MULTI-FACTOR GIS MODELLING FOR SOLID WASTE DUMPSITES IN LILONGWE CITY

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MULTI-FACTOR GIS MODELLING FOR SOLID WASTE DUMPSITES IN LILONGWE

MSc. (INFORMATICS) THESIS

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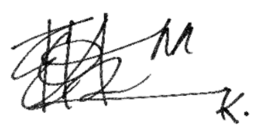
DECLARATION

I declare that this thesis is my original work and has not been submitted to any other institution for similar purposes. Acknowledgements have been duly made where other people's work has been used. I bear the responsibility for the contents of this paper.

Stephen Mandiza Kalisha

Full Legal Name



Signature

September 2024

Date

CERTIFICATE OF APPROVAL

The undersigned certifies that this thesis represents the student's work and effort and has been submitted with our approval.

Signature: ______________________________ Date: ______________________

Kondwani Godwin Munthali, PhD (Senior Lecturer)

Supervisor

DEDICATION

I want to dedicate this research to my wife, son, parents, brothers, and sisters, who remained supportive and understanding until the end.

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ABSTRACT

Solid waste disposal is an essential component of any waste management system; however, locating appropriate solid waste disposal sites is regarded as the primary issue in solid waste management. Disposal site selection is a step-by-step process in which environmental, engineering, and economic criteria are applied successively. This research aimed at identifying additional suitable sites for solid waste dumping in Lilongwe that do not pose logistical and operational challenges to improve efficiency in waste management. It assessed the suitability of the current dumpsite at Area 38 in Lilongwe City, examined site selection methods for solid waste disposal, and developed a multi-factor GIS model for the identification of suitable dumpsites in Lilongwe. A blended approach to research design was used in this research, and the study considered 10 factors: slope, rivers, soil types, built-up areas, airport, forests, wetlands, current dumpsite, roads, and railways. The findings recommend the closure of the current dumpsite and its relocation to a more suitable place because it is close to residences and creates major health risks. Additionally, the research reveals that the most popular techniques for choosing the location of a solid waste disposal facility are the Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC) coupled with GIS. Further, the findings showed that of the 46, 283 ha, 84.07% (38, 909 ha) are unsuitable, 14.97% (6, 928 ha) are suitable and 0.96% (446 ha) are highly suitable for solid waste disposal sites. Finally, the results show that 6 sites, with capacities ranging from 28 to 94 ha, were identified using the multi-factor GIS model developed in this study.

Keywords: Multi-factor, Modelling, Solid waste, Dumpsites, GIS, AHP, WLC.

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CHAPTER 1

INTRODUCTION

This chapter will provide an introduction to the study by first discussing the background of the study, followed by the research problem, the main research objective, specific objectives, and finally, the justification of the study.

Waste is material discharged from human activities, adversely impacting human health and the environment (Singh, 2019). Solid waste refers to the leaves/twigs, food remnants, paper/cartons, textile materials, bones, ash/dust/stones, dead animals, human and animal excreta, construction and demolition debris, biomedical debris, and household hardware debris such as electrical appliances and furniture debris (Ebistu & Sewnet minale, 2013). World global production of Municipal Solid Waste (MSW) was estimated to be about 1.3 billion tonnes per annum in 2012, and it is predicted to grow to 2.2 billion tonnes per annum by 2025 (Barré, 2014). The Sub-Saharan Africa (SSA) region produces around 62 million tonnes of waste per year (5% of global production). The amount of waste produced is defined by the population in a specific area and its consumption patterns (Barré, 2014). These two factors are increasing rapidly in the current context, especially in Africa. Enormous and quick accumulation of waste is difficult to handle, especially in urban areas where space is scarce. Waste management is an “economic abyss” for cities in Africa due to their need for labour, technology, transport, and energy (Barré, 2014).

Malawi is generating half a kilogram of waste per capita daily, which adds up to a total of 633 fifteen-tonne trucks of waste produced every 24 hours (Sabola, 2020). Lilongwe City in Malawi has been one of the areas where more waste is generated, and the effect has been the steady degeneration in the quality of solid waste management by the Lilongwe City Council (LCC) (Maganga, 2013). Lilongwe is the largest city in Malawi with 1.171 million people, growing at a rate of 2.39 % per year and an annual rate of urbanization of 4.41 %(Malawi Demographics, 2021), making it one of the fastest-growing cities in the world. The city has experienced an influx of rural immigration in recent years because of anticipation of better living in urban areas through employment and businesses.

Solid Waste Management (SWM) is a global environmental problem in today's world, both in developed and developing countries like Malawi. Although solid waste can be recycled, most countries manage their solid waste by depositing them in dumpsites, as such, dumpsite or landfill site selection is a critical stage in SWM. Traditional site selection methods have been used in developing countries, such as the determination of appropriate sites on topographical maps. The best site is selected between those areas according to some criteria such as proximity to tourist areas and major attraction centres (Yildirim, 2012). Solid waste landfilling sites are often selected randomly, affecting nature and human beings (Singh et al., 2019). However, an appropriate landfill site should have the least negative effect on an area's economic, sociological, and environmental aspects (Yildirim, 2012).

Recently, planners have used Geographic Information Systems (GIS) that integrate with other computerised software tools, and mathematical and statistical methods for efficient and effective suitability site analysis (Mornya et al., 2010). GIS can include ecological, biological, demographic, or economic information in site suitability analysis. It has since become a valuable tool in the environmental and engineering sciences, including dumpsite identification, site/location identification, etc. Furthermore, GIS can also be combined with Multi-Criteria Evaluation (MCE) or multi-criteria decision analysis (MCDA) techniques, which have been proven to be decision-support tools in dealing with scenarios where technological, economic, ecological, and social aspects have to be considered for proper land use planning (Estoque & Murayama, 2010). GIS provides efficient manipulation and presentation of data, and MCE/MCDA provides factors' weights (computed using Analytical Hierarchy Process-AHP) of the landfill sites according to the importance of the criteria (Mornya et al., 2010). AHP is a theory of measurement through pairwise comparisons and relies on the judgment of experts to drive priority scales. It was developed based on the inherent ability of people to make excellent decisions (Estoque & Murayama, 2010).

1.1 Problem Statement

Lilongwe City is challenged by the accumulation of waste, with the solid waste collection rate currently around 30 %, due to the increase in the urban population and the limited resources of public services to manage solid waste. Additionally, Lilongwe city has one dumpsite which is in Area 38, which is relatively far (almost 30 to 40 km) from most of the townships and residential areas. The current dumpsite location poses logistical and operational challenges to Lilongwe City Council (LCC). Long-distance garbage collection is increasing operational costs and reducing efficiency in waste management by the LCC.

1.2 Objectives

1.2.1 Main Objective

The study's main objective was to determine suitable locations for dumpsites in Lilongwe City using a multi-factor GIS model.

1.2.2 Specific Objectives

The research sought to:

1. Assess the suitability of the current dumpsite at Area 38 in Lilongwe City.
2. Examine site selection methods for solid waste disposal.
3. Develop a multi-factor GIS model for the identification of additional suitable dumpsites in Lilongwe.

1.2.3 Research Questions

1. How was the current dumpsite selected (*is this area suitable*)?
2. What methods are used in the selection of solid waste disposals?
3. What factors should be considered when selecting a suitable dumping site, and how important are the factors?

1.3 Justification of Study

The solid waste collection rate in Lilongwe City is currently around 30 %, implying that a staggering 70 % of waste lies unmanaged and is disposed of in undesignated places, which increases health risks (Kamakanda, 2019). This is a result of the inadequate capacity of LCC to collect and dispose of the solid wastes at the dump site. Currently, LCC has only four refuse vehicles, which are inadequate given the amount of solid waste being generated and the long distances from collection points to the dumpsite (Kamakanda, 2019). Further, the council is already struggling to generate about MK14.5 million per month, it spends on waste collection alone, and the amount could be higher if issues such as waste disposal are added (Mkaka, 2021). These operational costs could be huge amounts in the future (10 or 20 years from now), making it difficult for LCC to provide adequate waste management services. While LCC is the main waste management service provider, the emergence and increase in the number of private waste collection/management companies suggest that LCC is overwhelmed and has failed to manage solid waste in the city. These private companies are equally challenged by increasing operational costs due to the long distance from waste collection points to the single dumpsite and their services may not be sustainable in the long term. Heaps of solid wastes uncollected for days are dumped along the roads and other places, an indication of the inadequate capacity of the LCC to collect wastes (*see* Figure 1.1). This situation would only get worse as the population increases.

Figure 1.1: Waste in public places - around the Lilongwe bus depot

Therefore, waste must be managed properly and dumped at a properly selected site for effective management. Even though traditional methods of selecting dumping sites for solid waste have been useful, this research set forth that using GIS, integrated with MCE techniques, would help identify alternative sites that are environmentally suitable for locating solid waste dumpsites. It would also help address LCC's logistical and operational challenges. According to Balew et al (2020) GIS can store, manage, analyse, and visualize geospatial data required for decision-making. MCE techniques have a rich collection of procedures, techniques, and algorithms that best allow for structuring decision problems and designing, evaluating, and prioritising decision alternatives (Balew et al., 2020).

A series of studies have been conducted over the past years on SWM and suitable waste disposal site selection. However, very few studies focused much on identifying suitable dumpsites that do not pose logistical and operational challenges. Previous studies have almost exclusively focused on dumpsite selection methods, such as the Weighted Linear Combination (WLC), Artificial Neural Networks (ANN), Analytic Hierarchy Process (AHP), Fuzzy Analytic Hierarchy Process (F-AHP), Analytic Network Process (ANP), Fuzzy-Analytic Network Process (F-ANP), TOPSIS (a Technique for Order of Preference by Similarity to Ideal Solution), Grey theory and their integration with GIS to select potential areas for suitable solid waste dumping. Thus, this research focused on identifying suitable dumpsites that do not pose a logistical and operational challenge to reduce the operational costs that LCC faces, hence improving efficiency in waste management. Furthermore, this study proposes a model emphasising factors that the dumpsite is to be sited.

1.4 Chapter Summary

In chapter one, the background to the study has been provided, the research objectives have been identified and the value of such research has also been discussed. Chapter two reviews the existing literature, containing key terms, e.g., solid waste, waste management, dumpsites, GIS, and AHP. In chapter three, the methodology is presented, focusing on the methods used, the study area, data collection, data preparation, tools, and the research approach is discussed. Chapter four contains the results and discussion,s and finally, chapter five contains the research's conclusion and recommendations.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a review of the literature on Solid Waste Management (SWM) in Malawi, GIS and MCDA in Solid Waste Management, Analytical Hierarchy Process (AHP), Weighted Linear Combination (WLC), Solid Waste Dumpsite Selection and key terms in the dumpsite selection process are defined and their relationships are discussed.

2.1 Solid Waste Management (SWM)

Solid waste is defined as all discarded solid materials from households, industrial, healthcare, construction, agricultural, commercial, and institutional sources (Ziraba et al., 2016). Some authors have also defined solid waste as non-liquid and non-gaseous products generated from commercial centres, households, municipal and social sectors, government and non-government offices, construction, and industries (Balew et al., 2020; Yildirim, 2012; Singh, 2019). The solid waste generated in cities, many times, is called Municipal Solid Waste (MSW) (Ziraba et al., 2016). It has been defined further that MSW is the assorted mixture of solid wastes discarded by the urban and rural population daily as garbage, trash, and refuse (S. Nanda & Berruti, 2021). In developing countries, like Malawi, municipal waste includes waste that would not ordinarily be considered municipal waste because most of the solid waste is not sorted at source, collection, transportation, and disposal points (Ziraba et al., 2016).

Therefore, in this paper, no exclusions were made for the reason that solid or municipal waste that is collected and transported to the dumpsite in Malawi (Lilongwe in particular) comprises kitchen waste (e.g. spoiled meat, fish, bones, eggshells, vegetable refuse, fruit shells), yard waste (e.g. Leaves, grass, tree trimmings, twigs), paper and cardboard (e.g.

newsprint, advertisement flyers, magazines, books, tissue paper), plastic and rubber (e.g. shampoo and detergent bottles, bottle caps, plastic lumber, piping for water and sewer, potable water bottles and beverage bottles), metal (e.g. knives, wires metal utensils), glass (glass bottles, light bulbs) and electronic waste (e.g. thrashed computer monitors, laptops, tablets, mobile phones, sound systems, and dead batteries) among others (S. Nanda & Berruti, 2021). According to Ng'ang'a et al (2014), SWM is defined as the discipline associated with the control of generation, storage, collection, transfer and transport, processing, and disposal of solid waste. SWM is a dilemma in many large urban areas of the world as populations interested in cities continue to grow, and this has led to an ever-increasing quantity of domestic solid waste, while space for disposal decreases (Berisa & Birhanu, 2015). A previous study by Nanda & Berruti (2021) has shown that 2 billion tonnes of MSW are generated globally, out of which almost 33 % remain uncollected by municipalities and its generation is expected to rise to 3.4 billion tonnes by 2050. 70 % of MSW collected by the municipalities ends up in landfills and dumpsites, 19 % is recycled, and 11 % is used for energy recovery (S. Nanda & Berruti, 2021).

The main SWM techniques are recovering, recycling, reusing, composting, incineration, and landfilling. However, landfilling is the most common way of disposing of MSW, especially in developed countries, whereas in developing countries, landfill sites don't seem to be identified scientifically, this affects the aesthetic value of the environment and also the human habitat (Balew et al., 2020).

2.2 Solid Waste Management (SWM) in Malawi

Malawi shares its borders with Mozambique, Zambia, and Tanzania, and has an estimated population of 18.6 million that is expected to double by 2038 (WorldBank, 2022). In Malawi, the total waste generation is projected to increase by 33% by 2050, and the total waste generation could triple by 2050 (Turpie et al., 2019). The four cities in Malawi, namely, Lilongwe, Blantyre, Zomba, and Mzuzu, together generate more than 1,000 tons of solid waste per day, and most studies reported that the waste management system and public awareness are inadequate to cope with the amount of waste generated (Turpie et al., 2019). As a nation, Malawi currently lacks adequate waste collection services offered by either the public or private sector (WasteAid & International Conservation and Clean-Up Management, 2020).

Like other developing countries across Africa, Malawi wrestles with solid waste management, e.g. urban areas in Blantyre lack access to solid waste services, and also lack vehicles at Blantyre City Council (BCC), and because of this, 70% of waste is not collected (Mpanang'ombe et al., 2021). This accumulated waste is causing power supply disruptions as over 96% of energy in Malawi is attained from hydro schemes from the Shire River. All that waste spread in the river leads to power outages in the country (Lenkiewicz, 2021).

SWM in Malawi is very poor and it's partially a result of insufficient financing and lack of institutional will. Council offices of Lilongwe, Mzuzu, and Blantyre have reported that insufficient staff, inappropriate collection vehicles, and limited operating budgets are among the challenges that the council offices continue to face (Christianity et al., 2020). Lilongwe is experiencing the greatest challenges in managing waste due to the issues of human resources and capacity, and a lack of guiding documents on how the waste can be managed (Mzungu, 2021). Recently, the LCC developed a SWM Plan to achieve a clean and environmentally sustainable city. For instance, the plan seeks to address the problem of illegal dumping in the city, as LCC spends about K80 million per annum on clearing illegal dumping (Mzungu, 2021).

2.3 GIS and MCDA in Solid Waste Management

2.3.1 GIS and MCDA

Geographical Information System (GIS) is a computerised system that can be used to get optimal solutions for efficient and effective solid waste management planning. It is a system that helps to capture, store, analyse, manage, and present data that are linked to location(s) (Mohammedshum et al., 2014). The use of GIS is one of the most promising approaches for analysing complex spatial phenomena because GIS has the advantage of storing, retrieving, and analysing a substantial amount of data from various sources and displaying the results spatially, which helps decision-makers solve problems (Nascimento et al., 2017). GIS has been used for various purposes with applications in the environment, e.g., assessing water pollution and identifying forest fire susceptibility among others. It has also been used in several studies to improve municipal solid waste management (MSWM) like predicting generation and composition patterns of MSW, improving MSW collection and transport, selecting locations for MSW transfer stations, and identifying areas for siting landfills (Nascimento et al., 2017).

Multi-Criteria Decision Analysis, (MCDA) or Multi-criteria Analysis (MCA), on the other hand, is a valuable tool that is applied to many complex decisions and is most applicable to solving problems that are characterised as a choice among alternatives (Ncsu, 2011). It is a decision-making analysis that evaluates multiple conflicting criteria as part of the decision-making process (Janse, 2018). Because SWM involves multiple factors, integrating MCDA with GIS improves the analysis effectiveness and accuracy, helping to understand the complexity of the problem, and ensuring the robustness and reliability of the final decision (Nascimento et al., 2017).

2.3.2 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP), an MCDA method component, was developed by Saaty in the 1970s (Nascimento et al., 2017). It is a technique mostly applied in planning as it provides a hierarchical structure by reducing multiple variable decisions into a series of pair comparisons and develops subjective priorities based on user judgment (Ng'ang'a et al., 2014). The GIS and AHP integration is a powerful tool for the selection of landfill sites (Ghazifard et al., 2016) because using GIS provides efficient manipulation and presentation of the data while AHP supplies consistent ranking of the potential landfill areas based on a variety of criteria (Asefa, 2019). AHP is used to determine the consistency of weightings for criteria by constructing a matrix for pairwise comparisons and also integrating qualitative analysis with quantitative factors (Abdulhasan et al., 2019).

AHP is built on three principles: decomposition, comparative judgments, and synthesis of priorities (Zadeh et al., 2013). In the decomposition principle, the decision-making problem is divided into a hierarchical form where elements have a hierarchical structure in special levels by considering their origin in higher levels continuously from more general to more particular (Zadeh et al., 2013). The comparative judgment principle is applied to construct pairwise comparisons, it includes the building of a comparison matrix at each level of the hierarchy, computing weights for each component of the hierarchy, and estimating the consistency ratio of elements (Balew et al., 2020). Principle three of the AHP consists of an overall priority rating to produce composite weight (Balew et al., 2020). In the AHP technique, the relative importance between two criteria is measured according to a numerical scale of 1 to 9 given by Saaty (Benezzine et al., 2022) (*See Table 2.1*).

Table 2.1: The fundamental scale of AHP (Zadeh et al., 2013)

Intensity of Importance	Definition	Explanation
1	Equal Importance	Contribution to the objective is equal
3	Moderate importance	An attribute is slightly favoured over another
5	Strong importance	An attribute is strongly favoured over another
7	Very strong importance	An attribute is very strongly favoured over another
9	Extreme importance	Evidence favouring one attribute is of the highest possible order of affirmation
2,4,6,8	Intermediate values (2: weak or slight, 4: moderate plus, 6: strong plus, 8: very, very strong)	When compromise is needed

AHP also provides a technique to determine the consistency of results in the decision-making process (Benezzine et al., 2022). The consistency is measured by evaluating the term consistency ratio (CR), which is the ratio of the consistency index (CI) to the random index (RI) that varies with the number of criteria (Benezzine et al., 2022). The consistency ratio is calculated to determine whether the judgment is consistent or not during the comparison of criteria (Sisay et al., 2021). The CR is calculated by using

$$\boldsymbol{CR = {}^{CI}/_{RI}} \tag{2.1}$$

Benezzine et al (2022) use the pairwise comparison matrix to calculate CI by using

$$\boldsymbol{CI = \frac{\lambda max - n}{n-1}} \tag{2.2}$$

where λmax is a distinct value and n is the number of parameters (Sisay et al., 2021).

The consistency ratio (CR) is acceptable if its value is less than **10%,** otherwise the judgments may be inconsistent and should be re-assessed to identify the source of the inconsistency and perfect it (Nascimento et al., 2017).

The combination of GIS and MCDA (such as the AHP, Weighted Linear Combination (WLC), and Analytic Network Process (ANP)), among others, has been widely used in dumpsite or landfill site selection studies. Benezzine et al. (2022); Balew et al. (2020); Ajibade et al. (2019); and Islam et al. (2018), for instance, combined GIS and MCDA in their studies. ANP transfers the experts' judgements to the supermatrices, which are made up of all the criteria, sub-criteria (or factors), and alternatives. This is a method of incorporating professional viewpoints and figuring out interactions and interdependencies. This exceptional feature of the ANP has drawn the attention of numerous planners and decision-makers in the domains of resource management and service allocation in addition to urban planning(Afzali et al., 2014).

2.3.3 Weighted Linear Combination (WLC)

The WLC is an aggregation procedure of the multi-criteria family that has the concept of fuzzy set theory, and this weighted summation approach can be employed for normalising criteria (Balew et al., 2020) also known as the ‘‘scoring method’’ (Shahabi et al., 2013). The WLC is a GIS multi-criteria evaluation technique used to evaluate suitable areas for dumpsite or landfill site locations (Khorsandi et al., 2019). Decision-makers use this technique to assign criteria weights based on the relative importance of each criterion suitability map, and combine the reclassified criteria maps to get an overall suitability score (Balew et al., 2020). The WLC method has the following steps; (1) defining the set of evaluation criteria and set of alternatives, (2) standardizing each evaluation criteria/map layer, (3) defining criterion weight, (4) constructing weighted standardized map layers, (5) generating the score for every alternative and (6) ranking the alternatives on the bases of the overall score (Balew et al., 2020).

2.4 Solid Waste Dumpsite Selection

Identification of the most suitable disposal site for solid waste requires a comprehensive assessment of site conditions (Berisa & Birhanu, 2015), and a robust evaluation process must consider the economic, environmental, health, and social impacts (Mohammed et al., 2017). Many factors and criteria must be taken into consideration in evaluating new solid waste disposal sites and weights must be assigned to each of them (Ng'ang'a et al., 2014). These factors include distance to urban centres, water bodies, airports, infrastructures, and soil permeability (Mohammed et al., 2017), proximity to residential and industrial areas (Berisa & Birhanu, 2015). For example, a dumpsite must be far enough from a road and it should not be constructed too far from main roads because a faraway dumpsite increases the cost of new access road construction, and transportation (Rezaeisabzevar et al., 2020). Furthermore, a distance of less than 500 m is considered unacceptable, and a distance of 1000–2000 m from the main road is considered optimal (Rezaeisabzevar et al., 2020).

As can be seen, various environmental, social, and economic parameters make the process of dumpsite selection complicated and it is difficult to aggregate and analyse different factors and present the outcomes clearly (Karimi et al., 2018). Even though the process of selecting a dumping site is very complicated, some authors have found that models of the analytic multi-criteria decision-making process, such as AHP and WLC are one of the best techniques that can be used and combined with GIS for site selection or suitability analysis (Mohammed et al., 2017).

2.5 Chapter Summary

The literature on Solid Waste Management (SWM) in Malawi, GIS and MCDA in SWM, Weighted Linear Combination (WLC), Analytical Hierarchy Process (AHP), Solid Waste Dumpsite Selection, and important words in the dumpsite selection procedure are reviewed in this chapter. Literature has revealed that, despite the complexity of the dumping site selection process, models of the analytic multi-criteria decision-making process, such as AHP and WLC, are among the most effective methods when paired with GIS for site selection or suitability analysis.

CHAPTER 3

METHODOLOGY

This chapter presents an outline of the research methods used. It provides information on the participants and how they were sampled. The chapter also describes the research design chosen for the study, the data collection process, the data analysis process, and the modelling of dumpsites for solid wastes.

3.1 Study Area

Lilongwe, the largest city in Malawi, became the capital and administrative City of Malawi in 1975 after relocating from Zomba (UN-HABITAT, 2011). The city is in the central region of Malawi, located at latitude -13.96692 and longitude 33.78725 (see Figure 3.1) and it is an important economic and transportation hub for central Malawi.

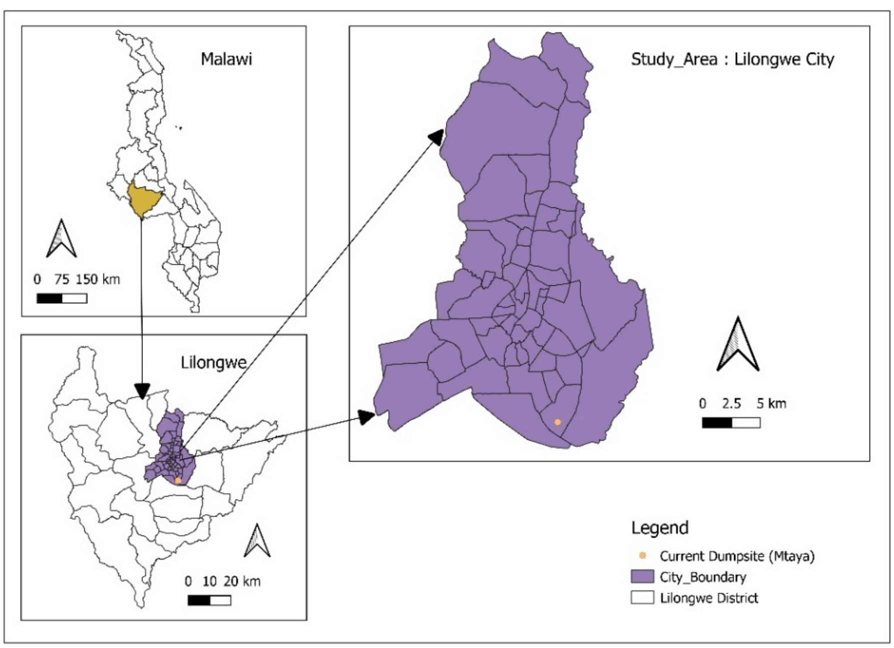

Figure 3.1: Study Area

3.2 Research design

A blended approach method of research design was used in this study. The qualitative approach helped the researcher to get an understanding of how the current dumpsite was selected, the factors that were considered, whether the area was suitable for the dumpsite, and the method used in selecting it. This information was collected using semi-structured interviews with the LCC staff, among others, and data were analysed using content analysis and thematic analysis. Content analysis was used to assess trends within a piece of content, such as a compilation of newspaper articles, to determine the frequency with which an idea is shared or discussed about the existing dumpsite and waste management in Lilongwe. Further thematic analysis classifies datasets based on shared characteristics, or themes. These themes aided in understanding people's perspectives, experiences, and thoughts on the current dumpsite. They were then integrated with quantitative factors produced after ranking the factors. Quantitative data was collected using a questionnaire where selection criteria were ranked using the AHP scale and analysed using descriptive analysis in maps. The results were used in dumpsite modelling and suitability analysis.

Although many studies used MCDA, e.g. AHP, in dump site selection, Abujayyab et al (2017), in their research stated that Artificial Neural Networks (ANN) can be used instead of MCDA. They argued that MCDA is inefficient as it relies on human knowledge to select weights and requires a massive understanding of the evaluating zone, which sometimes leads to inappropriate generalisations, wasted time and effort, and high cost. However, this paper used AHP for dumpsite modelling in Lilongwe, because it is flexible, it considers both objective and subjective factors when ranking alternatives, it checks inconsistencies, and the importance of each factor becomes clear since the problem is built into a hierarchical structure. In addition, AHP has procedures, techniques, and algorithms for structuring decision problems, designing, evaluating, and prioritising decision alternatives in the best way possible (Balew et al., 2020).

3.3 Data collection and tools

In this research, both primary and secondary data were used to gather information and different data collection instruments such as interviews, questionnaires, and Global Positioning Systems (GPS) receivers for spatial data collection as well as field observation were used during the data collection period.

The researcher interviewed 2 LCC staff who have first-hand experience with the current dumpsite in Area 38; 3 experts in dumpsite selection and waste management; and 6 households around the current dumpsite were also interviewed. These interviews helped in understanding how the current dumpsite was selected, how it got to be there, and what methods were used in selecting the site, the suitability of the dumpsite. As such, the participants in this research were purposefully sampled. Furthermore, the interviews helped in understanding the social impacts being caused by the current dumpsite. The interviews took place at participants' places of work using an interview guide with semi-structured questions. To get more information, participants were asked if they had any questions or comments to add to what they had been interviewed about.

An interview questionnaire was used, which had suggested selection criteria for the dump sites. Experts in dumpsite selection ranked the factors by using the pairwise comparison matrix - Analytic Hierarchy Process (AHP) Scale of 1 to 9 (*See Table 2.1*). Apart from the suggested factors in the questionnaire, space was provided to add other important factors in selecting sites for dumping solid waste. Further, data was also collected through physical observations of the current dumpsite and surrounding areas, and cameras were used to capture pictures at the dump site. In addition to that, a geographic location (coordinates) of the current dumpsite was captured using GPS.

Secondary data were acquired from the LCC (e.g., reports), the internet, books, journals, departments/ institutions, and other documents to further understand the requirements for solid waste location (see *Table 3.1*). Likewise, different factor maps such as land use maps and road network maps of the study area, among others, were used in selecting suitable solid waste dumpsites.

Table 3.1: Datasets and sources

Data	Source
Land use (Built-up area)	Sentinel-2 (of 2021) https://livingatlas.arcgis.com/landcover/ https://www.dof.gov.mw/resources/geospatial-data
Current dumpsite	Google Earth/Map
Rivers	Open Street Map
Roads, city boundary, Railway, wetland	Ministry of Lands
Airport, Rivers	Open Street Map
Soil	https://www.masdap.mw/
Slope	https://earthexplorer.usgs.gov/

The following software and tools were used:

- ArcMap 10.7.1 - for generating maps and running suitability analysis
- QGIS- for generating maps.
- Excel –for calculation of geometric mean for AHP respondents
- SpiceLogic Analytic Hierarchy Process- for calculation of consistency index (CI) and consistency ratio (CR) of ranking factors
- Google Earth Pro- to visualize and analyse satellite images, and verification of candidate sites.

3.4 Methods

In this study, the first step in modelling dumpsites for solid wastes is to clearly state the goal and this research aim was to determine suitable locations for dumpsites in Lilongwe. This step was followed by identifying siting criteria from literature and expert knowledge, from this, the study considered the following factors or criteria categorised into four groups: environmental, economic, access, and social-safety factors. Environmental factors consist of slope, rivers, wetlands, and Soil types. The second group consists of economic factors such as land uses (*built-up area, forest/ plantations*). The third parameter presents access factors roads and railways, and the final group presents social and safety factors such as distance from the airport and current dumpsite. All these datasets were georeferenced to WGS 84/UTM zone 36S, their buffer distances calculated, reclassified by giving weights to generate new maps and clipped based on the study area boundary.

3.4.1 Description of factors

Slope: The slope of the land is an important criterion in dumpsite selection (Al-Anbari & Ensaif, 2018) because it determines the runoff of the site (Asefa, 2019). A very steep slope is not suitable for dumpsites as it increases excavation costs and leachate, because of this a dumpsite should be built on a mild slope of less than 12% (Nanda et al., 2022).

Rivers: The dumpsite site should not be located close to rivers or surface water bodies due to leachate pollution. Leachate endangers water bodies, and groundwater, as such, the buffer distance of 500m must be established around rivers or water bodies (Mousavi et al., 2022).

Roads and railway: Roads and railways are very important as transport mediums that have to be considered critical. The selected site should be away from primary roads and secondary roads to prevent the potential interference between the main traffic and vehicles transferring wastes as such a buffer of 500m and 100m should be established respectively (Al-Anbari & Ensaif, 2018), for railway a buffer of 700m would be suitable (Jerie & Zulu, 2017). However, they must not be located very far away to minimise transportation costs. This research considered primary, secondary, district and tertiary roads.

Built-up area: The distance between dumpsites and built-up areas should be carefully assessed, as the dumpsites harm by a variety of factors, including odours, noise and health issues among others (Nanda et al., 2022). As such, dumpsites should be very far from built-up areas/ settlements/residential areas and a distance of more than 1000m is considered appropriate (Ndeke, 2018).

Soil type: Soil types must be properly evaluated when selecting dumpsites, clay soil is one of the best soil types for solid waste disposal siting because it can prevent leachate problems (Asefa, 2019).

Existing (current) dumpsite: A dumpsite must be located far enough from surrounding residents and water bodies (Xiang et al., 2019) and a distance of more than 1000m is considered safe (Dolui & Sarkar, 2021).

Wetlands: Wetland areas should be avoided when allocating dumpsites to minimise the effect of landfill leachate and more than 500m from the wetland area should be considered**.**

Forest: There must be a proper distance between the forest and dumpsites of at least 500m (Manoiu et al., 2013).

Airport: According to Alanbari et al. (2014), an airport should be at a safe distance of 3000m because birds are attracted to the waste, their presence is a real danger to aeroplanes.

3.4.2 Buffering

Buffering is a way of producing areas or regions of numerically calculated distances from a feature which can be a point, line, or polygon (Jerie & Zulu, 2017). This process usually creates two areas: one within a specified distance (also known as a buffer zone) to selected real-world features and the other area that is beyond. This area serves the purpose of keeping real-world features distant from one another and is often set up to protect the environment, residential areas, among others, from natural disasters or prevent violence (Sutton, 2009). The buffer distances were calculated using Euclidean distance in ArcMap as it does not require layers to be converted to raster before buffering. Table 3.2 and Table 3.3 present the factors with their siting criteria.

Table 2.2: Criteria and buffer distances

Criteria	Buffer distance	References
Airport	3000 m	(Alanbari et al., 2014)
River	700 m	(Jerie & Zulu, 2017)
Road	700 m	(Jerie & Zulu, 2017)
Built-Up Area	1000 m	(Ndeke, 2018)
Wetland	500 m	(Ngwijabagabo et al., 2020)
Forest/Plantations	500 m	(Manoiu et al., 2013)
Railway	500 m	(Chabuk et al., 2016)
Existing dumpsite	1000m	(Dolui & Sarkar, 2021)

Table 3.3: Factors and siting criteria

Built-up Area Distance (m)	Suitability Class	Score Value
0-250	Not Suitable	1
250-500	Less Suitable	2
500-750	Moderately Suitable	3
750-1000	Highly Suitable	4
>1000	Very Highly Suitable	5
Wetland Distance (m)	**Suitability Class**	**Score Value**
0-200	Not Suitable	1
200-300	Less Suitable	2
300-400	Moderately Suitable	3
400-500	Highly Suitable	4
>500	Very Highly Suitable	5
Road Distance (m)	**Suitability Class**	**Score Value**
0-200	Not Suitable	1
200-300	Less Suitable	2
300-400	Moderately Suitable	3
400-500	Highly Suitable	4
>500	Very Highly Suitable	5
River Distance (m)	**Suitability Class**	**Score Value**
0-200	Not Suitable	1
200-400	Less Suitable	2
400-600	Moderately Suitable	3
600-700	Highly Suitable	4
>700	Very Highly Suitable	5
Railway Distance (m)	**Suitability Class**	**Score Value**
0-200	Not Suitable	1
200-300	Less Suitable	2
300-400	Moderately Suitable	3
400-500	Highly Suitable	4
>500	Very Highly Suitable	5
Forest Distance (m)	**Suitability Class**	**Score Value**
0-200	Not Suitable	1
200-300	Less Suitable	2
300-400	Moderately Suitable	3
400-500	Highly Suitable	4
>500	Very Highly Suitable	5
Airport Distance (m)	**Suitability Class**	**Score Value**
0-500	Not Suitable	1
500-1000	Less Suitable	2
1000-2000	Moderately Suitable	3
2000-3000	Highly Suitable	4
>3000	Very Highly Suitable	5
Land Slope (%)	**Suitability Class**	**Score Value**
0-12	Very highly Suitable	5
12-16	Highly suitable	4
16-20	Moderately Suitable	3
20-30	Less Suitable	2

>30	Not Suitable	1
Soil Type	**Suitability Class**	**Score Value**
Not clay	Not Suitable	0
Sandy Clay Loam	Highly Suitable	1
Clay	Very Highly Suitable	2
Current Dumpsite (m)	**Suitability Class**	**Score Value**
0-250	Not Suitable	1
250-500	Less Suitable	2
500-750	Moderately Suitable	3
750-1000	Highly Suitable	4
>1000	Very Highly Suitable	5

3.4.3 Factor weighing using AHP and Overlay Analysis

At this stage, each factor was assigned weights or ranked using the AHP scale (see Table 2.1) based on expert judgment where a 45 pair-wise comparison of all factors was done to determine the weight value for each factor. The weights from experts were summarised in Microsoft Excel where the geometric mean of the values was calculated as shown in Table 3.4.

Table 3.4: AHP respondents' geometric average values

Key: BU (Built-up area), RV (Rivers), RD (Roads), AP (Airport), SP (Slope), SL (Soil), FP (Forest/plantations), WL (Wetland), CD (Current dumpsite) and RW (Railway)

BU,RV	**BU,RD**	**BU,AP**	**BU,WL**	**BU,SP**	**BU,SL**	**BU,CD**	**BU,FP**	**BU,RW**
8	5	4	5	6	3	6	6	3
7	4	3	4	5	2	9	5	2
7	7	3	5	4	3	7	4	3
7.3186	**5.1924**	**3.3019**	**4.6415**	**4.9324**	**2.6207**	**7.2304**	**4.9324**	**2.6207**

RV,RD	**RV,AP**	**RV,WL**	**RV,SP**	**RV,SL**	**RV,CD**	**RV,FP**	**RV,RW**
3	3	1	4	3	7	3	3
5	2	1	5	3	5	3	3
5	3	1	6	2	3	2	1
4.2171	**2.6207**	**1**	**4.9324**	**2.6207**	**4.7176**	**2.6207**	**2.0800**

RD,AP	RD,WL	RD,SP	RD,SL	RD,CD	RD,FP	RD,RW
3	2	4	3	2	3	1
3	3	2	1	3	3	2
2	3	2	1	2	2	2
2.6207	**2.6207**	**2.5198**	**1.4422**	**2.2894**	**2.6207**	**1.5874**

AP,WL	AP,SP	AP,SL	AP,CD	AP,FP	AP,RW
2	2	2	1	2	3
2	2	1	1	3	2
2	1	1	1	2	2
2	**1.5874**	**1.2599**	**1**	**2.2894**	**2.2894**

WL,SP	WL,SL	WL,CD	WL,FP	WL,RW
3	2	2	2	4
4	3	4	2	3
3	2	3	2	3
3.3019	**2.2894**	**2.8844**	**2**	**3.3019**

SP,SL	SP,CD	SP,FP	SP,RW
2	3	2	1
1	2	2	2
1	2	2	1
1.2599	**2.2894**	**2**	**1.2599**

SL,CD	SL,FP	SL,RW
3	1	1
2	1	1
2	1	1
2.2894	**1**	**1**

CD,FP	CD,RW
2	1
1	2
1	1
1.2599	**1.2599**

FP,RW
2
1
1
1.2599

After the matrix had been produced, the Consistency Index (CI) and Consistency Ratio (CR) were calculated using equations *2.1* and *2.2* respectively. Finally, a weighted overlay was applied to reclassified layers to produce a common measurement scale of values where weights were assigned to each input layer (*Built-up area, Rivers, Roads, airports, Slope,* *Soil, Forest/plantations, Agricultural land and Railway*). This weighted combination technique was applied to normalise or standardise all combined factors and produce an overall dumpsite suitability map. This was done by applying a weight to each factor followed by a summation of the results to yield a suitability map (Drobne & Lisec, 2009), using : $S = \sum w_i x_i$, (3.1)

where S is suitability, w_i is the weight of the factor i, and x_i is the criterion score of the factor i (Drobne & Lisec, 2009). Figure 3.2 highlights the conceptual model, where the environmental, economic, social, and safety considerations—among the other site criteria—were taken into account and buffered when preparing data from various sources. These elements were then weighted using AHP and combined using WLC to create the final suitability map.

3.5 Chapter Summary

In this study, a hybrid approach method of research design was employed. Residents living close to the current dumpsite in Area 38 as well as employees of the Lilongwe City Council (LCC), who are specialists in waste management, participated in this study. During the data collecting period, a variety of data collection tools were employed, including field observation, questionnaires, interviews, and GPS devices for gathering spatial data. To simulate suitable solid waste dumpsites in Lilongwe, AHP and GIS were employed.

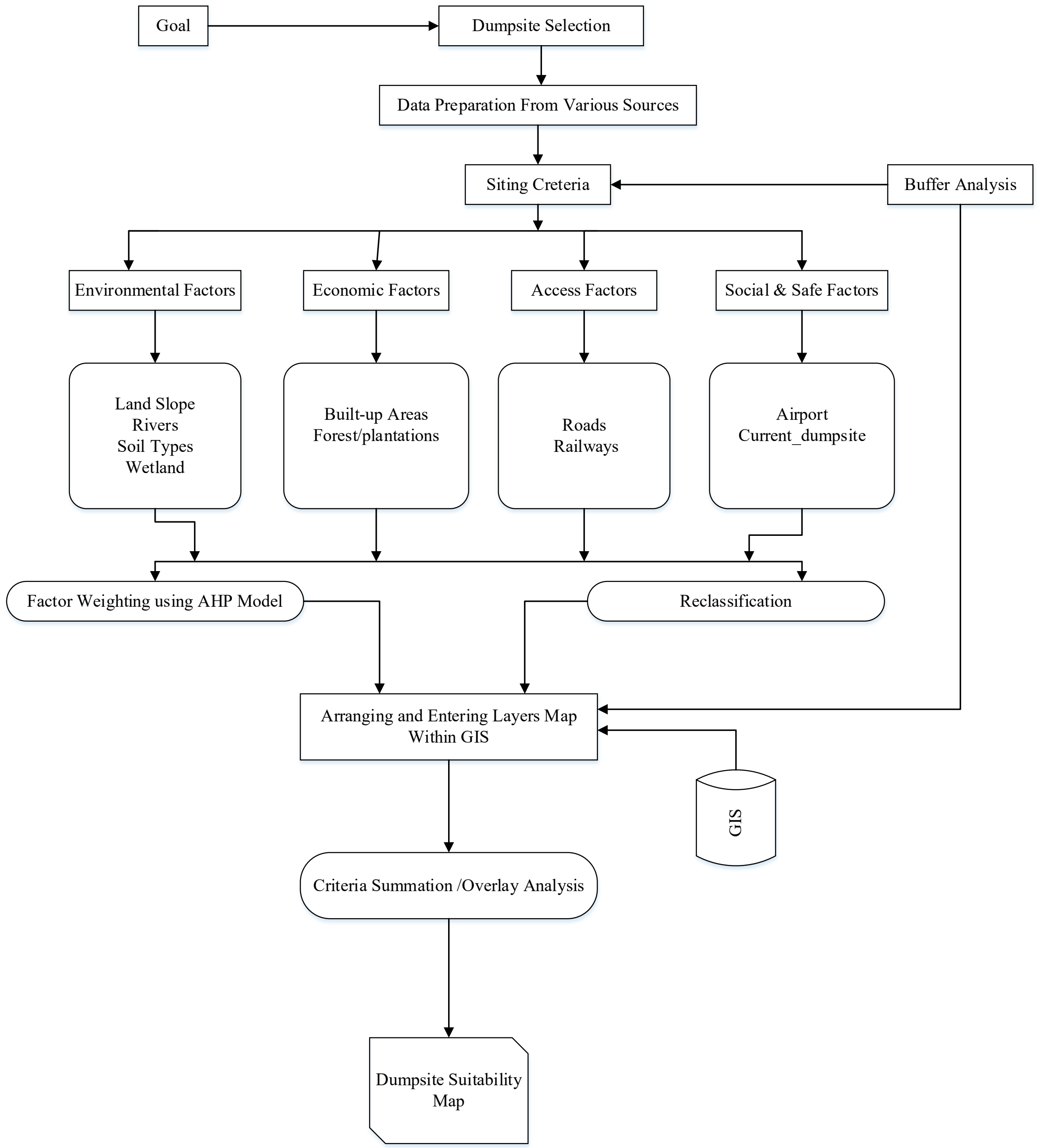

Figure 2.2: Dumpsite location conceptual model

CHAPTER 4

RESULTS AND DISCUSSIONS

This research aimed at identifying suitable sites for solid waste dumping in Lilongwe City to improve efficiency in waste management by assessing the suitability of the current dumpsite at Area 38 in Lilongwe City, examining site selection methods for solid waste disposal and developing a multi-factor GIS model for the Identification of suitable dumpsites in Lilongwe. Therefore, this chapter presents the results, describes the results and interprets the results/findings of the research.

4.1 The suitability of the current dumpsite

The current dumpsite was chosen based, primarily, on the availability of vacant land, which at the time consisted entirely of bushland or bare land with no developments except for subsistence farming occupying 26.3ha. The soil samples were taken and tested to check their suitability for the dump site. Being clay soil, it has low permeability, limiting the passage of water through, and this made it suitable. The siting also incorporated the slope of the area to afford construction, access, and maintenance.

Health-wise, the study reveals that diseases are one of the concerns of people living around the dumpsite. All respondents indicated that cholera, malaria, and stomach aches are common diseases around the area. Flies lay eggs on animal faeces and garbage, as a result, spreading diseases such as food poisoning and dysentery, and four people in the vicinity of the dumpsite have died of cholera, which is believed to be related to the condition of the dumpsite (Malata, 2023). Mosquitoes are also the cause of diseases in Area 38 as empty cans, containers, tyres and gullies that contain stagnant water enhance mosquito breeding which causes malaria (See Figure 4.1). Environmentally, residents report breathing offensive odours. With the dumpsite comprising a mixed type of waste that is not biodegradable, bad smells persist.

Figure 3.1: Dumpsite close to houses

Socially, the dump site has led to school dropouts, 2 of the 6 respondents highlighted that when pupils lack school materials like notebooks, they resort to scavenging from the dumpsite to fend for their needs. Furthermore, collectors usually dump their waste along the road connecting 6 miles and Area 24. This makes it difficult for people around the area and others to pass in the dry season, and impassable during rainy seasons.

In addition, others dump waste at night close to residents' gates, obstructing the road to houses and other areas (see Figure 4.2).

Figure 4.2: Waste along the Road, close to residents' gates

It is evident that elements like buffer zones, land-use changes and future infrastructure development were not considered, and these have impacted the viability of the dumpsite and made it an unsuitable location over time, affecting the community socially. The current dumpsite is causing serious threats to Area 38 residents who are now calling for its permanent closure and relocation.

4.2 Dumpsite Selection in Lilongwe

Most researchers combine GIS and AHP, and some combine AHP and WLC to rank alternatives Donevska et al. 2021; Yap et al. 2019; Dolui & Sarkar, 2021;Abdulhasan et al., 2019; Nascimento et al., 2017;Khorsandi et al., 2019; Adewumi et al., 2019 and Ajibade et al., 2019). GIS and AHP, along with WLC, are the most frequently used methods by researchers in site selection because AHP provides a structured framework for determining the relative importance of criteria, WLC mathematically integrates these criteria, and GIS enables the analysis and visualisation of spatial data. This integration improves the decision-making process through the provision of a methodical, quantitative, and spatially informed approach to dumpsite selection.

4.2.1 Individual suitability factors

Slope: An area whose steepness results in a high cost of dumpsite construction is not recommended. The study area is dominated by a slope of 0-12° (see Table 3.3), which is acceptable for the development of dumpsites with 59.65% of the area very highly suitable (see Figure 4.3). 23.26% of the area is highly suitable ranging from 12-16°, 10.76% of the area ranges between 16-20° representing a moderately suitable area, 5.86% (20-30°) less suitable and 0.48% of more than 30° is not suitable for the construction of dumpsites. The findings also indicate that the current dumpsite is situated in a moderately suitable area in terms of slope.

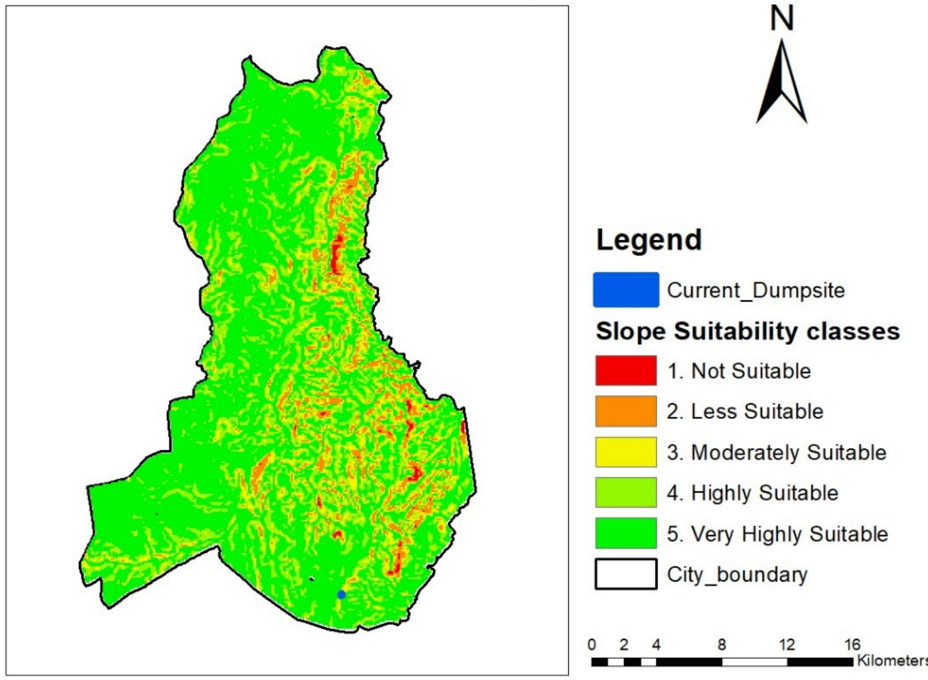

Figure 4.3: Slope Suitability Map

Soil: Soil condition is one of the important factors to be considered when selecting sites for solid waste. The study area contains three types of soils, namely, Chromic Luvisol, Eutric Cambisols and Leptosols (see Figure 4.4). Chromic Luvisol is the dominant type of soil in the study area representing 99.1% of the total area (see Figure 4.5). It is a type of soil with high clay accumulation (Young, 2016) which is highly suitable for solid waste disposal sites because of its low permeability (Paul & Ghosh, 2022).

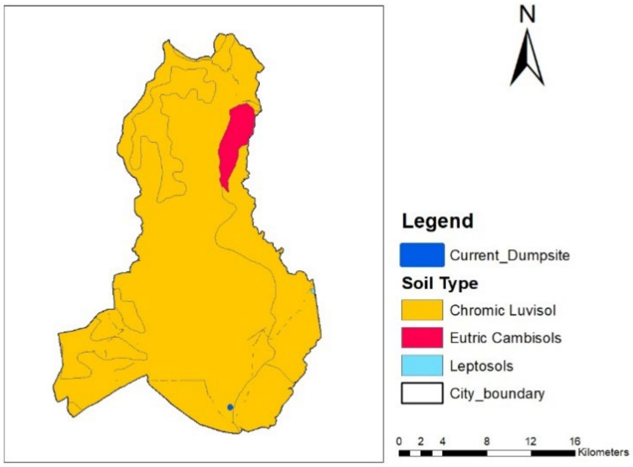

Figure 4.4: Soil Type Map

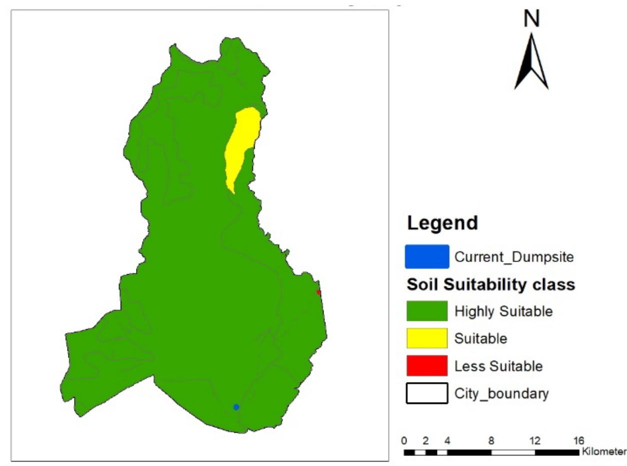

Figure 4.5: Soil Suitability Map

Built-up area: To minimise negative effects on human health and society, such as offensive odours, diseases, and flies, dump sites should be placed at an appropriate distance from urban areas, businesses, and other built-up areas. 77.59% of the total area is unsuitable for solid waste disposal. Furthermore, 5.09% is moderately suitable, 2.7% and 1.4% (with a buffer distance of more than 1000m) are highly suitable and very highly suitable, respectively.

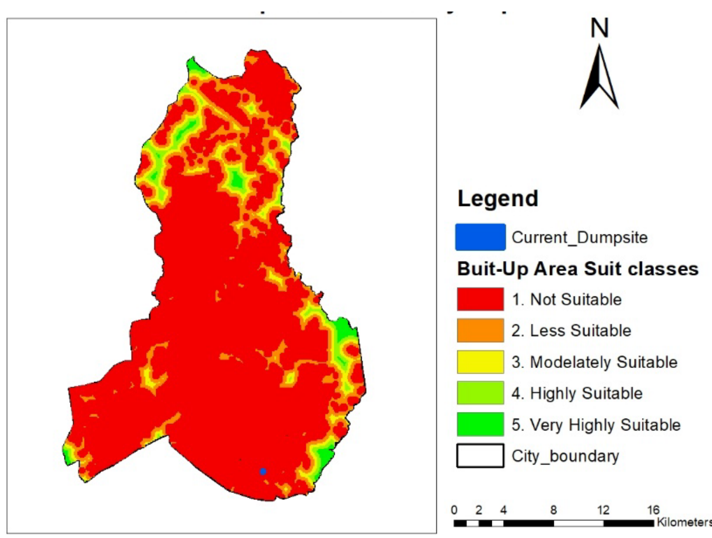

Figure 4.6: Built-Up Area Suitability Map

Road and Rail: For transit convenience and reduced logistical and operational costs, 62.13% of the area is at > 700m making it very highly suitable (Figure 4.7). With limited rail connectivity over 94 % of the area is very highly suitable (Figure 4.8).

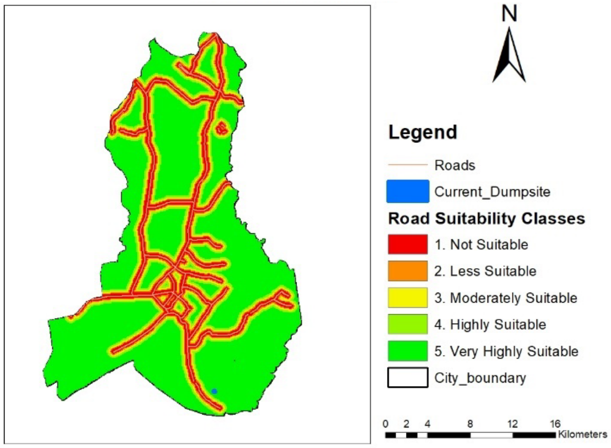

Figure 4.7: Road Suitability Map

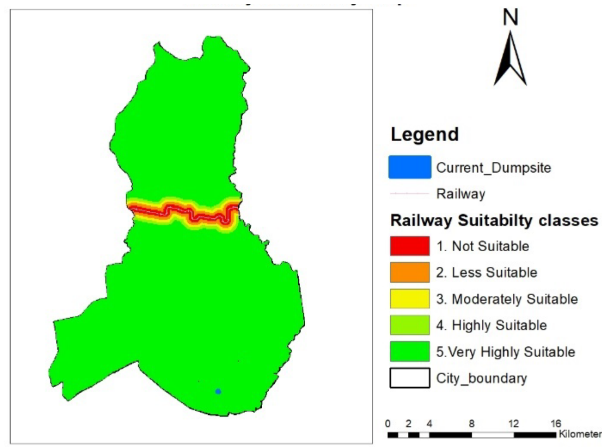

Figure 4.8: Railway Suitability Map

Protected areas: According to Ngwijabagabo et al. (2020) and Manoiu et al. (2013), wetlands and forests must not be selected for dumpsites. At a buffer distance of 500m, 78.32% and 97.65% were very highly suitable in terms of wetlands and forest cover buffering (Figure 4.9 and Figure 4.10).

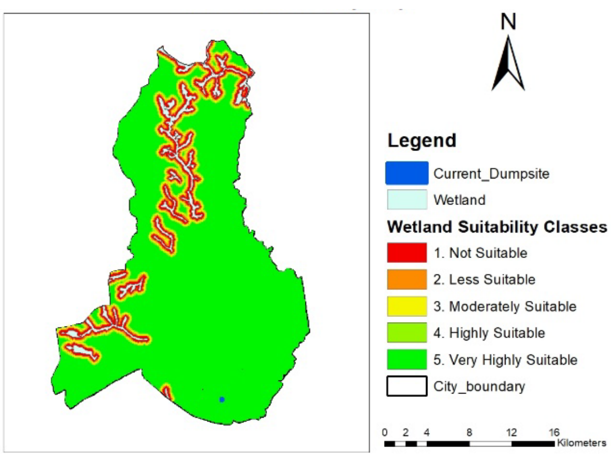

Figure 4.9: Wetland Suitability Map

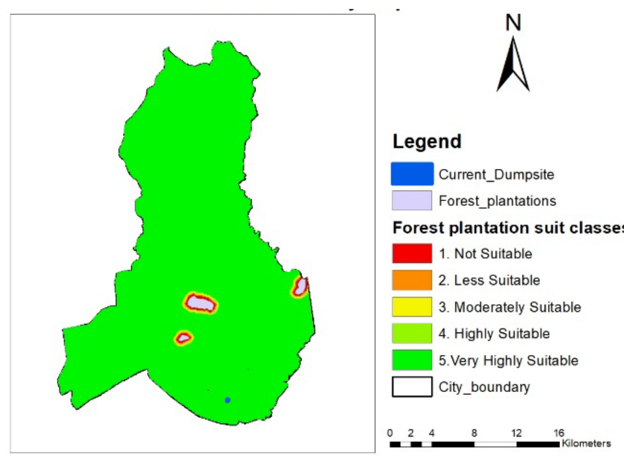

Figure 4.10: Forest Suitability Map

Airport: According to Alanbari et al.(2014) a distance of more than 3000m is considered very highly suitable for solid waste dumpsites for airport clearance for which 90.03% was very highly suitable (Figure 4.11).

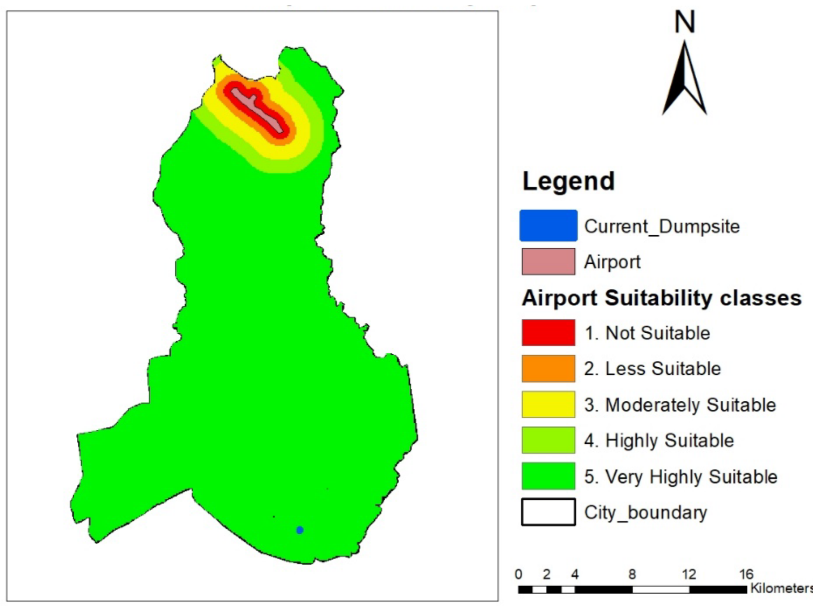

Figure 4.41: Airport Suitability Map

River: dumpsites ought to be located far from water sources for which we prescribed more than 700 metres (see Table 3.2). At this threshold, 47.12% was very highly suitable (Figure 4.12).

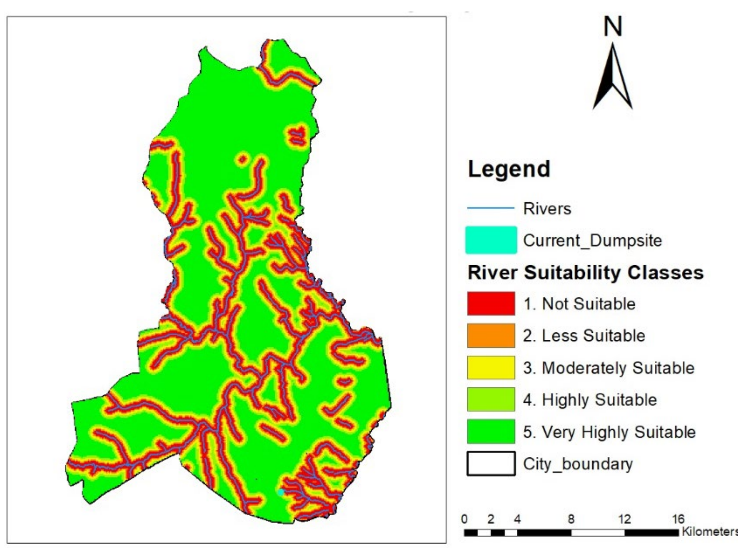

Figure 4.12: River Suitability Map

To reduce operational costs, solid waste dumpsites should be placed away from roads and rail, with a minimum distance of 700 metres for roads (Jerie & Zulu, 2017) and 500m for rail (Chabuk et al., 2016b). Proximity to rivers (water bodies) is an important environmental criterion, as such solid waste disposal should be placed at a minimum distance of 700m (Jerie & Zulu, 2017) and all other factors should be properly buffered as specified in Table 3 and Table 4 for the proper location of disposal sites. It is thus evident that the existing dumpsite is in an unsuitable place close to homes, rivers or streams, and on a moderate slope, which is causing negative impacts on human and environmental health.

4.2.2 Criteria evaluation using AHP and WLC

AHP is one of the most applied Multi-Criteria Evaluation (MCE) methodologies in assigning weight to factors. This method allows decision-makers to make the right decisions based on empirical data with subjective judgements of decision-makers (Chabuk et al., 2016b). The main purpose of weighting is to know which factors have more influence and their importance relative to each other based on expert judgements and literature. On a 1-9 scale (Table 2.1), indicates how important a criterion is and how much more over another criterion and can be derived from the eigenvector of a square reciprocal matrix of pair-wise comparisons (Table 4.1). The WLC method, which sums weight to 1, was used to find the suitability index value of potential areas.

Table 4.1: Normalised Comparison Matrix

	BU	**RV**	**RD**	**AP**	**WL**	**SP**	**SL**	**CD**	**FP**	**RW**	**Priorities**	**Priority %**
BU	**1**	7	5	3	5	5	3	7	5	3	0.303	30.3
RV	0.143	**1**	4	3	1	5	3	5	3	2	0.163	16.3
RD	0.2	0.25	**1**	3	3	3	1	2	3	2	0.114	11.4
AP	0.333	0.333	0.333	**1**	2	2	1	1	2	2	0.08	8.0
WL	0.2	1	0.333	0.5	**1**	3	2	3	2	1	0.084	8.4
SP	0.2	0.2	0.333	0.5	0.333	**1**	1	2	2	1	0.052	5.2
SL	0.333	0.333	1	1	0.5	1	**1**	2	1	1	0.063	6.3
CD	0.143	0.2	0.5	1	0.333	0.5	0.5	**1**	1	1	0.041	4.1
FP	0.2	0.333	0.333	0.5	0.5	0.5	1	1	**1**	1	0.044	4.4
RW	0.333	0.5	0.5	0.5	1	1	1	1	1	**1**	0.056	5.6

Key: BU (Built-up area), RV (Rivers), RD (Roads), AP (Airport), SP (Slope), SL (Soil), FP (Forest/plantations), CD (Current dumpsite), Wetland (WL) and RW (Railway)

WLC = 0.3 * [BU] + 0.16 * [RV] + 0.11 * [RD] + 0.08 * [AP] + 0.08 * [WL] +0.05 * [SP] + 0.06 * [SL] + 0.04 * [CD] + 0.04 * [FP] + 0.06 * [RW] = **1**

The consistency ratio (CR) was found to be 0.078 which is less than 10% denoting a respectable consistency level. Built-up areas turned out to be the most significant component and had a greater impact on choosing a location for the disposal of solid waste, with a factor weight of 30.3% among the 10 factors, as shown in Table 4.1. It also demonstrates that environmental features, specifically rivers and access factors, in this case roads, are essential when selecting sites for solid waste disposal sites. Rail, forest, slope and soil have little influence for various reasons that include limited coverage in the city for rail and forest, and homogeneity across the area in the case of slope and soil.

That notwithstanding, all factors were included in the weighted overlay analysis after assigning the AHP-derived weights to each factor and Figure 4.13 (combined very lowly suitable and unsuitable) show the results where 5.78%, 78.28%, 14.97% and 0.96% (446ha) of the total 46 283ha are very low suitable, unsuitable, suitable and highly suitable for solid waste disposal sites respectively. 96 sites, ranging in size from 1 ha to 1,324 ha, were selected from the suitable locations. Out of these, 24 sites, ranging in size from 1 - 94 ha, were highly suitable.

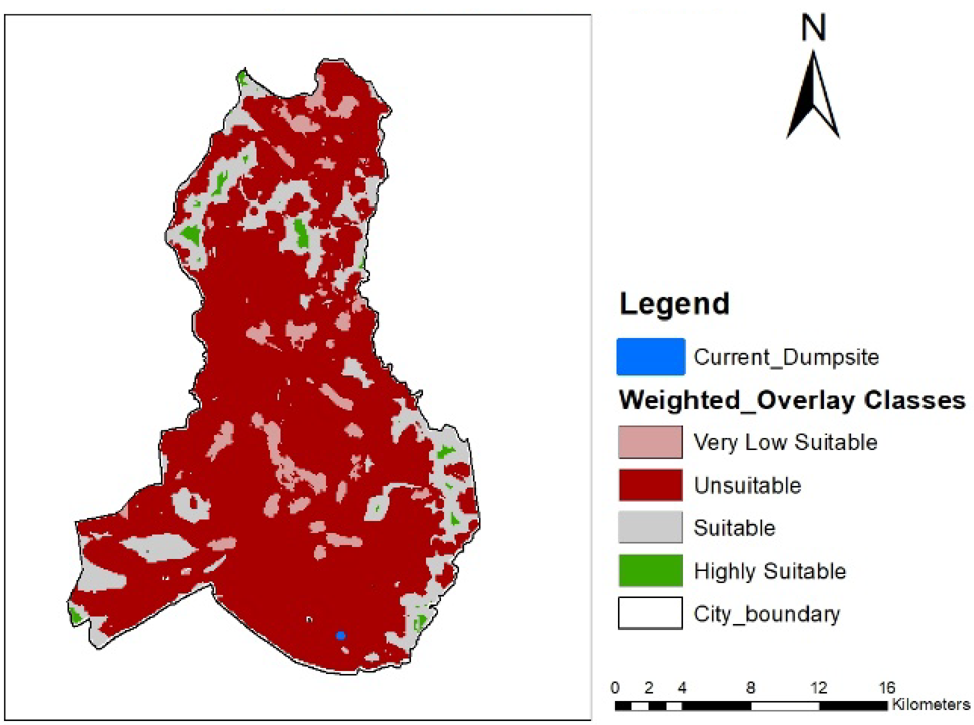

Figure 4.5: Weighted Overlay Suitability Map

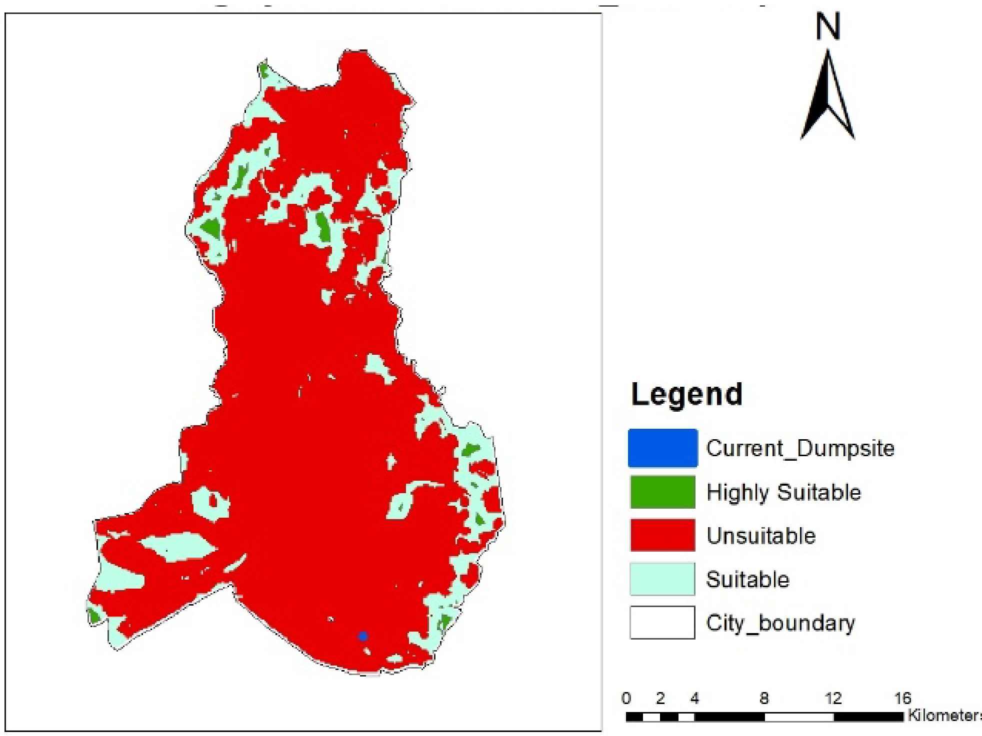

Figure 4.14: Highly Suitable Candidate Sites

While several factors determine the longevity of a dump site, the key is the rate at which the waste is generated (Akyen et al., 2017). It is estimated that Lilongwe generates 553 tonnes of waste every day (Bell, 2022). Secondly, with Lilongwe's fast-growing population, the proposed dumpsite ought to be bigger than the current dumpsite size (26.3ha). Thus, with these additional conditions, six (see Figure 4.15) Optimum locations were identified in areas 61, 58, 44 and area 55, as summarised in Table 4.2 and ground truthing was done physically (see Figure 4.16) and also using Google Earth imagery dated 02 June 2023. Further, while all these sites are independently optimal given the study criteria, it would be prudent to consider multiple sites running concurrently for two reasons. Firstly, the longevity of the dumpsites would be increased as they would share the load. Secondly, when geographically well distributed, the operational costs would be minimised. For instance, sites 1, 2 and 3, which have the longest lifespans, are all located in the northern part of the city such that while they may have an even longer cumulative lifespan when operated together, they are likely to suffer the high operational cost issues of the current dumpsite located on the opposite southern part.

Table 4.2: Proposed sites in order of lifespan

Sit Name	Capacity	Estimated Lifespan
Site 3	94ha	18 years and 2 months
Site 2	81ha	15 years and 6 months
Site 1	50ha	9 years and 7 months
Site 4	44ha	8 years and 5 months
Site 6	34ha	6 years and 6 months
Site 5	28ha	5 years and 4 months

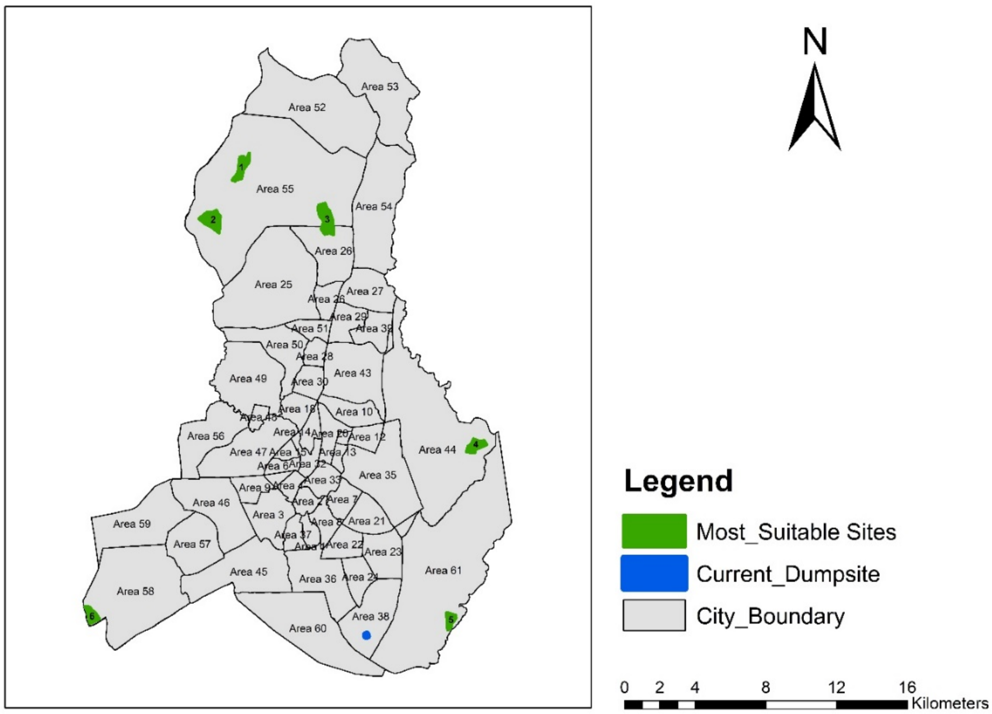

Figure 4.15: Proposed optimal dumpsite locations

Figure 4.16: Area 55 and 26 site Physical verification

4.3 Chapter Summary

This study aimed at finding new viable sites for solid waste dumping in Lilongwe to alleviate the current logistical and operational problems. The current dumpsite is unsuitable due to its proximity to residents and health risks. This study recommends relocation to more suitable locations using multi-criteria decision-making, subjective, and objective weightings, geographical analysis and flexibility. Six sites with capacities ranging from 28 to 94 Ha were identified as optimal to reduce operational costs. Waste recycling initiatives are advised to reduce the volume of solid waste at disposal sites and promote sustainable waste management practices

CHAPTER 5

CONCLUSION

To increase waste management efficiency, this study set out to find new viable sites for solid waste dumping in Lilongwe that do not pose logistical and operational problems. The findings show that the current dumpsite is unsuitable since it is close to residents and poses serious health risks. Based on this, it is recommended to relocate the current dumpsite to more suitable locations. To inform the process of relocation, the study combined the advantages of multi-criteria decision-making, subjective and objective weighting, geographical analysis, and flexibility to create a strong and transparent decision-making process. Thus, out of the 46, 283 ha in Lilongwe City, 84.07% (38, 909 ha) are unsuitable, 14.97% (6, 928 ha) are suitable and 0.96% (446 ha) are highly suitable for solid waste disposal sites. Additionally, 6 sites, with capacities ranging from 28 ha to 94 ha, were identified to be optimal both in terms of capacity and location to reduce operational costs. To complement these efforts, the implementation of waste recycling initiatives is advised to reduce the volume of solid waste that ends up at disposal sites, thereby promoting sustainable waste management practices.

It should be noted that the current dumpsite has been overtaken by events such as population growth, and land use change, despite not being an elaborate decision process to site it. While this study has employed an in-depth decision support criterion, it would be interesting to integrate these temporal and dynamic factors into the model for enhanced long-term planning and sustainability. In addition, more research should be done to examine the climate change resilience of solid waste dumpsites in Lilongwe using multi-factor GIS modelling by analysing the vulnerability of dumpsites to extreme weather events such as cyclones (e.g., Tropical Cyclone Freddy, which hit Blantyre in March 2023), floods, storms, and heatwaves. These would inform adaptation strategies for dumpsite management in response to climate change. These findings are a step in the process of streamlining city operations to minimize transportation costs and enhance the overall efficiency of waste disposal. Furthermore, an assessment of the potential environmental impact of the proposed sites on groundwater contamination and air quality degradation should be undertaken. While AHP required the acquisition of precise and comprehensive data, this study needed to balance its efforts and resources. This entailed making economic choices on the scope of the study and narrowing the study results to pre-emptive rather than conclusive suggestions. Secondly, the subjectivity of the experts consulted limits the applicability of the results, and hence scalability, to jurisdictions of a similar size.

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APPENDICES

Appendix 1: Approval letter

OFFICE OF THE CHIEF EXECUTIVE

Our Ref:
LCC/ADMIN/COMM/3

26th January, 2022

LILONGWE CITY COUNCIL
P.O. Box 30396
Lilongwe 3
MALAWI
Cell: +265 (0)999510741
fb//Lilongwe_City_Council
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Stephen Mandiza Kalisha
Malawi Assemblies of God University
P.O Box 184
Lilongwe

Attention: Stephen Mandiza Kalisha

RE: **REQUEST FOR THE PERMISSION TO CONDUCT RESEARCH**

Please refer to your letter dated 20th January, 2022 requesting for approval from the council to conduct an academic research, in partial fulfilment for the award of a Master's Degree at University of Malawi Chancellor College.

We wish to inform you that permission has been granted and you can proceed with your planned program on conditions that you conform to research ethics in the course of your data collection and your findings will be used for research purposes only.

Yours faithfully

John Chome
CHIEF EXECUTIVE OFFICER

ALL CORRESPONDENCE TO BE ADDRESSED TO THE CHIEF EXECUTIVE OFFICER

Appendix 2: Dumpsite Selection Interview Guide

Lilongwe City Council – Interview guide

1. How was the current dumpsite selected (*How did the dumpsite get to be there? What was involved to get to the point that the dumpsite is there*)?
2. What methods are used in the selection of solid waste disposals?
3. What are /is the impact (s) of the current dumpsite on surrounding areas?
4. Are there any plans for changing the location of the current dumpsite?
5. What can be done to ensure effective waste management in the city?

Area 38 residence – Interview guide

What are /is the impact (s) of the current dumpsite?

Appendix 3: Dumpsite Selection Questionnaire

My name is Stephen Kalisha, a Master's student in the Department of Computer Science at Chancellor College. I am working on my Master's thesis focusing on **Multi-factor GIS Modelling for Solid Waste Dumpsites in Lilongwe.** The main objective of the study is to determine suitable locations for dumpsites in Lilongwe based on key considerations e.g., environmental, economic, access, social, and safety factors that influence the siting process of dumpsites.

The questionnaire will take you not more than 10 - 15 minutes to complete.

Simple Guide.

- Tick factors that you think are more important by comparing one factor between two or more factors
- Use the scale provided when ticking/ranking the factors
- Some questions will require your explanation. Therefore, use the spaces provided for answering such questions.

NOTE

- Information provided will be kept confidential and used for academic purposes only

Table 1: Analytic Hierarchy Process (AHP) Scale

Importance Scale	Definition of Importance
1	Equally Important
2	Equally to Moderately Important
3	Moderately Important
4	Moderately to Strongly Important
5	Strongly Important
6	Strongly to Very Strongly Important
7	Very Strongly Important
8	Very Strongly to Extremely Important
9	Extremely Important

Table 2: Factors to consider when selecting dumpsites

Dumpsite Selection	Environmental Factors	Land slope Distance from rivers Groundwater Depth Soil types Elevation
	Economic Factors	Land Uses Distance from residential areas Distance from urban areas
	Access Factors	Distance from Roads Distance from Railways
	Social and Safety Factors	Distance from Airports Distance from restricted areas

1. Which factor is more important concerning dumpsite selection and how much on a scale of 1 to 9?

Access Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental Factor
Access Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic Factor
Access Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social and Safety Factor
Environmental Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic Factor
Environmental Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social and Safety Factor

2. How important are the following environmental factors in comparison?

Land slope	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from rivers
Land slope	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Groundwater Depth
Land slope	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Soil types
Land slope	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Elevation
Distance from rivers	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Elevation
Distance from rivers	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Groundwater Depth
Groundwater Depth	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Soil types
Groundwater Depth	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Elevation
Soil types	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Elevation
Soil types	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from rivers

3. How important are the following access factors in comparison?

Distance from Roads	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from Railways

4. How important are the following access factors in comparison?

Distance from Airports	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from restricted areas

5. How important are the following economic factors in comparison?

Land Uses	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from residential areas
Land Uses	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from urban areas
Distance from residential areas	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from urban areas

6. Please provide any other factors that are important in the selection of a dumpsite

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7. How much on a scale of 1 to 9 factors are suggested in (6)?

Factor	**Scale**

END OF QUESTIONS

THANK YOU FOR PARTICIPATING