWM process. The study found that the satellite map data a source of spatial data is used for the analysis and classification of locations that generate SW (Ramuu 1994). The spatial data on the satellite image is used in the GIS platform when a city is selecting a suitable dumping site, selecting routes for SW transfer and source of both attribute and spatial data recorded in a GIS-based SWM process (Ramuu 1994).

4.4.12. Road networks as Sources of Spatial Information for the Selection of Routes for SW Transfer

Further analysis was done to establish the routes from the City that are used by transfer vehicles to reach the dump site. The study found that Lilongwe City Council has no map or existing drawings that show routes selected specifically for transferring solid wastes from the point of generation to the transfer stations and the Dump Site. The study found that the Council through the Department of Planning has the spatial data on City routes but the SWM process does not integrate the data in GIS for selection to be used when transferring the SW around the city to the dumping site. The study found that vehicles that collect solid wastes from Lilongwe City use any route to the dump site. However, during data collection, it was noted that the routes used by vehicles collecting the solid wastes are chosen by the vehicle drivers themselves. Field observation found that the routes are selected according to the proximity of the collected solid waste to the main road. The study also found that spatial information regarding road networks is available from both LCC and Online Spatial Layer sources. Figure 25 shows routes that are used for transferring vehicles to the Dump Site.

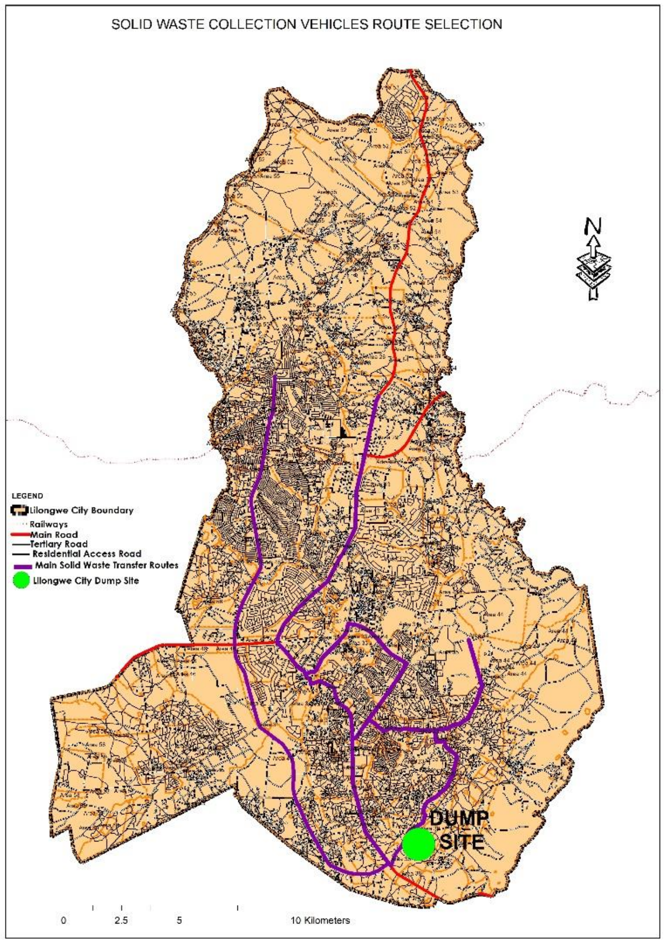


Figure 25: Map showing routes used by SW collection Vehicles (Author's compilation 2019)

The study found that the routes marked with dark purple color in Figure 25, are usually used by the vehicles that collect SW from different points of SW generation in Lilongwe City to the dump site. However, the study found out that this spatial data is available but it is not integrated into the SWM process.

4.5. SWM challenges addressed by the Lilongwe City Council

It was noted that the process of solid waste management is facing several challenges and the following table presents the challenges faced by the Lilongwe City Council when performing its SWM services.

Table 16: General Waste Management Challenges in Lilongwe City

CHALLENGE	SOLUTION
Inappropriate legal framework in waste management	To have a national safety legal framework in place
Weak enforcement of existing regulations for solid waste management	Review of legal management frameworks and enforcement of waste management regulations
Poor coordination among waste management service providers	Participation of stakeholders in waste management (local government, non-governmental organisation, community-based organisations, and the private sector
Indiscriminate waste disposal in the informal settlements	Expansion of waste management services to the informal settlements
Inadequate public awareness of best waste management practices	Sensitization of the public on good waste management practices
Lack of adequate resources to support waste management	Local government to support Lilongwe City Council on the funds
Lack of proper designated dumping sites resulting in haphazard waste disposal	Expansion of waste management services to the informal settlements
Rapid urban population increase leading to an increase in waste generation	Expansion of waste management services to the informal settlements
Lack of inclusion of waste management at the planning stage	Involve waste management at the planning stage

Source: (Lilongwe Urban Profile 2010)

Through key informant interviews, the study found that there are SW challenges that Lilongwe City faces. Table 10 gives a summary of the challenges of SW waste in general as captured by the respondents and according to the Lilongwe Urban Profile (2010).

Table 17: Specific Challenges faced by SWM in Lilongwe City

CHALLENGES	WHERE THE CHALLENGE ORIGINATES	RESPONSIBLE INSTITUTION FOR ACTION
Lack of utilisation of the available spatial information	Lilongwe City SWM Process	Lilongwe City Council
Lack of SW vehicles e.g. Skip Carriers and Compactors	SWM Process	Lilongwe City Council
Inadequate Financial, Human resource and working equipment	Department of Health and Social Services	Lilongwe City Council
The Dump Site is no longer in an appropriate location	Department of Health and Social Services	Lilongwe City Council
The Dump Site Attendants are not well-treated	Department of Health and Social Services	Lilongwe City Council
The Dump Site has no security fence	Dump Site	Lilongwe City Council
The Dump Site has no site office, water and it is not treated by chemicals hence flies are found everywhere	Dump Site	Lilongwe City Council
Lack of public awareness of solid waste management in Lilongwe City	Dump Site	Lilongwe City Council
Lack of GPS tracking devices for vehicles transferring the solid waste to the dump site.	Department of Health and Social Services	Lilongwe City Council
The Low-income settlements like Areas 23, Kawale, Biwi, Mchesi, Chinsapo, and 25 are not well serviced by the Lilongwe City Council compared to the High-income settlements like Areas 43, 10, 12, 47	Department of Health and Social Services	Lilongwe City Council

Source: Key Informants interviews (Author, 2019)

4.6. Conclusion

Research results focused on assessing the integration of GIS in the SWM Process in Lilongwe City. The study started by analysing the institutional arrangement of LCC where it was noted that the Council gets its mandate of functions from the Local Government Act of 1998. Lilongwe City Council has got 9 departments but amongst these departments, only the Department of Health and Social Services and Department of Planning and Development are directly involved in SWM for Lilongwe City. The DHSS has a section of SWM while the DPD has a section of GIS. The DHSS is responsible for SWM in Lilongwe City through its section of SWM. The DHSS follows the process that is used for SWM. The study found that the DPD has all the spatial information through its GIS section but this information is not used in SWM.

It was concluded that there are spatial information gaps and GIS is not integrated into all stages involved in the process of solid waste management in Lilongwe City despite the availability of the spatial information The study found that if GIS is integrated into the SWM process it will be used as a tool to display all locations that SW accumulates and left unattended by the Lilongwe City Council and this will benefit the DHSS to address issues of public health that emanate from uncollected SW. However, the limitation of the use of spatial information in SWM dwells much on the capacity to use the GIS technology from the human and financial resources.

CHAPTER 5: DISCUSSION

5.1. Introduction

The following chapter discusses the results and the interpretation of the results based on the research objectives and the literature reviewed. The main objective of the study was to assess the integration of GIS in the SWM process in Lilongwe City. The study analysed the SWM process in Lilongwe City. The study assessed the spatial information needs for the SWM process in Lilongwe City. The study analysed the sources of spatial information for solid wastes management in Lilongwe City and finally assessed solid waste management challenges in Lilongwe City.

5.2. Solid Waste Management Process

Tembo (2003) conducted a study in Tanzania where he assessed spatial information gaps in natural resources management planning and found that the process had gaps it did not integrate GIS and it was difficult to obtain spatial information on natural resources which is a similar case with Lilongwe City's SWM process. The study analysed the structure of LCC and the SWM process followed to see if GIS is integrated into the process. As already alluded to earlier, SWM is just a small section within the Department of Health and Social Services, the study confirmed that the GIS Unit is indeed just a small section in the Department of Planning and Development. There are also spatial information gaps in all the stages of the SWM process despite the availability of spatial data in the Department of Planning and Development. The study further analysed the SWM process and found that the Lilongwe City SWM collects 2,629 tonnes instead of 22812.5 tonnes per month which represents 19% total SW collected in a month.

5.2.1. Solid Waste Management Process for Lilongwe City Council

The process focusses on the collection of waste from the point of generation up to the point where the waste is finally transferred to the dump site. The LCC only collects solid waste generated in public facilities, markets, local centers and other paying institutions. With reference to Figure 9 (Chapter 4), the SWM process starts by identifying areas or locations with accumulated wastes and these are areas that are serviced by LCC. The next step is the deployment of collection vehicles followed by solid waste collection. When the waste is collected, it is transferred to the Solid Waste Transfer Stations or the dump site. In the process LCC uses the main factor that is normally considered is the provision of transport to transfer waste from the point of generation to the disposal site. In this study, it was not established how the Council identifies or determines suitable sites to position their collection bins and how transfer routes are also identified when transferring the solid waste to the disposal site. The method of SW collection that Lilongwe City Council uses is also highlighted in the study by Valley (2013) who indicated the steps that are followed in the SWM process in a study on solid waste management plan in Chilliwack City in Canada.

Much as these two sections should be dependent on each other, the structure for Lilongwe City Council shows that there is a big gap in such a way that the SWM section collects attribute data on SW generation in the city and the DPD through its GIS section collects spatial information on the development taking place in the City but the two departments do not merge the data in their database to benefit the SWM process.

5.2.3. Solid Waste Collection in Lilongwe City Council

LCC focusses on collecting SW from the markets, public facilities and other institutions that pay the Council for the services. Residential areas are left out and yet they are the ones that generate a lot of solid waste within the city. If the Council does not collect SW from the residential areas, it gives a conclusion that the amount of SW collected by the City is very minimal compared to the amount of SW generated. This was also noted in a study by Shoba and Rashappari in 2013 who conducted a study to use the application of GIS to find out the waste generation and collection rates in various wards of Coimbatore City. The question that remains unanswered is where the uncollected solid waste goes or how is this uncollected waste managed. The analysis in this study found that a lot of people in residential areas find their own means of managing their solid waste. It was also found that most of these local SWM methods used by the communities are always not healthy and good for both people and the environment and this was witnessed by Kumwenda (2013) who carried out a study on emerging environmental health risks. Kumwenda (2013) found that the cities of Malawi are suffering from environmental issues due to poor waste management. Results of this study indicate that most of the residents dispose of their solid waste in river banks, open spaces, graveyards, road junctions, and storm water drains among others.

5.2.4. Lilongwe City's Dump Site.

It was established in this study that Lilongwe City has only one dump site that is located in Area 38. GIS assessed the site in relation to the surroundings and concluded that the dump site for Lilongwe City is no longer suitable; the site refers to Figure 13 (Chapter 4) above. Minale (2013) highlighted factors that must be considered when siting a SW dump site in his study that investigated SW dump site suitability analysis using Geographic Information System (GIS) and Remote Sensing for Bahir Dar Town, North Western Ethiopia. These factors include soil suitability, proximity to residential and other uses, water sources, mineral content and safety of the dump site. It was established that the Lilongwe City dumping site was identified by LCC in the 1980s and during this time the site was suitable for dumping solid wastes considering that the City was small. The results of the study show that the current rapid urbanisation rate in Lilongwe City has increased the generation of solid waste and the demand for land to settle. The study found that the dumpsite is now surrounded by dwelling houses hence posing a health hazard to people and the environment as a whole.

5.3 Assessment of Spatial Information Needs for Solid Waste Management in Lilongwe City.

The assessment showed that Lilongwe City has spatial information that is needed for SWM but the information is underutilized. The available spatial information is mainly used by the Department of Planning and Development for planning and development purposes. Kyessi (2009) did a study on GIS application in coordinating SWM in Dar es Salaam City, Tanzania. In the study, Kyessi (2009) highlighted the importance of spatial information in mapping out the extent of SW generation and collection in an area. Spatial information shows the space where the waste is generated and helps authorities make decisions on how to manage the waste.

The results of this study show that the GIS section of LCC has a spatial database that has spatial information needed for SWM. The available spatial information includes vector layers for rivers, road networks, land use/land cover, demographic data, and topographic information. The spatial information is available in both analogue and digital formats. The analogue spatial information is in the form of printed maps 1:50,000 topo sheets, reports and other census documents while the digital spatial information is stored as shape files, scanned maps and soft copies for reports. The GIS section in the DPD is not linked to the SWM section to provide spatial information for SWM despite the availability of the information. The study found that the SWM section collects and captures solid waste data. The data is collected by the dump site attendants; refer to Figure 18 (Chapter 4). The study observed that spatial information is recorded in the record books. The books indicate the location of where solid waste was collected but it is not fully highlighted on the use of this location data. The SWM section has the database and the main focus in this database is to capture quantitative data in terms of tonnage of solid waste dumped at the city's dump site.

The study established that spatial information is needed at every stage in the process of solid waste management used by LCC. With reference to Figure 9, spatial information is needed from the stage of identifying the accumulation of solid waste at a specific spot in the city. At this stage area maps are needed to geographically show which area needs SWM services. The spatial information is needed to help LCC plan in terms of logistics like fuel and the type of vehicle to collect the solid wastes. The Council can easily calculate the distance from the identified solid generation spot to transfer stations or dump sites by having an area map which can facilitate making effective plans. This is also evidenced in a study by Ammar (2007) who indicated the integration of GIS in the process of SWM process. Ammar (2007) highlighted the need for spatial information at every stage of SWM and gave a GIS-based approach.

Routes used by transporting vehicles are another critical area in which spatial information is needed (Ammar 2009). Normally vehicles that transport SW from different locations within Lilongwe City do not have selected routes to use to the dump site as a result the drivers of SW collection vehicles use any street within the city. The study reveals that having spatial information concerning the road network within Lilongwe City is vital because the SWM section can use it to select and regulate which routes must be used by vehicles transferring SW to transfer stations and dump sites. The study observed that currently, the vehicles that transfer waste cause chaos in the streets as waste may sometimes spill all over the streets and bad odour develops wherever these vehicles are moving.

The LCC needs spatial information for monitoring the management of SW within the City. As explained earlier, residential areas find their own means of dumping solid waste like in rivers, open spaces and road junctions. The Council can use GIS as a tool for monitoring areas, rivers, or roads often used as dump sites. Monitoring reports can be released and used to make decisions in finding measures that can be applied to stop the situation hence promoting healthy living standards that prevent diseases that arise due to mismanagement of solid wastes especially in residential areas.

Another area where Lilongwe City Council needs spatial information for SWM is the position of the dumpsite. According to a study conducted by Valentina (2013) in Prahova County, Romania, GIS was highlighted as the best tool for determining suitable sites for dumping solid wastes. When all the spatial information is at hand, it is easy to analyse before deciding to position the solid waste dumpsites.

The study discovered that the Lilongwe City Council constructed solid waste transfer stations in Areas 13, 24, 25 and area 7. The criteria or factors considered for positioning these facilities were not highlighted in the study. According to a study by Kibetu and Muchiri (2016) conducted in Kenya, GIS can be used to highlight factors that must be considered in determining transfer station sites. These factors include *inter alia* land use, area population size and proximity to waste receptacles. The respondents did not manage to provide information regarding the criteria that were used to select the current positions of the transfer stations. However, GIS can be used to help in determining all suitable locations for these stations.

The LCC's SWM section has a database where information regarding collected and disposed SW is entered. The database only focuses on quantitative data of tonnage collected and dumped while information concerning locations where the waste is generated, is not entered in the database. The study established that spatial information on locations needs to be entered into the SW database in order to complement the non-spatial or attribute data that SWM has through its SWM section.

This study found that GIS data is available at LCC that can be used to monitor this situation faced by residential areas within the City. According to NSO (2018), LCC has developed and doubled its population from the census of 2008. The development of Lilongwe City has extended beyond the City's jurisdiction and there is no distinction between the city dwellers and city peripheral dwellers but all of these dwellers generate solid wastes hence a need for GIS to map out the extent of solid waste generation in Lilongwe city and its peripherals. In 2013, Shoba and Rashappari conducted a study where they applied GIS tools to find out SW rates in 72 wards of Coimbatore City in India and the results came out successfully whereby the exact tonnage of SW generation was defined. This can also be adopted by Lilongwe City to define the exact tonnage of solid waste generation in the city.

5.4. Sources of spatial information for solid waste management in Lilongwe City

The study analysed the availability of spatial information sources that can be used for SWM in Lilongwe City. The results showed that both primary and secondary sources are available for use as indicated in Chapter 4 above. According to Naibbi (2017), Spatial information is a good platform that municipal institutions use to analyse, present, report and decisions making on SW collection and route selcetion for transfering. The LCC has spatial information available through its GIS section within the Department of Planning and Development. The Department of Land Surveys is also another source of information that can be used for SWM in Lilongwe City. The other sources include the National Statistics Office which provides demographic data. The study further explored the online open sources as other spatial information sources with geo-referenced spatial information for solid waste management. These sources provide secondary spatial information. The study found that the sources are accurate and can provide both primary and spatial information.

The NSO (2018) provides census reports on demographic data that can be used for solid management waste. The study found that population data can help the SWM section of Lilongwe City to estimate the amount of SW Lilongwe City generates. For example, the JICA Report (2010), established that the average solid waste generation per person is 0.75kgs per day. SWM section of Lilongwe City can easily calculate the total amount of tonnage generated by the city by just multiplying the population figures. The available spatial information is in the form of vector data and saved as shape files. Shapefiles are files compatible with GIS software and represent the earth's surface as polygons, points and lines (ACHI 2012). This spatial information is available to the Lilongwe City Council, through the Surveys Department and online open sources. The study assessed the shape file for buildings, rivers, road networks and land uses that have turned into solid waste dump sites for many people, especially in the residential and other commercial areas near rivers. Another secondary source of spatial information was the raster data format. Raster data is data that is structured based on cells or pixels of an image or presented in an image format (Church 2002). An example of this data is the satellite images and these images were sourced from online open sources and used in this study. The online open sources include Google Earth, Google Maps and BING satellite maps among others as indicated by Chalkias and Lasaridi (2011) who did a study in Athens on the optimisation of municipal solids using GIS models. This information was used in the study to analyse all hot spot areas that are affected by solid waste and used as dump sites in Lilongwe City. Through this available spatial information, different thematic maps were produced (Refer to Figures 5, 13, 18, 19, 20, 21, 22, 24, 25, 26 and 27).

During the data collection of the study, the researcher collected primary data using handheld GPS. The GPS data depicted the positions of skips/bins Lilongwe City Council put in different markets and public facilities in Lilongwe City. Figure 18 in chapter four shows the positions of solid waste skips and markets that are served with the skips. The GIS analysis of the positions of the skips was based on the primary source of spatial information. To obtain this information the researcher had to visit every market within the city with a hand Garmin GPS to capture the XY coordinates of the positions of the skips and the markets as well as other public facilities. The collected primary data was processed in Excel and generated in Quantum GIS to show the polygons of the markets served with skips versus those that are not this idea was adopted from Chalkias and Lasaridi (2011) who carried out a similar study. LCC can collect the primary spatial information from the ground to use for SWM. The study established that the secondary spatial information is available for the Solid Waste Management section to use but the information is never used hence a big spatial information gap in the SWM process. Primary spatial information requires LCC to go on the ground to collect solid waste data.

Between the two spatial information sources, secondary data is cheaper and easy to find while primary spatial information is difficult and expensive to obtain as it requires expertise to operate the GPS and manage the spatial information and it also has financial implications.

5.5. Integration of GIS in Lilongwe City Solid Waste Management.

The question that remains is “Can Lilongwe City Council through its Solid Waste Management department integrate GIS in the City’s SWM process? This study reveals that LCC can integrate GIS in its SWM process but due to several challenges faced by LCC, it is difficult for the Council to use GIS technology in SWM.

The study established and concluded that GIS is not integrated at each stage despite the need for this spatial information. Chalkias and Lasarid (2011) indicate that spatial information is crucial in the Solid Waste Management process since it helps in providing information regarding population density, waste generation rate in specific areas, positioning of SW collection bins, road network to be used in transferring the solid waste and determining identification of suitable SW disposal sites.

The study listed a number of the geographical issues that prevent GIS from being integrated into the SWM process and the following are some of the challenges:

5.6. Solid Waste Management Challenges in Lilongwe City

1. Lack of GIS knowledge among working staff.
2. Lack of equipment e.g. computers, scanners, GPS and GIS software in the SWM section.
3. The gap between the GIS section and the SWM Section of LCC.

Apart from the Geographical Information issues LCC, there are other general problems in the management of SW within the City. These problems emerge at different stages of the SWM process. The problems include a lack of local knowledge from the communities in Lilongwe City. The majority of the people are not aware of how they can be responsible in the management of their solid waste as a result they dump the waste haphazardly despite the Council's initiative of placing bins, especially in markets and other local centers. At the institutional level, the Council is also challenged by a lack of adequate resources to efficiently manage the solid waste within the city. The inadequate resources include finances, Solid Waste Management equipment like vehicles, equipment for the management of the dump site and inadequate human capacity. The working environment for the Council's staff at the dump site is very pathetic. The dump site has no office for on-site workers to use. The dump site is not treated with chemicals as a result there are a lot of flies and a bad odour. The dump site is not fenced as a result the site is invaded by people who come to collect some items that they feel could be of use. The situation has always endangered the lives of the Council's staff who work at this dump site with no office water to use and proper working equipment. The dump site is big and there are only four working personnel to manage the site. Sometimes fights erupt from the people who invade the site as they struggle to pick the dumped items for reuse recycling or consumption and this also endangers the lives of the City's working personnel at the dump site.

5.7. Chapter Summary

The chapter has discussed and highlighted the results and results of the study. The main objective of the study was to investigate the integration of GIS in SWM. This chapter has discussed the current SWM process that is being used by LCC. It has also discussed the institutional arrangement for LCC. The discussion also sheds more light on the analysis of the spatial information needs as well as the sources of spatial information needed for Lilongwe City SWM. It has also been highlighted in this chapter that the SWM is affected by several challenges.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1. Introduction

This chapter presents the conclusions of this study in line with the research objectives. This chapter will also highlight the recommendations on how LCC can integrate GIS in SWM.

6.2. Summary

The main objective of the study was to assess the integration of GIS in SWM in Lilongwe City. The study concluded that Lilongwe City Council has its GIS unit but there was no evidence of integrating the GIS in the SWM process hence a gap in spatial information for effective SWM

6.2.1. Solid Waste Management Process for Lilongwe City

The first specific objective of the study was to analyse the existing process of SWM for Lilongwe City. The study concludes the LCC follows a process that has 9 stages and these stages include; Solid generation, Transport Determination, SW Location, SW Collection, SW Transfer, SW Dumping Site, SW Data Capturing and SW Data compilation. The study further concludes that GIS is not used at any of the stages of the process used by LCC.

6.2.2 Spatial Information Needs for Solid Waste Management in Lilongwe City

The second specific objective was to analyse spatial information needs for SWM in Lilongwe City. The study concluded that spatial information is needed at every stage in the Solid Waste Management SWM process used by Lilongwe City. The study concluded that spatial information is needed for easy and improved solid waste management at Lilongwe City Council.

6.2.3 Analysis of Spatial Information Sources for Solid Waste Management in Lilongwe

The third objective was to analyse spatial information sources for SWM in Lilongwe. The study concluded that Lilongwe City through its GIS unit has spatial information sources but the information is not used in SWM at Lilongwe City Council.

6.2.4. Solid Waste Management Challenges in Lilongwe City

The final objective was to analyse SWM challenges in Lilongwe City. The study concluded that several challenges affect solid waste management in Lilongwe e.g. Inadequate Financial, Human resources and working equipment, The Dump Site no longer being in an appropriate location, Lack of public awareness on solid waste management in Lilongwe City and Lack of GPS tracking devices for vehicles transferring the solid waste to the dump site.

6.3. Conclusion

Based on the results provided by the study, it is concluded that GIS can indeed be integrated into the waste management processes in Lilongwe City and improve the process. The study found that Spatial Information is available but is not integrated into any of the SWM stages.

6.3 Recommendations

In light of these conclusions, the following are the recommendations;

- To integrate GIS in SWM, Lilongwe City Council should train the staff involved in SWM how to use the GIS technology in delivering SWM services
- The SWM process that Lilongwe City Council uses should be an improved monitoring system that will enable the efficiency and effectiveness of the process.
- To close the gaps in spatial information needs, LCC should invest in GIS technology that will supply spatial information for SWM
- To solve the SWM challenges in Lilongwe City, the Council should sensitize the local people to methods of SW management and the Local government should allocate enough funding for SWM services

- The study recommends that further research should be on the topic title; Mapping of solid waste hot spots in Lilongwe City

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Appendix

Appendix A: MZUNIREC Approval

MZUZU UNIVERSITY

DIRECTORATE OF RESEARCH

Mzuzu University
Private Bag 201
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MALAWI
TEL: 01 320 722
FAX: 01 320 648

MZUZU UNIVERSITY RESEARCH ETHICS COMMITTEE (MZUNIREC)

Ref No: MZUNIREC/DOR/23/115 **01/11/2023.**

Wise George Kamwiyo,
Mzuzu University,
P/Bag 201,
Luwinga,
Mzuzu 2.

wise.kamwiyo@gmail.com

Dear Wise,
RESEARCH ETHICS AND REGULATORY APPROVAL AND PERMIT FOR PROTOCOL REF NO: MZUNIREC/DOR/23/115: ASSESSING GEOGRAPHICAL INFORMATION SYSTEMINTEGRATION IN SOLID WASTE MANAGEMENT IN LILONGWE CITY.

Having satisfied all the relevant ethical and regulatory requirements, I am pleased to inform you that the above referred research protocol has officially been approved. You are now permitted to proceed with its implementation. Should there be any amendments to the approved protocol in the course of implementing it, you shall be required to seek approval of such amendments before implementation of the same.

This approval is valid for one year from the date of issuance of this approval. If the study goes beyond one year, an annual approval for continuation shall be required to be sought from the Mzuzu University Research Ethics Committee (MZUNIREC) in a format that is available at the Secretariat. Once the study is finalised, you are required to furnish the Committee with a final report of the study. The Committee reserves the right to carry out compliance inspection of this approved protocol at any time as may be deemed by it. As such, you are expected to properly maintain all study documents including consent forms.

Committee Address:
Secretariat, Mzuzu University Research Ethics Committee, P/Bag 201, Luwinga, Mzuzu 2; E-mail address: mzunirec@mzuni.ac.mw

Wishing you a successful implementation of your study.

Yours Sincerely,

Gift Mbwele

SENIOR RESEARCH ETHICS ADMINISTRATOR

For: CHAIRMAN OF MZUNIREC

Appendix B: Informed Consent

Mzuzu University Research Ethics Committee (MZUNIREC)

Assessing Geographical Information System integration in solid waste management in Lilongwe City

Introduction

I am **Wise George Kamwiyo** from the Department of Built Environment, Faculty of Environmental Sciences. I am conducting research on **Assessing Geographical Information System integration in solid waste management in Lilongwe City.**

This consent form may contain words that you do not understand. Please ask me to stop as we go through the information and I will take time to explain. If you have questions later, you can ask them to me or another researcher.

Purpose of the research

The main objective of this study is to assess Geographical Integration System (GIS) Integration in Solid Waste Management in Lilongwe City

Type of Research Intervention

This research will involve your participation in an individual/ household interview.

Participant Selection

You are invited to take part in this research because you are a resident of this area and may have experienced solid waste problems.

Voluntary Participation

Your participation in this research is entirely voluntary. It is your choice whether to participate or not. If you choose not to participate nothing will change. You may skip any question and move on to the next question.

Duration

The research takes place for **2 years**.

Risks

You do not have to answer any questions or take part in the interviews if you feel the question(s) are too personal or if talking about them makes you uncomfortable.

Reimbursements

You will not be provided any incentive to take part in the research.

Sharing the Results

The knowledge that I will get from this research will be used for academic purposes and will be shared with the Universities with similar programmes (like Geographic Information Systems, Urban Planning, and /or Disaster related programmes).

Following, the results will be reported as a thesis for academic purposes.

Who to Contact

If you have any questions, you can ask them now or later. If you wish to ask questions later, you may contact: Mr. Wise George Kamwiyo, Mzuzu University, P/B 201, Luwinga, Mzuzu. Cell: +265(0)999 362 207 or Associate Prof. Mavuto Tembo, Mzuzu University, P/B 201, Luwinga, Mzuzu 2. Cell: +265(0) 997 376 822.

This proposal has been reviewed and approved by Mzuzu University Research Ethics Committee (MZUNIREC) which is a committee whose task is to make sure that research participants are protected from harm. If you wish to find out more about the Committee, contact Mr. Gift Mbwele, Mzuzu University Research Ethics Committee (MZUNIREC) Administrator, Mzuzu University, P/Bag 201, Luwinga, Mzuzu 2, Phone: 0999404008/0888641486

Do you have any questions?

Part II: Certificate of Consent

I have been invited to participate in research about **Assessing Geographical Information System integration in solid waste management in Lilongwe City**.

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions I have been asked have been answered to my satisfaction. I consent voluntarily to be a participant in this study

Print Name of Participant__________________Signature of Participant ___________________

Date ___________________________

Day/month/year

If illiterate [1]

I have witnessed the accurate reading of the consent form to the potential participant, and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

[1] A literate witness must sign (if possible, this person should be selected by the participant and should have no connection to the research team). Participants who are illiterate should include their thumb print as well.

Print name of witness____________ **Thumbprint of participant**

Signature of witness _____________

Date ______________________

Day/month/year

Statement by the researcher/person taking consent

I have accurately read out the information sheet to the potential participant, and to the best of my ability made sure that the participant understands the research project. I confirm the participant was allowed to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

Signature of Researcher /person taking the consent__________________________

Date __________________________

Day/month/year

Appendix C: QUESTIONNAIRE FOR FIELD SURVEY INTERVIEWS

Preamble:

I am a researcher from Mzuzu University working on my Master's dissertation on the Assessment of Spatial Information Gaps in the solid waste management case of Lilongwe City Council. This is academic research and all the information collected is meant for academic use only. This study is aiming at identifying and assessing the SWM spatial information gaps that may be there at the Lilongwe city council or it is not used to affect the management of solid waste within the city. I am emphasizing that all the information provided by you as a respondent will be treated as private and confidential and the results of the study will be made available to you.

Thank you for your participation.

Interview number: ____________________________

Name of interviewer: ____________________________

Date of interview: ____________________________

Place of interview: ____________________________

Interview format: Face-to-face Interviewee filled in other: ____________

The research explained and introductory (preamble) provided: yes/no (reason: __________)

Consent form signed: yes/no (reason: ________________)

SECTION A: SOLID WASTE MANAGEMENT – GENERAL:

I would like to start the interview with a few questions about solid waste management in Lilongwe city

A1. Can you please tell me what constitutes solid waste management to you?

A1. How is solid waste activity managed in the city? By whom?

A2. What would you say are the major problems with solid waste management in Lilongwe city?

A3. What is the state of the natural environment with respect to solid waste handling practices in Lilongwe city?

A4. What are the most common environment and health issues that you face in the city with respect to solid waste management?

A5. What agencies are involved in/ responsible for solid waste management in Lilongwe city?

____

____

i.) What is the level of their involvement/ responsibility?

____

____

____

A6. What agencies are involved in/ responsible for addressing environmental problems in the City?

____

____

i) What is the level of their involvement/ responsibility?

____

____

____

A7. Which of the following environmental problems have been experienced by the city/ Community/area in relation to solid waste?

[] water pollution [] flooding

[] air pollution [] smoke

[] Fire hazards [] pests, vermin, and flies

[] littering [] other:_______________________________________

A8. How much volume of solid waste is generated by a person/day in your house on average?

( ) 0.1 – 0.2

( ) 0.2 – 0.3

( ) 0.3 – 0.4

( ) 0.4 – 0.5

( ) 0.6 – 0.7

( ) 0.7 – 0.8

SECTION B: KNOWLEDGE AND INFORMATION SOURCES:

B1. What are the focal areas of information, data gathering and intervention by you/your agency/group in managing solid waste in the city/ area? Why?

____

____

____

B2. Do you know about local (traditional) ecological knowledge of solid waste management at your household level? How?

____

____

i.)What do you think of it?

____

____

____

B3. Do you think it has a role/(s) to play in the management of solid waste in this city? Why?

____

____

B4. What role do you think local (traditional) ecological knowledge will be best suited to play in managing solid waste in this city? Why?

___

___

___

B5. How effective do you think informal and community attempts at facilitating information/ knowledge for managing solid waste has been?

[] Most Effective [] Very Effective

[] Effective [] Partially Effective

[] Not Effective

i.) Why?

___

___

___

B6. In what ways have these attempts been effective?

___

___

___

B7. What do you consider to be the most appropriate way for managing solid waste?

___

___

___

B8. Based on your knowledge or experiences, what will be the anticipated barriers to the implementation or use of local (traditional) ecological knowledge in the management of solid waste? Why?

____

____

B9. Based on your knowledge and experience, what kinds of approaches have been employed in

the management of solid waste in this city?

____

____

____

i) Were they successful? Why/ why not?

____

____

____

B10. Tell me what you know about the ecological well-being of your area/community/city.

____

____

____

B11. What kind of information would be helpful in effectively managing solid waste in the city?

____

____

____

B12. Do you think there are particular groups of people in the area /community/city who are knowledgeable on traditional ways of managing solid waste?

B13. Do you trust your sources of knowledge/ information?

SECTION C: LOCAL (TRADITIONAL) KNOWLEDGE, PRACTICES, PROCESSES AND BELIEFS:

C1. How do you apply your traditional knowledge with regard to solid waste management? practices within the community/ area/city?

C2. Are there any government departments/ agencies involved in the application and use of your local knowledge? If so, what role(s) do they play?

C3 Does local (traditional) knowledge play a role in the decision-making process of your day-to-day activities of Solid waste management? If so, what role(s) does it play?

C4. Are there any non-governmental organisations (NGOs) or community-based organisations (CBOs) involved in the use/ gathering of traditional knowledge about solid wastes? [Can you tell me the names of these organisations and the role(s) they play?]

C5. How involved are the indigenous and local chiefs and leaders in the decision-making process? of managing solid waste? [Can you identify some of those actively involved and the role(s) they play?]

C6. What traditional or local **norms** practiced by people regularly influence their attitudes and perceptions regarding waste handling? [Can you tell me how these norms play a role/(s)?]

C7.What traditional or local **beliefs** held by people influence their perspectives, attitudes and perceptions regarding solid waste handling? [Can you tell me how these beliefs play a role/(s)?]

C8. Does the Waste Management Department involve local (traditional) knowledge as part of the decision-making process in managing waste collection? YES/ NO/ DON'T KNOW

I. How frequently is this done?

II. What is the source of this knowledge/ information?

III. How is this knowledge used/ incorporated into decisions and management activities?

Why has the Waste Management Department been engaging local (traditional) Knowledge in its management Initiatives?

V. Has this approach been successful? YES/ NO/ DON'T KNOW In what way has it been a success?

C10. Are there any informal approaches to handling solid waste that you can think of that are important in the management approach and decision-making process about waste services? Yes/no/ DON'T KNOW

i. Who/What is involved in these informal approaches?

Ii How often have these approaches been employed and in what capacity or role?

C11. Are there any alternatives to the current arrangements of solid waste management being employed? Yes / No/ DON'T KNOW

If so, what were they:

C12. What implications do you think the involvement of local knowledge in waste management has for the planning of solid waste management at the institutional level?

SECTION D: HOUSEHOLD SURVEY - SOCIO-ECONOMIC AND DEMOGRAPHIC CHARACTERISTIC OF RESPONDENT:

D1. Sex: [ ] male [ ] female

D2. Educational Status:

[ ] no formal education

[ ] primary level

[ ] secondary level (Junior/Senior)

[ ] elementary level

[ ] tertiary/ post-secondary

[ ] Employment Business ( ) Employed ( )

D1. SOURCES OF SPATIAL INFORMATION AT THE HOUSEHOLD LEVEL

1. House ownership Renting ( ) Owned ( )
2. How do you handle your household solid waste?

   ____

   ____

3. What type of solid wastes are generated at your house?

   a.) Plastics ( )

   b.) Kitchen wastes ( )

   c.) Other wastes name them

   ____

   ____

4. Where do you dump your waste?

   a.) In the bin ( )

   b.) In the pit ( )

   c.) In the river bank ( )

   d.) On the road ( )

   e.) On open space ( )

   f.) Other

   (Specify)____

Appendix D: INTERVIEW FORM GUIDE FOR SPATIAL DATA SOURCES

Preamble:

I am a researcher from Mzuzu University working on my master's dissertation on the role local (traditional) knowledge has to play in managing solid waste in African cities. This is aimed at helping to invoke action to improve the existing solid waste management situation, as well as to explore the possible ways of integrating geographical information systems into the management of solid waste. I am especially interested in assessing the spatial information gaps in solid waste management. This interview should take about 30 minutes. If you have any questions at any point do not hesitate to ask. With your agreement, I would like to tape-record the interview to accurately document your views. Your name or address will not appear on any tapes or manuscripts as stated in the consent form. This is neither a government survey nor a profit-oriented project. The information from this interview will be aggregated with others from similar interviews and will be used for academic purposes. The information collected here is **confidential and no direct reference will be made to individual names**. A brief summary of the results of the study will be provided to all participants in appreciation of their involvement in the study.

Thank you for your participation.

Interview number: ____________________________

Name of Interviewee/(s) Present: ____

Date of Interview: ____________________________

Place of Interview: ____________________________

Interview format: [ ] Face-to-face [ ] Interviewee filled in [ ]Other:___________

Research explained and introductory (preamble) provided: yes/no (reason: __________)

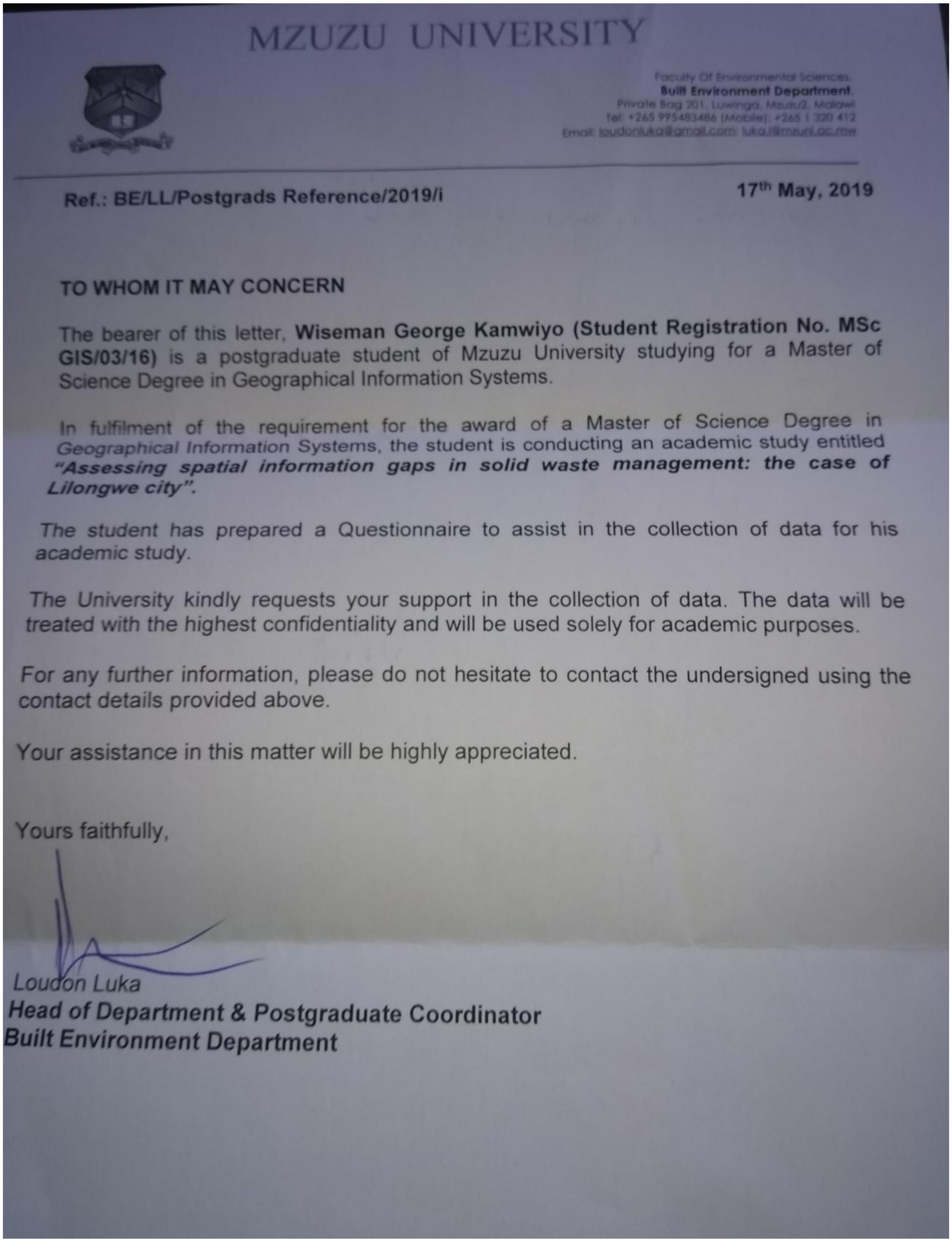
Consent form signed: yes/no (reason: ________________)

SPATIAL INFORMATION KNOWLEDGE:

1. I am interested in learning about spatial information knowledge in relation to solid waste management. Can you tell me what spatial information means to you?
2. Do you have a solid waste database?
3. If you have the database, in what format do you store your solid waste data?

4. Who in your view possesses and manages this data?
5. How do you apply your spatial information with respect to solid waste management practices within the community/area/city?
6. What constraints or barriers make it difficult for spatial information to be used in the management of solid waste activities?
7. What are the various sources of solid waste spatial information in your institution?
8. What strategies do you embark upon to cope with problems and issues arising from the positioning of solid waste collection and disposal in your community/area/city?
9. Do you think that spatial information can help to properly handle the issues in question above?
10. Do you have by-laws that constitute solid waste management in this city?
11. In brief, what do the by-laws entail regarding solid waste?
12. Do the by-laws talk about solid waste data management?

Appendix E: Letter of Introduction Data Authorisation from Mzuzu University



MZUZU UNIVERSITY

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Built Environment Department,
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Tel: +265 995483486 (Mobile); +265 1 320 412
Email: loudonluka@gmail.com; luka.l@mzuni.ac.mw

Ref.: BE/LL/Postgrads Reference/2019/i

17th May, 2019

TO WHOM IT MAY CONCERN

The bearer of this letter, **Wiseman George Kamwiyo (Student Registration No. MSc GIS/03/16)** is a postgraduate student of Mzuzu University studying for a Master of Science Degree in Geographical Information Systems.

In fulfilment of the requirement for the award of a Master of Science Degree in Geographical Information Systems, the student is conducting an academic study entitled ***"Assessing spatial information gaps in solid waste management: the case of Lilongwe city".***

The student has prepared a Questionnaire to assist in the collection of data for his academic study.

The University kindly requests your support in the collection of data. The data will be treated with the highest confidentiality and will be used solely for academic purposes.

For any further information, please do not hesitate to contact the undersigned using the contact details provided above.

Your assistance in this matter will be highly appreciated.

Yours faithfully,

Loudon Luka
Head of Department & Postgraduate Coordinator
Built Environment Department

Appendix F: Letter of Authorisation and Data Collection Permission from Lilongwe City Council

LILONGWE CITY COUNCIL

ALL CORRESPONDENCE TO BE ADDRESSED TO THE CHIEF EXECUTIVE OFFICER

Our Ref : LCC/ ADMIN/7

P.O Box 30396
Lilongwe 3
Malawi
Tel: (265) 773 144
Fax: 01 770 885

28th May 2019

Mr. Wiseman George Kamwiyo
Mzuzu University
Private Bag 201
Luwinga
Mzuzu 2.

Dear Mr. Wiseman George Kamwiyo

RE: REQUEST FOR PERMISSION TO COLLECT DATA ON THE ASSESMENT OF SPATIAL INFORMATION GAPS ON SOLID WASTE MANAGEMENT

We acknowledge receipt of your letter dated 13th May, 2019, requesting permission from the Council to collect data on the Assessment of Spatial Information Gaps on Solid Waste Management.

We wish to inform you that permission has been granted and you can proceed with your planned program. Please be advised to liaise with the Council's Director of Health and Social Welfare for appropriate guidance and support.

Kindly note that this approval is granted on condition that your findings will be used for your research purposes only.

Yours faithfully

pp

John Chome
CHIEF EXECUTIVE OFFICER

Cc : Director of Health and Social Welfare