

IDENTIFICATION OF OPTIMAL WASTE COLLECTION POINTS AND DUMP SITE USING GIS-BASED MULTI-CRITERIA ANALYSIS IN ZOMBA CITY

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DECLARATION

I BRIAN MUKHWIYO confirm that the research project title "IDENTIFICATION OF OPTIMAL WASTE COLLECTION POINTS AND DUMP SITE USING GIS-BASED MULTI-CRITERIA ANALYSIS IN ZOMBA CITY" is my work. I have never submitted it to any other institution for academic purposes. Any information I have used or mentioned from other sources has been properly credited with complete references.

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ABSTRACT

Urban environmental planning must include effective solid waste management, particularly in fast-growing cities like Lilongwe, Blantyre, Mzuzu and Zomba. In Zomba city due to a number of factors, including population growth, poor infrastructure, and the growth of residential areas into areas used for waste disposal, like the Chikumbeni dumpsite, which is now getting to capacity, Zomba is currently facing many difficulties with solid waste collection and disposal (Zomba City Council, 2023). These circumstances have resulted in an increase in the number of illegal dump sites, ineffective waste collection methods, and hazards to the environment and human health. In order to tackle these issues, this research uses network analysis methods like kernel density, buffer analysis, and service area allocation, as well as geospatial information systems (GIS) and remote sensing tools, specifically Site Suitability Analysis using the Analytical Hierarchy Process (AHP) to identify optimal locations for additional waste collection points and suitable waste disposal sites.

A lot of spatial factors were taken into account in the study, such as land use, slope, geology, soil texture, proximity to rivers, and road accessibility. These factors were then weighted and prioritized using AHP according to how important they were in relation to the suitability of landfill sites. Finding regions with significant waste generating pressure and limited access to waste collection services was made easier with the use of network analysis techniques. By integrating field-based data and geographic decision-making tools, the study offers evidence-based suggestions for enhancing Zomba's solid waste management plan.

By guaranteeing that everyone has access to secure, inclusive, and sustainable human settlements, including waste management systems, this activity supports Sustainable Development Goal 11, which encourages sustainable cities and communities. The results also support Malawi Vision 2063, which aims to create a foundation for clean, well-planned, and ecologically conscious urban growth.

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TABLE OF CONTENTS

ABSTRACT iv
Acknowledgements v
Chapter 1 : INTRODUCTION 11
1.1. BACKGROUND INFORMATION 11
1.1.1. PROBLEM STATEMENT 13
1.1.2. MAIN AND SPECIFIC OBJECTIVES 14
1.1.3. RESEARCH QUESTIONS 14
1.1.4. SIGNIFICANCE OF THE STUDY 15
1.1.5. STUDY AREA 17
CHAPTER 2: LITERATURE REVIEW 18
2.1. BLOBAL PERSPECTIVE ON SOLID WASTE MANAGEMENT IN SITE SELECTION AND WASTE COLLECTION POINTS 18
2.2 SOLID WASTE MANAGEMENT IN SOURTHERN AFRICA 19
2.3 SOLID WASTE MANAGEMENT IN ZOMBA 20
2.4 CURRENT STATE OF WASTE MANAGEMENT IN ZOMBA CITY 21
2.5 GIS AND REMOTE SENSING APPLICATIONS IN WASTE MANAGEMENT 23
CHAPTER 3: METHODOLOGY 24
3.1. MATERIALS AND METHODS 24
3.1.1 Data Collection 24
3.1.2 Methods 26
3.1.2.1 Analysing spatial distribution of existing waste collection points and dump site 27
3.1.2.2 Identifying additional optimal waste collection points around the city 28
3.1.2.3 Analytical Hierarchical Process 32
33

Chapter 4: results and discussions 34
4.1 RESULTS 34
4.1.1 Criteria's used to identify suitable sites for a waste disposal 34
4.1.2 Criteria's used to propose additional waste collections stations 43
4.1.2.1 .....Population density 43
4.1.2.2Markets and existing waste collection points 45
4.1.2.3 .....Roads..... 46
4.1.2.4 .....Rivers..... 47
1.2. DISCUSSION 49
CHAPTER 5: CONCLUSION AND RECOMMENDATION.....51
5.1 Conclusion 51
5.2 Recommendations..... 52
References 54

ACRONYMS/ABBREVIATIONS

CPS: Waste collection Station

MSWM: Municipal Solid Waste Management

MCDA: Multi-Criteria Decision Analysis

EIAs: Environmental Impact Assessments

NIMBY: Not In My Back Yard

AHP: Analytic Hierarchy Process

LULC: Land Use Land Cover

CR: Consistency Ratio

SDG: Sustainable Development Goals

LIST OF FIGURES

Figure 1: Map of Zomba City

Figure 2: The city Dump site at Chikumbeni 4 miles

Figure 3: Map showing Kernel Density Estimation

Figure 4: The Analytic Hierarchy Process (AHP) EVM

Figure 5 Land use land cover map

Figure 6: Geology map of Zomba City

Figure 7: The Map showing Proximity to the Rivers

Figure 8: The Map Showing Proximity to Roads

Figure 9: The Map showing the elevation of a City

Figure 10: The Surface soil Structure of Zomba City

Figure 11: The Map of Suitable Sites for Dumpsite

Figure 12: Zomba City Population Density

Figure 13: City Waste Collection Stations

Figure 14: The City Roads networks

Figure 15: The Map of Zomba City Rivers

Figure 16: The Map of Waste Proposed Stations

LIST OF TABLES

Table 1: The Data used and their sources

Table 2: Showing City Waste Collection frequency

Table 3: The Criteria Matrix Table

CHAPTER 1 : INTRODUCTION

1.1. BACKGROUND INFORMATION

The management of solid waste is serious a problem in main urban areas of developing country including Malawi (Ahasanul et al., 2008). One of the Malawi's cities, Zomba, is having a difficult time in managing solid waste because of the city's growing population, which is forcing it to grow, and the rising amount of rubbish being produced, which puts a lot of strain on waste collection efforts. Because of the rise in garbage production, some people choose to dispose of their rubbish in approved locations, which makes it challenging for those who collect waste in the city to do so effectively. The uncollected waste in un-theorized site tends to accumulate and brings about some environmental problems such as Air pollution, biodiversity impacts, groundwater pollution, soil fertility effects, Visual and health impact and environmental degradation (N. Ejaz, N. Akhtar, H. Nisar & U. Ali Naeem). The work of collecting waste and deposit them to the city dump city has been facing a lot of challenges (Zomba City council 2023). Effort to manage these require a very effective method and GIS and remote sensing can play a very important roles. For example the GIS software ArcGIS 10 (Environmental Systems Research Institute, ESRI) is a great tool to analyze land use suitability, store and handle spatial data, and combine different types of numeric and descriptive values with spatial data (Elsai Mati Asefa, Kefelegn Bayu, Dechasa Adare Mengistu, 2022). Many researchers have applied GIS to capture, store, analyze, manage, and present data on waste collection, transportation, transfer method, specific site situation, distribution of road network in many cities of the Africa (Meribe et al.,, 2021) and across other cities in the world (Tapiwa Shaban et al, 2024).

This study use the advantage that remote sensing and GIS has to identify potential sites for solid disposal around the city and find optimal waste collection points in the city in additional to existing points in order to increase the efficiency on solid waste collection which is the very big challenge and in addition to that it will help to reduce

the illegal dump sites that may arise due to increase in population growth and commercialization (ISSA et al., 2022) . When the population is so huge the chances of producing large quantity of waste are very high so there is demand of having good quite number of waste collection site in order to meet the size of the population but this sites has to be optimal in order to avoid the some environmental problem that may arise due to uncollected waste when this waste accumulate.

1.1.1. PROBLEM STATEMENT

In Zomba City, fast population growth puts waste management at a great pressure there are a lot of challenges faced by the city in relation to waste collection and disposal, these challenges includes, Inadequate infrastructure, illegal dump sites, and poorly situated waste collection stations (WCPs) and all these plus others negatively affects the waste management efforts.

The current condition of the major city dump site at Chikumbeni in 4 Miles is not good because of encroachment by neighboring residential and the dumpsite is getting close to capacity therefore, it is no longer suitable (Zomba City Council, 2023). Although there are plans to move the dump site to Nambesa, the environmental safety there at Chikumbeni is at risk due to delays and hence the need for suitability analysis.

1.1.2. MAIN AND SPECIFIC OBJECTIVES

The main objective of the study was to identify places suitable for waste disposal problems and propose additional waste collection stations in order to reduce environmental and public health problems and increase waste collection coverage hence improve efficiency in solid waste management in the city.

The specific ones include:

i. To analyze spatial distribution of existing waste collection points and disposal site
ii. To propose additional optimal waste collection points around the city.
iii. To identify potential locations for waste disposal sites in the city

1.1.3. RESEARCH QUESTIONS

1. What are the spatial patterns and limitations of the current waste collection points and disposal site in Zomba City?
2. Where can additional waste collection points be optimally located to improve coverage and reduce illegal dumping in Zomba City?
3. Which areas in and around Zomba City are most suitable for the establishment of a new waste disposal site based on environmental and spatial criteria?

1.1.4. SIGNIFICANCE OF THE STUDY

Solid waste management as it stated it involves a lot of activities from where waste are generated, collected and separated, transported to the disposal site (United Nation Environmental Programmes). For them to be managed properly it means a lot of work have be done and all these requires good management strategies. The paper was focusing on how often solid waste can be managed from the point of generation to the point where it was disposed. Due to shortage of waste collection points which increases the illegal dumping of wastes and the study through GIS has come up with proposed waste collection points around the city, even though this may increase cost for the city council but the good side of it, will increase efficiency in as far as solid waste management specifically waste collection is concerned. This means that, with increased waste collection or established waste collection points to the areas where there was no collection points illegal dumping of waste to unauthorized places like roads, rivers, near institutions like schools, hospitals, markets and other places will be minimised and as results problems that may occurs due to poor waste management like uncollected waste for example water, air and soil pollution which may leads to a lot diseases such choleras, respiratory diseases, pests and plant diseases. In addition it will also prevent environmental degradation (Jagbeer et at., 2018)

The second part of the study also contributed to the prevention and minimizing of environmental and health risks, optimizing utilization of resources and ensuring sustainable management of solid waste as it capitalised the knowledge of GIS and remote sensing to identify and rank the potential site for the city landfill (Karsauliya, 2013). For environmental protection poor waste disposal may lead to soil and water contamination, air pollution and destruction of habitat for wide range of species, so selecting appropriate sites for waste disposal minimizes all these risks. For public health land fill and other waste disposal sites may pose health hazards such as spread of diseases and exposure to toxic substances as it seen to the to the way how people are exposed at petit hostel in Chikanda informal settlement, so strategic site selection can reduce these risks (Nazombe et al., 2019). For resource optimization and sustainability efficient waste management including site selection for waste disposal

help to optimize utilized resources and reduces costs associated with waste transportation and disposal it also ensure long term sustainability.

1.1.5. STUDY AREA

Zomba city lies on the lower slopes of Zomba Mountain in the shire highlands, 60 kilometres northeast of Blantyre. The city is composed of land mass of about 16 square miles (42km²) and it has a population of 105,013 (National Statistics Office, 2018). Trade and distribution, community and social services, agriculture, and a few minor industries make up City's local economy. More than 60% of people reside in informal settlements, and 29% of people live in poverty. Numerous issues will be positively addressed with the support of municipal economic development plans, land use development, and comprehensive urban management. The city has thirteen wards in total which are Sadzi Ward, Chambo Ward, Zakazaka Ward, Mbedza Ward, Mtiya Ward, Masongola Ward, Zomba Central Ward, Chikamveka Ward (Matawale Township), Chirunga Ward, Chikamveka North Ward, Chirunga East Ward, Likangala South Ward, Likangala Central Ward, and Likangala ward in addition to the city waste dumping facility, located at 4 miles, the study was conducted on the aforementioned wards, including the dump site at 4 miles.

Study Area Map of Zomba City

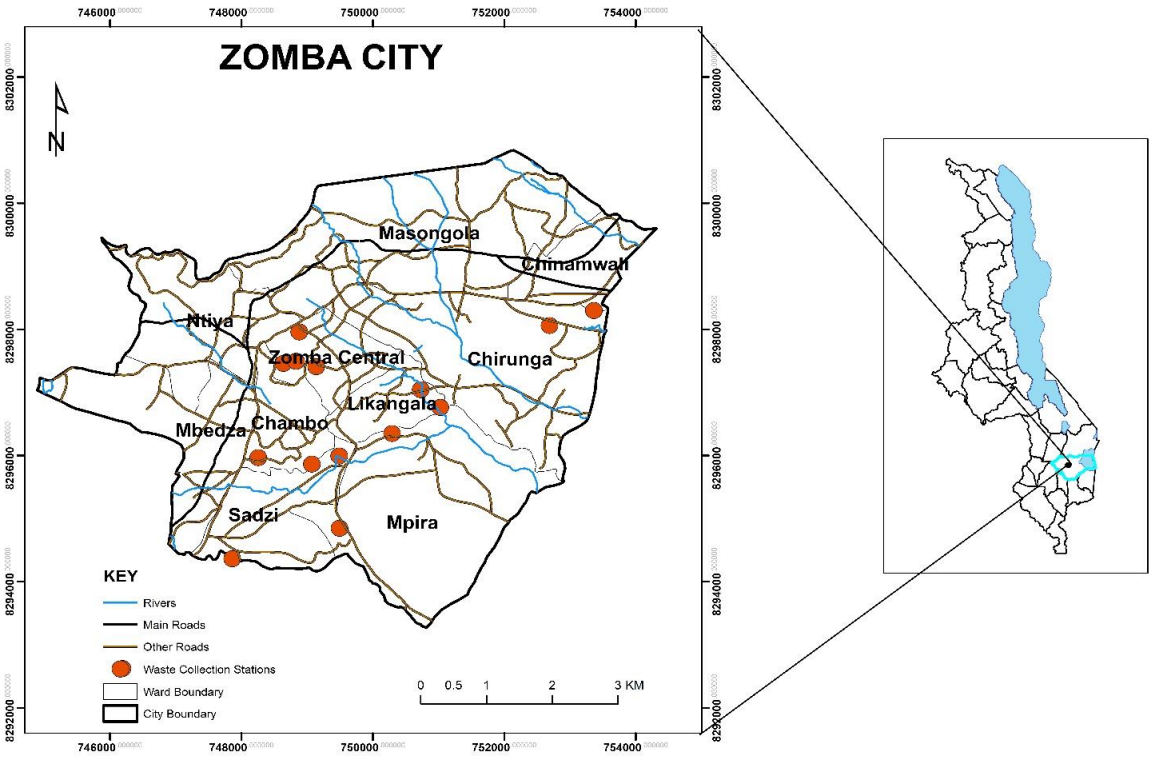


Figure 17: Map of Zomba City

CHAPTER 2: LITERATURE REVIEW

Solid waste generated globally, regionally, nationally and locally, their challenges is experienced in all these levels and mostly in developing country the level of challenge experienced seems to be more affecting than in developed countries due to inadequate capacity to manage the waste properly (Willison, 2015). This chapter presents all the available literatures explaining about this topic, particularly the use of Geo –information Systems and remote sensing for land fill selection and waste collection points allocation.

2.1. BLOBAL PERSPECTIVE ON SOLID WASTE MANAGEMENT IN SITE SELECTION AND WASTE COLLECTION POINTS

Solid waste management (SWM) is a global issue as garbage creation rises due to urbanization and population growth. The World Bank estimates that 3.40 billion tons of solid waste is going to be generated worldwide by 2050 (World Bank Group, 2022), necessitating the use of appropriate waste collection and disposal systems. The main issues with SWM are inappropriate land disposal, ineffective collecting methods and others which leads to growing environmental difficulties such greenhouse gas emissions, water pollution, and land degradation (Wilson et al., 2015). To further optimize WCP location planning and landfill placement selection, developed countries have set up planned and technologically sophisticated waste management facilities, such as GIS and remote sensing. According to (Al-Khatib et al. 2017) technologies are used to identify patterns in waste generation, enhance collection routes, and determine the best place for landfills based on social, economic, and environmental factors. For example developed countries like Germany, Sweden, Japan others were able to reduce their reliance on landfills by implementing waste-to-energy, source segregation of wastes, and rigorous recycling programs (Tchobanoglous & Kreith, 2002)

In order to maintain environmental sustainability and public health, landfills and waste collection locations must be carefully chosen. Ineffective landfill and WCP

placement can contaminate water sources, pollute the atmosphere, and spread vector-borne illnesses. When selecting appropriate sites for WCPs and landfills, city planners frequently use GIS-based multi-criteria decision analysis (MCDA) to make it easier to take into account a variety of factors, including accessibility, land use, population density, and environmental constraints (Morrissey., 2004).

According to Wilson et al. (2015), the European Union employs strict landfill site location regulations to guarantee that waste management facilities meet environmental criteria to stop methane emissions and groundwater contamination. Landfill site selection in North America is regulated with environmental impact assessments (EIAs) and public hearing to ensure minimal negative impacts on communities. Developing countries like Malawi, however, still face critical waste management issues as an effect of poor infrastructures, limited financial resources, and poor enforcement of policy. Open dumping and poorly managed landfills remain prevalent among most urban cities in Asia and Latin America, which have resulted in significant health and environmental issues (Al-Khatib et al., 2017).

Despite all these setbacks, global trends identify a new trend towards sustainability in waste management strategies, such as the use of smart waste management technologies such as robotic waste collection, real-time waste monitoring of landfills, and artificial intelligence-based waste sorting platforms. Application of such technologies in site selection and WCP provision enhances efficiency, reduces environmental impact, and enhances overall collection efficiency of the wastes.

2.2 SOLID WASTE MANAGEMENT IN SOURTHERN AFRICA

In the southern part of Africa, solid waste management is a problem due to a lack of infrastructure, budget constraints, and weak enforcement of waste management regulations. Godfrey and Oelofse (2017) note that sub-Saharan Africa is characterized by uncontrolled dumping and open dumping of waste with the resultant consequence of environmental degradation. South Africa has, for instance, implemented strict regulations such as the National Environmental Management: Waste Act 2008, promoting environmentally friendly waste site selection and organized waste collection systems. GIS-based approaches have extensively been

utilized to enhance waste collection effectiveness and landfill location selection in cities such as Johannesburg and Cape Town (Morrissey, 2004). Namibia and Botswana have also made advancements through the integration of integrated waste management plans that emphasize spatial analysis to improve waste collection and disposal (Mugadza et al., 2021). Most regional nations, such as Malawi, continue to rely mainly on informal waste disposal and, hence, proper site selection for WCPs is a necessity for improved waste management systems. Besides this, the inability to implement waste management policies further exacerbates inefficiencies, resulting in the expansion of illegal dumpsites and environmental pollution. Existing studies show that application of GIS-based models can significantly improve the efficiency of waste collection in urban zones across the region by optimizing collection routes and optimally locating WCPs based on waste generation and accessibility (Mmereki et al., 2016).

2.3 SOLID WASTE MANAGEMENT IN ZOMBA

In malawian cities like zomba, solid waste management (swm) continues to be a significant problem due to their growing urbanization. Waste generation issues have escalated due to the growing population, infrastructural constraints, and financial constraints (kumwenda et al., 2018). Large volumes of waste are produced worldwide by urban areas, and underdeveloped countries struggle with ineffective collection, transportation, and disposal since they lack many resources (hoornweg & bhada-tata, 2012). City authorities in malawi are primarily responsible for managing swm, however rising waste generation rates typically exceed their capacity (manda, 2014).

Due to its inadequate landfill facilities, low waste collection coverage, and urban population growth, Zomba City, is experiencing serious solid waste management issues. Although the city produces between 50 and 70 tons of waste per day, only a small portion of it gets picked up and properly disposed of (Gondwe et al., 2020). Environmental degradation and public health issues result from the remaining material being burned, illegally disposed of, or decomposing in open areas. This review literature review looks at the current state of SWM in Zomba City, as well as the problems that still remain and possible solutions, such as using remote sensing and Geographic Information Systems (GIS) to optimize waste collection and landfill location.

2.4 CURRENT STATE OF WASTE MANAGEMENT IN ZOMBA CITY

2.4.1 Waste Generation and Collection Issues

The composition of waste in Zomba City includes a high percentage of organic wastes which include food and kitchen stuffs, green garbage, recyclable materials such as plastics papers, bottles and kitchen utensils and small percentage of non-biodegradable substances such as metals and plastics (Gondwe et al., 2020). Waste collection is the mandate of the Zomba City Council (ZCC), but it is hindered by financial resource constraints in offering routine services. Manda (2014) adds that

waste collection vehicles are frequently out of order, and the limited available ones are not able to reach all the residential and commercial areas. Consequently, the majority of the inhabitants practice indiscriminate dumping along open spaces, drainage, and riverbanks, which fuels flooding and water pollution (Mkandawire et al., 2021).

2.4.2 Inadequate Dumping Facilities

The city dump site which located at 4 miles lacks engineering controls such as liners, leachate collection systems, and segregation of wastes (Kumwamba et al., 2019). As open dumping most of the time result in groundwater contamination, methane generation, and disease vectors for example mosquitoes and rodents surging. A study by Mbulaje et al. (2022) confirmed that the residential areas close to the dumpsite they can suffer from respiratory infections and waterborne diseases due to exposure to decomposing garbage.

The absence of landfill engineered attributes at 4 Miles dump site causes leachate, liquid waste that percolates from decomposing solid waste to percolate into the ground, posing a high threat to groundwater resources. Studies have shown that groundwater contamination from landfill leachate can lead to the presence of heavy metals, bacteria, and toxic chemicals, which can cause serious health problems such as gastrointestinal infections, liver damage, and neurological disorders (Chidya et al., 2016). The effect of this pollution is not limited to the immediate area around the dumpsite, since groundwater is one of the main sources of drinking water for most Zomba inhabitants.

Besides, methane gas released from the decomposing organic waste at Dump site and some other illegal dump sites and areas is causing air pollution and climate change. Methane is a potent greenhouse gas with high global warming potential than carbon dioxide (EPA, 2019). Lack of methane recovery systems at the dumpsite not only exacerbates the global climate problem but also increases the risk of fire outbreaks due to spontaneous combustion, a problem prevalent in most uncontrolled landfill dumps (Mkwambisi et al., 2011).

The other critical issue is an increase in disease vectors, such as rodents and insects, which are abundant in uncontrolled waste disposal sites. The proliferation of these vectors is a public health issue because they are known carriers of infectious diseases, like malaria, cholera, and typhoid fever (Gondwe et al., 2020). The presence of scavengers, who utilize waste picking as a survival mechanism, further exposes vulnerable populations to risky conditions, including physical injuries and respiratory diseases resulting from inhaling poisonous gases emitted by decomposing trash.

2.5 GIS AND REMOTE SENSING APPLICATIONS IN WASTE MANAGEMENT

2.5.1 Site Suitability Analysis for Landfills

A multi-criteria decision analysis (MCDA) method should be utilized in selecting appropriate landfill sites, considering environmental, social, and economic factors Sener et al., 2011. GIS-based approaches allow slope, proximity to water bodies, land use, and population density to be combined to identify the most suitable disposal sites (Kassahun & Omran, 2019. In Zomba, GIS can be used to evaluate potential landfill locations by overlaying environmental constraints. Accessibility of infrastructure for example nearness to roads for transport. Social considerations for example preventing exposure to residential areas and public places like schools, hospitals, markets and others. Applied Analytical Hierarchy Process (AHP) to rank potential landfill locations using GIS in Blantyre, Malawi (Munthali., 2022), demonstrating how similar processes could be adapted for application in Zomba.

2.5.2 Optimal Waste Collection Point Allocation

Efficient waste collection with strategically located collection points help to minimize transport cost and achieve better coverage. GIS-based location-allocation models can determine the best waste location points taking into account Population density because high-generation areas need more collection points. Road network to provide

accessibility for collection vehicles. Existing waste hotspots .A Nairobi, Kenya case study used GIS to reduce collection route distances by 30%, promoting operational effectiveness (Otieno & Omwenga, 2020). The same techniques can be applied in Zomba to increase waste collection coverage.

CHAPTER 3: METHODOLOGY

3.1. MATERIALS AND METHODS

3.1.1 Data Collection

The study employ quite number of data collection methods such as, field data collection and observation where by GPS were used to collect the data for the waste collection points and the dump site around the city and observe the physical state of city dump site and the waste collection points and is shown in the figure bellow. Both primary and secondary data methods were used, where by there was interaction with the city council expertise about the way solid waste are managed in the city they presented their collection schedule, the challenge they are facing and other things . For the secondary part, data were gathered from journals, reports, and books from the internet, different institutions and departments, for example Population density data in order to identify waste generation hotspot was obtained from national statistics office documents published online and the city council reviews. For raster data Sentnel2 was used with resolution of 10 meters downloaded on European Union Space Agency, for the Aster DEM at a 30-meter resolution, sourced from the USGS. Google earth engine to generate road networks data.

Figure 18: The city Dump site at Chikumbeni 4 miles



Source: picture captured during field data collection in Zomba city

There are a lot of data used in these project and the table below shows the data used and their sources

DATA	DATA SOURCE
Digital Elevation Model (DEM)	SRTM(30m)
population density	National statistical Office (NSO)
Roads	Malawi Spatial Data Platforms (MASDAP)
Rivers	Malawi Spatial Data Platforms (MASDAP)
Geology	Department of Geological Survey
Soil	Food and Agriculture Organization (FAO) Soil database
Land use Land cover (LULC)	Sentnel2 (supervised classification using Qgis)
Administrative Boundary	Malawi Spatial Data Platforms (MASDAP)
Waste collection points	Zomba City council
Waste collection schedule	Zomba City Council

Table 4: The Data used and their sources

3.1.2 Methods

The study uses quite number of approach to achieve its main objective for example it uses the following materials and methods. Arc map 10.8.2 and Qgis were used for map generation and performing analysis such suitability analysis, Buffer, overlay proximity analysis, kernel density, service area allocation and many other analysis and tools. Supervised classification in Qgis was used to come up Land use land Cover (LULC) with four classes which are Rivers, Vegetation, Built up and Bare land.

Analytic Hierarchy Process (AHP) for structured and systematic approach to evaluate and prioritize multiple criteria and alternatives leading to a more informed and rational decision

The study was demarcated in two areas which is first to analyze the existing waste collection points and then find the additional optimal collection points to unsaved areas in order to reduce illegal dumping of waste to unauthorized places for example rivers, roads, public places like markets, protected areas like forests and overall improve waste management efficiency. The second part was to identify and rank the potential site for landfill in order to prevent environmental degradation, soil, water and air pollution which affects public health.

3.1.2.1 Analysing spatial distribution of existing waste collection points and dump site

To achieve this objective primary data containing coordinates of waste collection points around the city and disposal site were collected using GPS and city council reviews on waste management in order to understand current waste collection system. The state of collection points in terms of waste composition, the number and state of collection bins placed at each collection points was physically observed and recorded. The city council collection schedule was also observed in order to see the weekly waste collection frequency. The waste collection points coordinates was overlaid using arc map 10.8.2 with city council wards data and population density data in order to see the how waste collection points are distributed throughout the city, and the maps were produced. It was observed that there are few number of bins in many waste collection points and it takes two to three days and even a week for the city council to come and empty the bins at the collecting point, this makes bins to be full and a lot of waste accumulate around the bin others are carried away by wind, scavengers and running water particularly during the rainy season and gets deposited in homes, rivers and many other places. It has also observed that there are few waste collection points in densely populated places like in Chinamwali, Likangala ward which covers the residence of Chikanda, Zomba central ward covers the

residence of Fago, Sadzi ward. This facilitate and increase the practice of illegal dumping of waste in unauthorized places as many people find it difficult to move a long distant to disposal their waste at collecting points designed by the city council instead there opt to dump their waste anyhow putting pressure to environment and public health . Other areas have no waste bins in their waste collection points, they dump their waste on the land and the city council come and collect them while in other places there no waste collection points as it shown on the map bellow.

DAYS	COLLECTION AREAS
Monday	C. Ben, Chinamwali Market, Bus Deport, Central Market, Zambezi, Sewage Banker, Central Hospital Banker,
Tuesday	Chirunga, Nandolo TD, Chanco, Matawale Turn Off, Matawale Area.
Wednesday	Chinamwali, V Ben, C Market, Mpunga ,Sadzi, Central Hospital Ben, Banker
Thursday	Central Hospital, Ben And Banker, Chinamwali, C Ben , C Market , Bus Deport And Zambezi
Friday	Chinamwali, C Ben, Central Market, Central Hospital, Sadzi.
Saturday	Central Hospital, C Ben, Ben, Chinamwali, Central Market, Bus Deport, Matawale Turn Off.
Sunday	Central Hospital, Ben, C Ben, Chinamwali Central Market, Mpunga and Sadzi Market

Table 5: Showing City Waste Collection frequency, Information sourced from Zomba City Council

3.1.2.2 Identifying additional optimal waste collection points around the city

Zomba city generate 0.5 kilograms of waste per person per day (Munthali, 2023). The goal of finding more suitable waste collection sites was achieved by utilizing a geospatial analysis technique that combined population density, waste generation, and accessibility data.

First, localized waste generation (kg/day) was estimated using wards boundaries and a combination of waste and population analysis.
A heat map using boundaries like the centroid points in Kernel Density analysis was used to demarcate the high-density waste locations. By overlaying land use data and existing collecting points on this heat map, gaps in service were also identified. By using buffer analysis and service area allocation new collection point priority locations were identified in high-waste areas with insufficient coverage, away from sensitive areas like schools, residential areas hospitals and other places.

KERNEL DENSITY

First, high-priority waste generating zones were identified using Kernel Density analysis. Ward centroids were converted into points weighted by their daily trash output, and a heat map was produced using ward-level population data and the established waste generation rate of 0.5 kg/person/da (Nazombe et al., 2019). A 500-meter search radius smoothed the findings of the Kernel Density tool's trash concentration calculation over the city, revealing distinct hotspots. Areas highlighted in bright red or yellow showed an urgent need for collecting infrastructure. This result served as the basis for focusing actions, guaranteeing that funds were distributed to areas with the greatest waste load, notably crowded wards like Chinamwali, Sadzi, Chikanda and Masongola ward

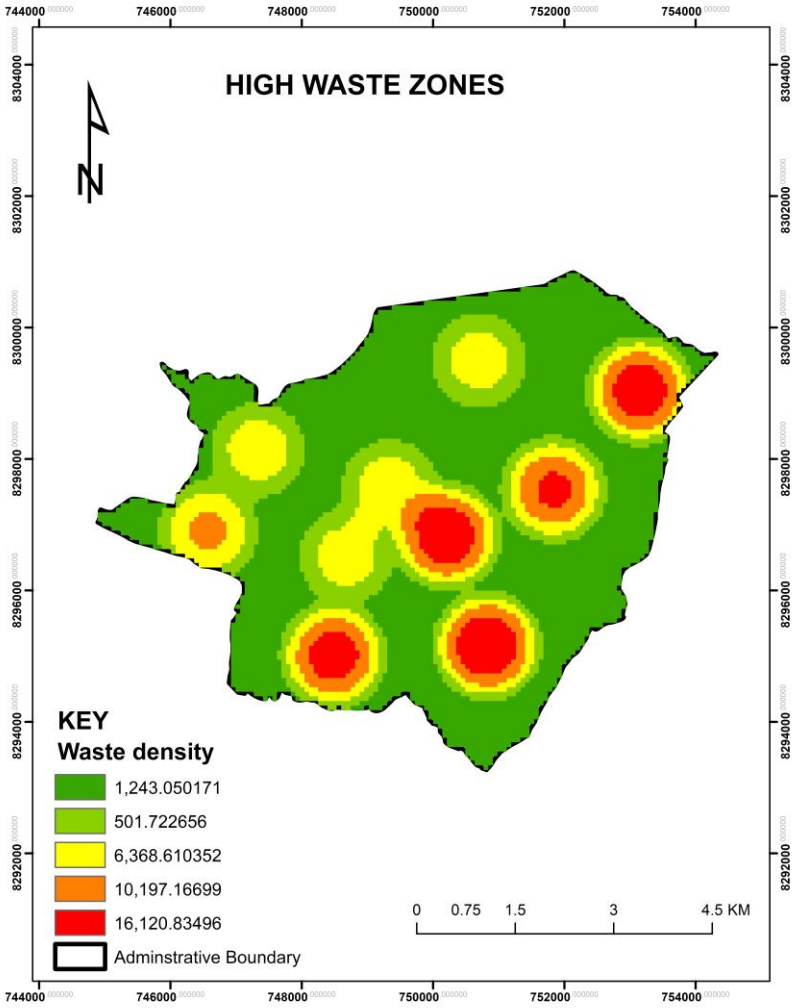


Figure 19 Map showing Kernel Density Estimation

BUFFER ANALYSIS

To assess the gaps in the current waste collection coverage, a buffer analysis was performed. Every existing Waste collection Points (WCP) has a buffer zone of 300 meters, which is a manageable walking distance for locals. The research identified "unserved areas" without accessible WCPs after removing these buffered zones from Zomba's border layer. The Extract by Mask tool was then used to overlay these gaps with the waste density heatmap, identifying high-waste areas that were also underserved. Certain areas of Chikanda Ward, for example, were identified as ideal candidates for new WCPs because to their high waste generation and poor service coverage.

SERVECE AREA ALLOCATION

In order to guarantee fair spatial distribution, Service Area Allocation improved the positioning of the suggested WCPs. The analysis determined 500-meter pedestrian service areas surrounding each potential WCP location using Zomba's road network. By methodically addressing gaps and minimizing duplicating coverage, network analyst tools assessed overlaps between these service areas and population demand. For instance, it has been demonstrated that three carefully positioned WCPs in Chikanda cover 95% of families that were previously unserved. This process also included restrictions such as preserving 200-meter setbacks from schools and rivers, which were accomplished by removing inappropriate areas prior to choosing final sites. As a result, Zomba City's objectives to enhance waste management were directly supported by a data-driven, optimized WCP network that struck a balance between environmental safety, efficiency, and accessibility.

(1) Identify the potential locations for waste disposal sites in the city

This objective was achieved by applying site suitability analysis using GIS based on environmental, social and economic factors. Site selection criteria's was defined by taking into the consideration distance from water bodies, land use/land cover, slope, soil type, the geology of the area, proximity to main road, residential and commercial areas, accessibility to major roads and land availability

In site selection for solid waste disposal the environmental protection and the public health are the major controlling factors. The following steps or factors were evaluated accordingly because these are very important in as far as site selection for waste disposal site is concerned, soil and rock properties (geology), surface and groundwater condition, soil permeability to identify the pollution mechanism and to present controlling method leachate in the landfill. There is a waited approach that was proposed for site selection and these weighted approach that is proposed

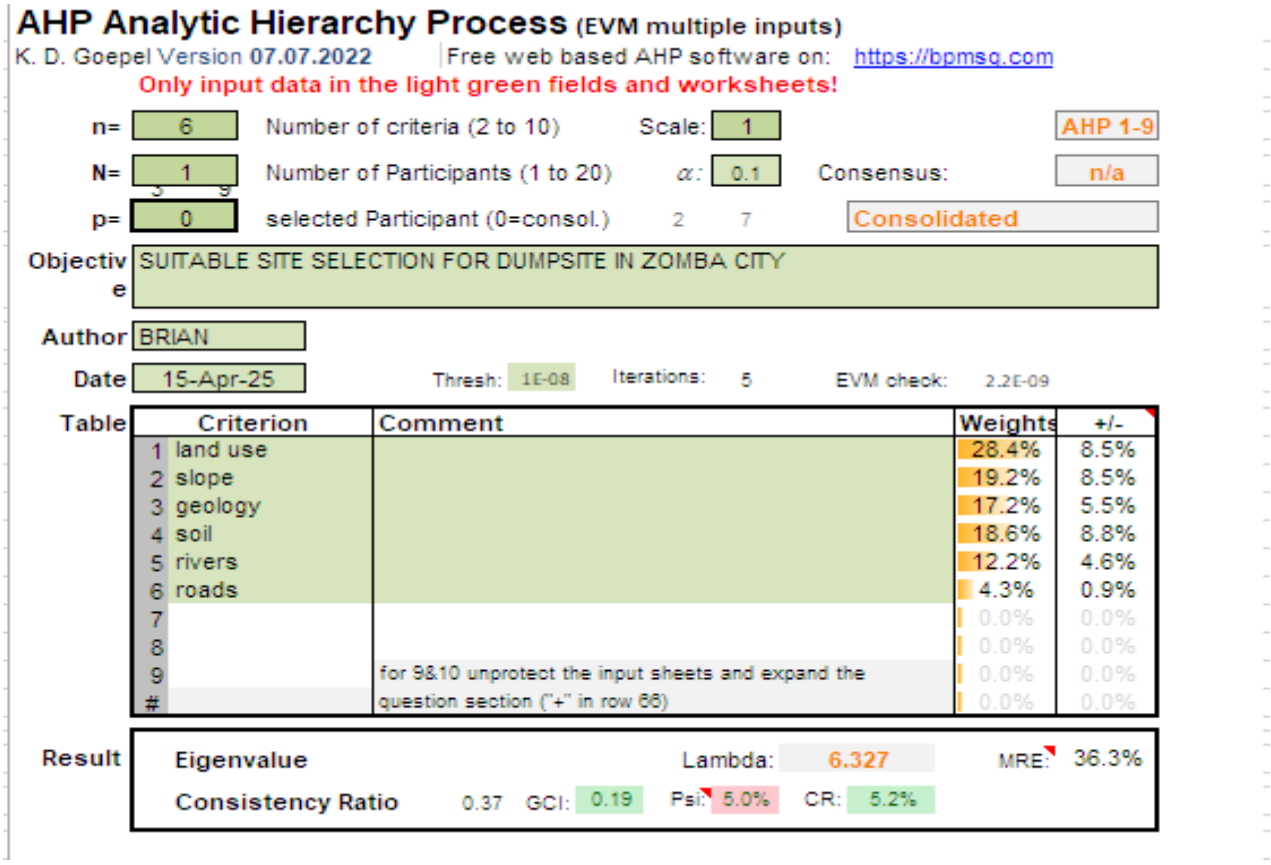
for Zomba city dumpsite selection is presented in Fig 11. And for this city's landfill site selection weighted factors is presented in the table 2

3.1.2.3 Analytical Hierarchical Process

In order to prioritize and rank different elements according to their relative importance toward a specific goal in this case, finding appropriate sites for waste disposal Analytic Hierarchy Process (AHP) was used. The Analytic Hierarchy Process (AHP) is a structured multi-criteria decision-making (MCDM) method. Thomas Saaty created AHP (Nadali et al.., 2016), which divides difficult decisions into a hierarchy of simpler sub problems that may be examined separately. The AHP uses pair wise comparison between factors involved. Using both qualitative and quantitative data, it enables decision-makers to consistently reach conclusions.

Six important criteria land use, slope, geology, soil, rivers, and roads were ranked in this project using AHP. These criteria were first arranged in a hierarchical framework, with the final objective of locating appropriate dump sites at the top. Then, using a scale of 1 to 9 (where 1 denotes equal value and 9 denotes excessive importance of one over another), a pairwise comparison matrix was created, in which each criterion was compared with every other criterion according to its relative relevance. For instance, due to its impact on leachate flow and erosion, slope may be more important than road proximity. Following matrix filling, eigenvalue methods were used to determine priority weights for each criterion.

These weights were utilized in the weighted overlay analysis in a GIS environment and represent the relative impact of each factor on the choice. To make sure the decisions were trustworthy, a consistency check was also carried out using the Consistency Ratio (CR). A more accurate and convincing site suitability analysis for waste disposal was produced as a result of the methodical and objective assessment of environmental and physical criteria made possible by this AHP-based technique.



AHP Analytic Hierarchy Process (EVM multiple inputs)

K. D. Goepel Version 07.07.2022 | Free web based AHP software on: https://bpmsg.com

Only input data in the light green fields and worksheets!

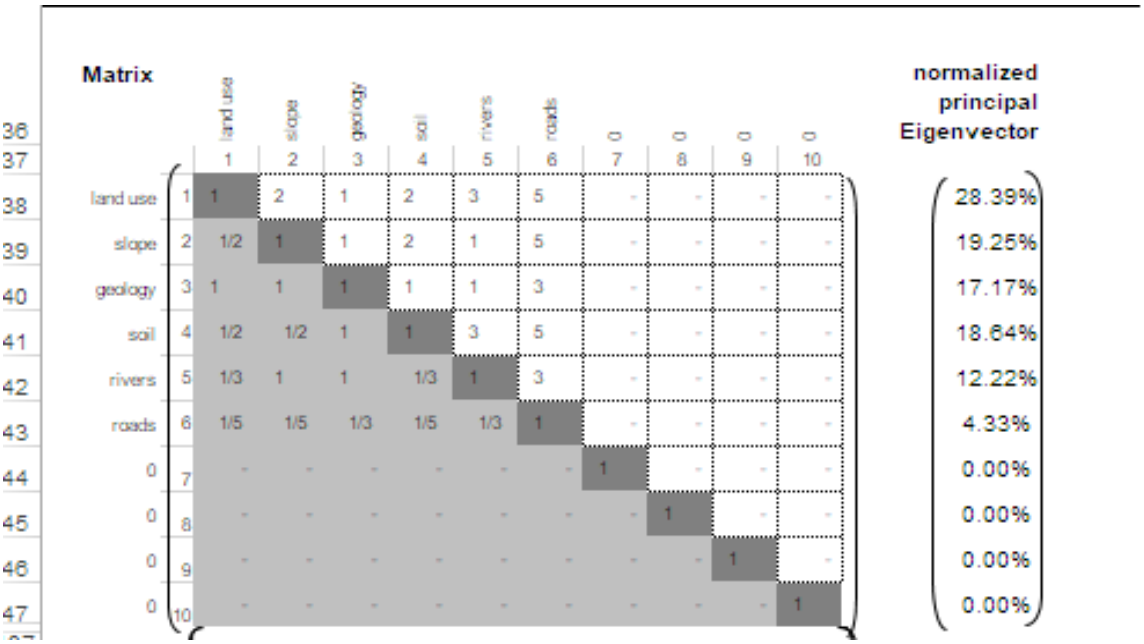
n=	6	Number of criteria (2 to 10)	Scale:	1	AHP 1-9
N=	1	Number of Participants (1 to 20)	α:	0.1	Consensus: n/a
p=	0	selected Participant (0=consol.)	2	7	Consolidated
Objective	SUITABLE SITE SELECTION FOR DUMPSITE IN ZOMBA CITY				
Author	BRIAN				
Date	15-Apr-25	Thresh: 1E-08	Iterations: 5	EVM check: 2.2E-09	

Table	Criterion	Comment	Weights	+/-
1	land use		28.4%	8.5%
2	slope		19.2%	8.5%
3	geology		17.2%	5.5%
4	soil		18.6%	8.8%
5	rivers		12.2%	4.6%
6	roads		4.3%	0.9%
7			0.0%	0.0%
8			0.0%	0.0%
9		for 9&10 unprotect the input sheets and expand the	0.0%	0.0%
#		question section ("+" in row 66)	0.0%	0.0%

Result						
Eigenvalue			Lambda:	6.327	MRE:	36.3%
Consistency Ratio	0.37	GCI: 0.19	Psi: 5.0%	CR: 5.2%		

Figure 20: The Analytic Hierarchy Process (AHP) EVM

Table 6: The Criteria Matrix Table



Matrix

		land use	slope	geology	soil	rivers	roads	0	0	0	0	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10	
land use	1	1	2	1	2	3	5	-	-	-	-	28.39%
slope	2	1/2	1	1	2	1	5	-	-	-	-	19.25%
geology	3	1	1	1	1	1	3	-	-	-	-	17.17%
soil	4	1/2	1/2	1	1	3	5	-	-	-	-	18.64%
rivers	5	1/3	1	1	1/3	1	3	-	-	-	-	12.22%
roads	6	1/5	1/5	1/3	1/5	1/3	1	-	-	-	-	4.33%
0	7	-	-	-	-	-	-	1	-	-	-	0.00%
0	8	-	-	-	-	-	-	-	1	-	-	0.00%
0	9	-	-	-	-	-	-	-	-	1	-	0.00%
0	10	-	-	-	-	-	-	-	-	-	1	0.00%

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 RESULTS

4.1.1 Criteria's used to identify suitable sites for a waste disposal

4.1.1.1 Land use Land cover (LULC)

Land use land cover (LULC) is a crucial factor that needs serious consideration when siting a landfill to avoid the Not In My Back Yard (NIMBY) syndrome (Nadali et al.., 2016). The 2024 Sentinel 2 Satellite Imagery was subjected to a supervised classification process in Quantum GIS. In this study, classification was based on a predefined LULC classification scheme. Consisted of four classes namely water bodies, vegetation, built-up areas, and bare land. Supervised classification was performed to highlight the specified classes.

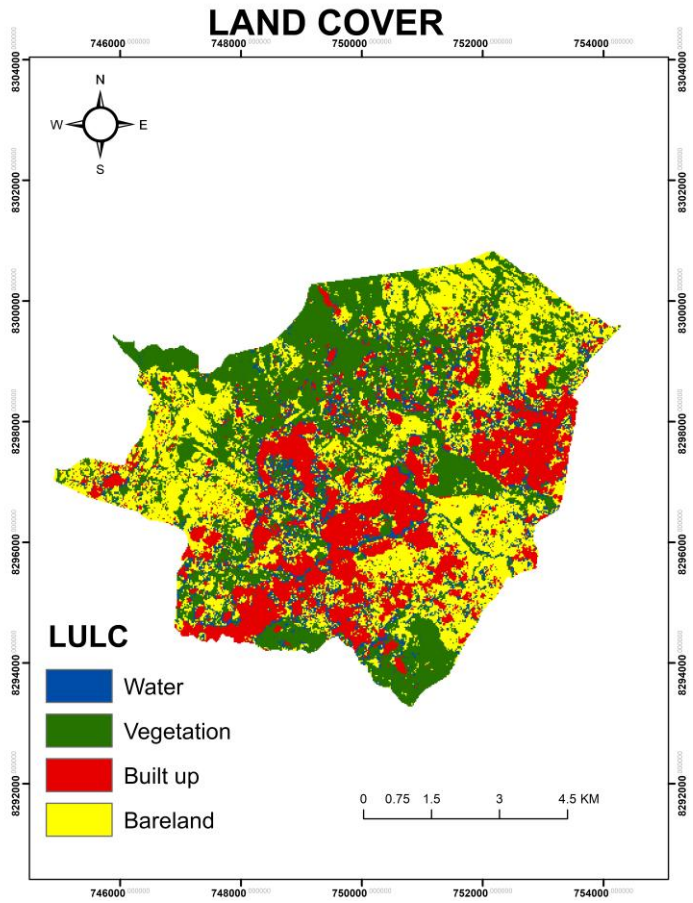


Figure 21 Land use land cover map

4.1.1.2 Geology

Geology was one of the key factors considered in identifying suitable sites for waste disposal. The geological data for Zomba City was obtained from the Geological Survey Department. According to the provided data, Zomba's geology is characterized mainly by basement complex rocks, including gneisses, schists, and granites, as well as limited areas of sedimentary formations, particularly in low-lying zones. These different geological formations influence the permeability, stability, and drainage characteristics of the land all of which are crucial in landfill siting to prevent groundwater contamination and ensure structural stability (Fei et al., 2016).

Using the obtained geological data, a detailed geology map of Zomba City was produced. This map was then reclassified based on the suitability of different rock types for landfill construction. Hard, impermeable rocks like granite and gneiss were considered more suitable due to their low permeability and stability, while sedimentary formations and areas with highly fractured rocks were rated as less suitable due to their higher risk of leachate infiltration into groundwater. The reclassified geology map was subsequently integrated into the weighted overlay analysis, where it was assigned a weight based on its relative importance compared to other criteria like slope, land use, soil, rivers, and roads. This approach ensured that geological stability and protection of groundwater resources were adequately prioritized in the final site suitability model.

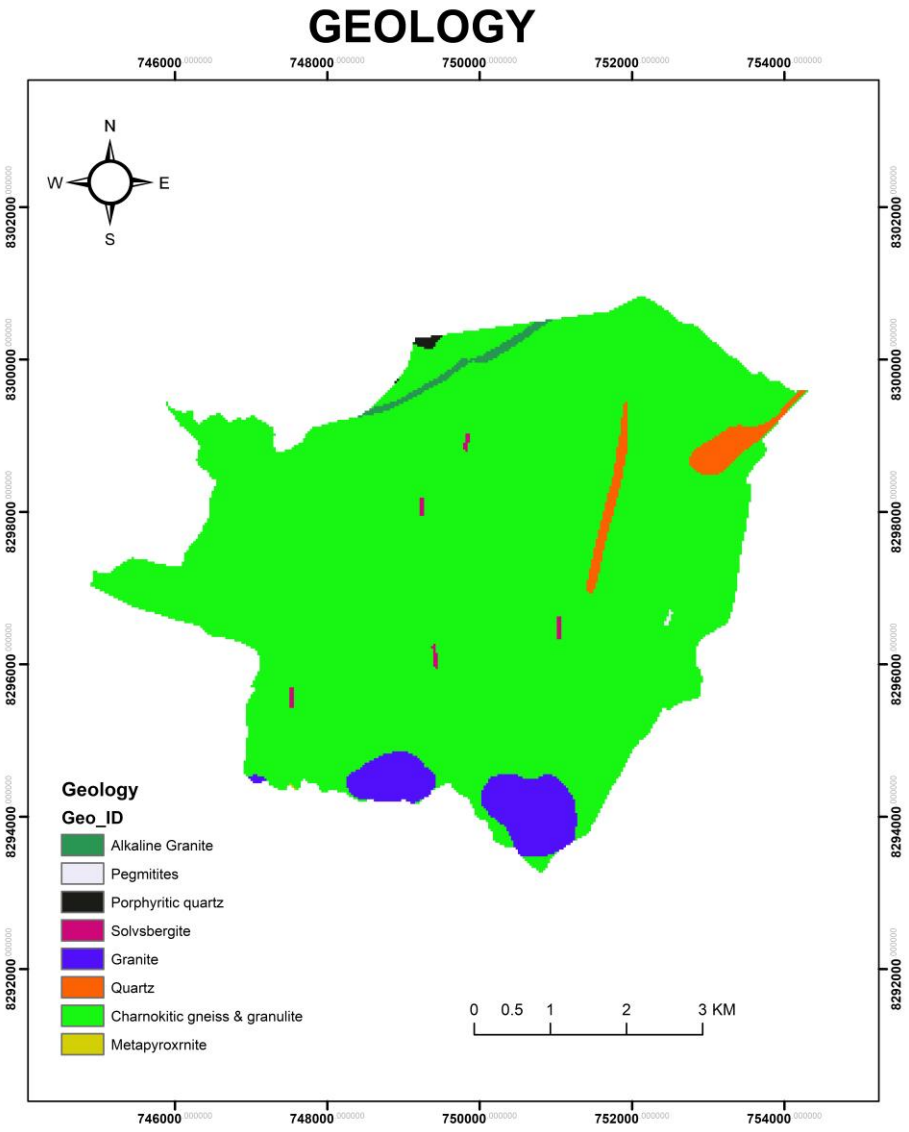


Figure 22: Geology map of Zomba City

4.1.1.3 Rivers

A safe distance or reasonable buffer zone from rivers or streams, should be considered when planning a landfill. This is important because landfills are sources of leachate production and obnoxious gaseous emissions, which are potential groundwater pollutants (Asefa, 2019). In this study the river or criteria's ware set as follows: < 300 m as unsuitable, 300 – 500 m as suitable and > 500 m as most suitable.

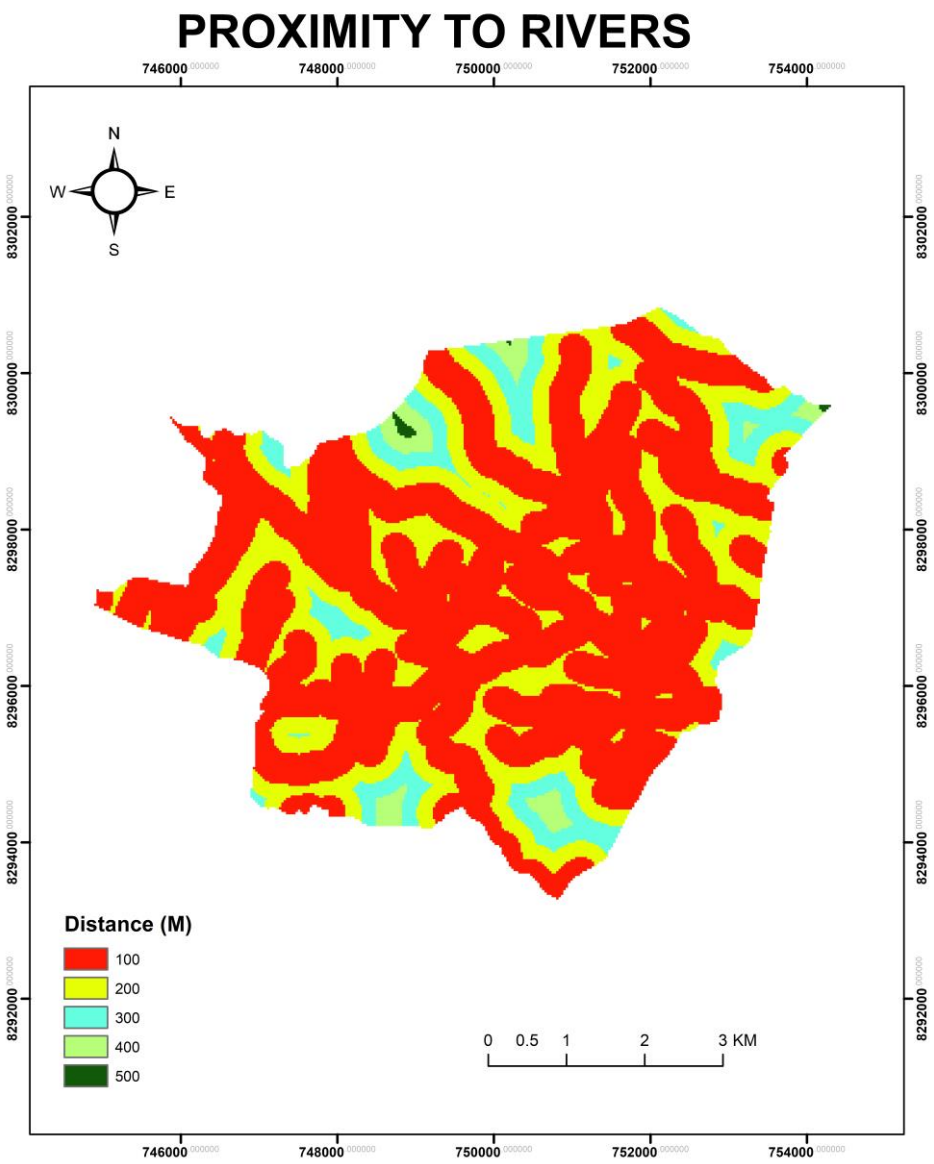


Figure 23: The Map showing Proximity to the Rivers

4.1.1.4 Roads

One of the most important considerations when choosing a landfill location is accessibility. As a result, the roads ought to be open all year round. The cost of transportation from waste collection centres to landfills is determined by the distance from the highways. However, in order to prevent unpleasant odours and aesthetic impacts, a landfill shouldn't be located too close to the highways. A landfill must be positioned adequately apart from major and secondary highways, according to (Kebede). Highways, major roads and secondary roads were the categories into which the adequacy of the roads was considered in this study. The literature has proposed various buffer distances. For example, the best distance for main roads is less than 1000 meters, whereas the best distance for secondary roads is more than 2000 meters. In this study the buffer distance of <100 meter for unsuitable, 1000 to 2000 meters for suitable and >2000 meters for most suitable was used

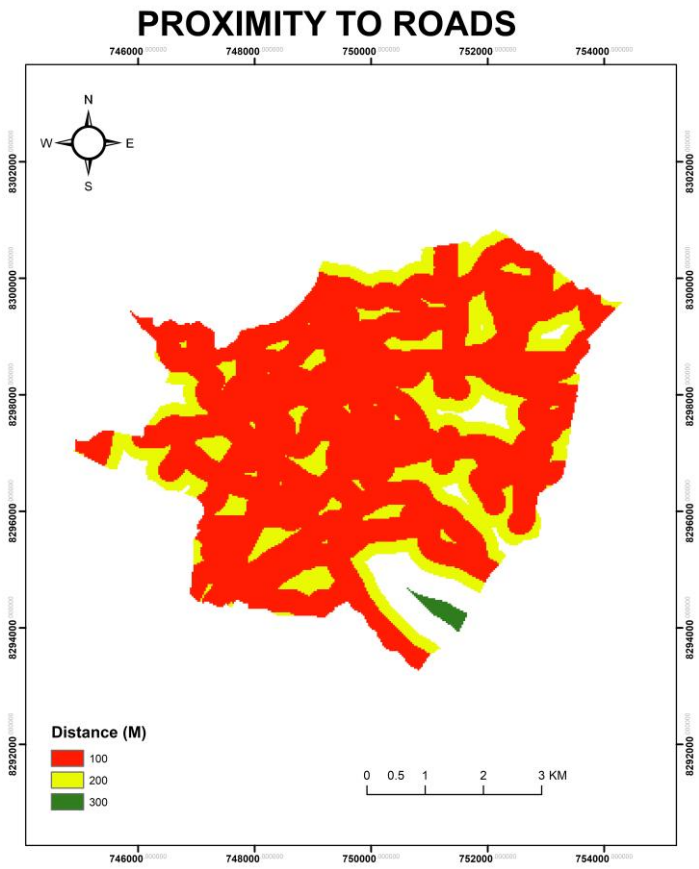


Figure 24: The Map Showing Proximity to Roads

4.1.1.5 Slope

When choosing a landfill, one aspect that must be carefully taken into account is the slope. Land with a gradual slope is deemed most suitable and given the highest value in order to reduce landscaping expenses and leachate leakage. Steep slopes, on the other hand are seen to be inappropriate and assigned the lowest suitability ratings (Munthali, 2023). Furthermore, the expense of building and maintaining a landfill is higher in places with higher slope values. In this study slope values vary from 0◦ to 40◦. An area was deemed unsuitable if its slope was greater than 15◦, generally acceptable if it was between 5◦ and 10◦, and most suitable if it was between 0◦ and 5◦

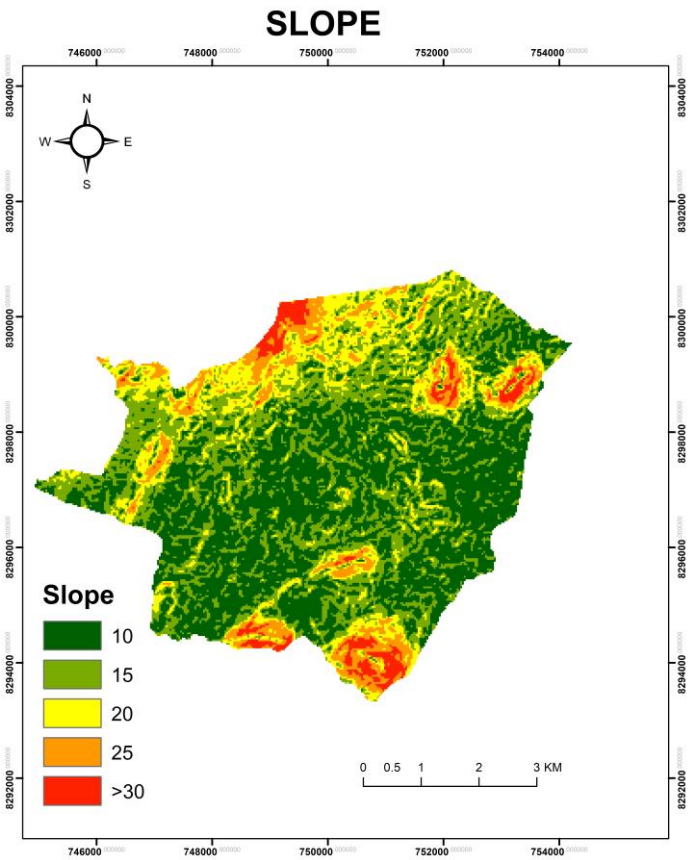


Figure 25: The Map showing the elevation of a City

4.1.1.6 Soil

A site's permeability and structural stability are two crucial aspects of sustainable landfill development and they are influenced by the texture of the soil. Because of their high permeability and ease of leachate infiltration into groundwater, coarse-textured soils like sandy loam and loamy sand are less suitable for landfill siting. Conversely fine-textured soils such as clay loam and sandy clay loam have low permeability which reduces the danger of contamination and helps to retain leachate. Additionally, these soils offer improved structural support for landfill operations, lowering the possibility of infrastructure and ground instability.

The study prioritized areas that offer superior engineering adaptability and environmental protection by integrating soil texture data into the weighted overlay analysis in GIS. While sandy and rocky soils, like rock outcrops, received lower suitability values, less permeable and more compactable soils, such clay loam, were given higher weights. This supported Zomba City's long-term objectives of environmentally responsible and effective solid waste management by guaranteeing that the waste could be contained in the designated disposal sites without endangering surrounding residents or groundwater supplies.

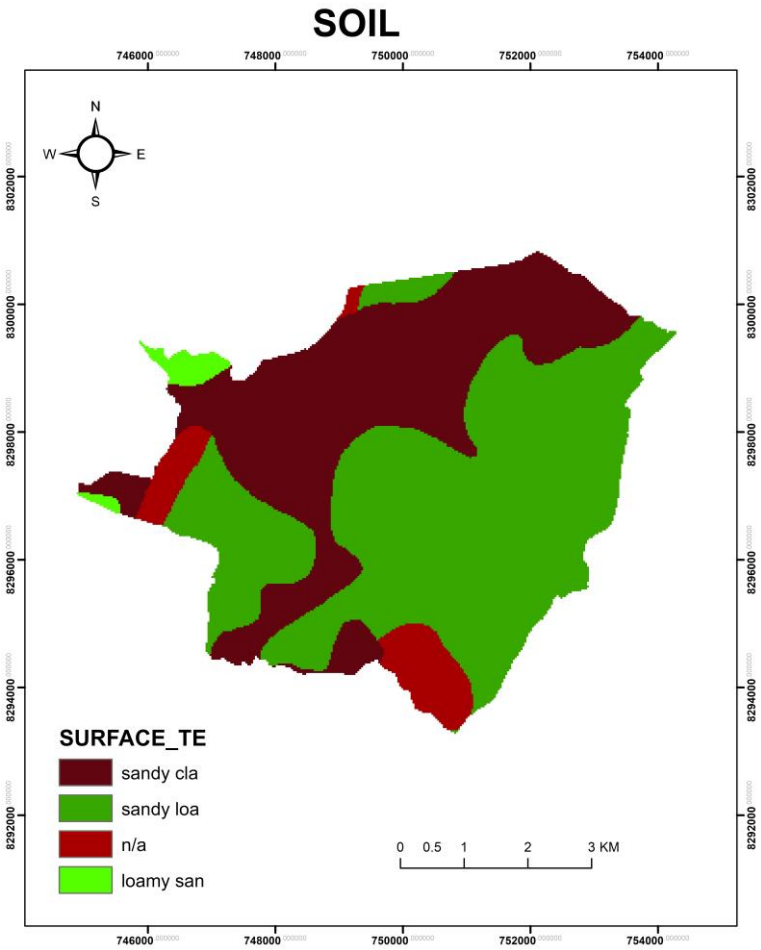


Figure 26: The Surface soil Structure of Zomba City

Here is the suitability map showing the suitable sites where the dumpsite for the city can be constructed.

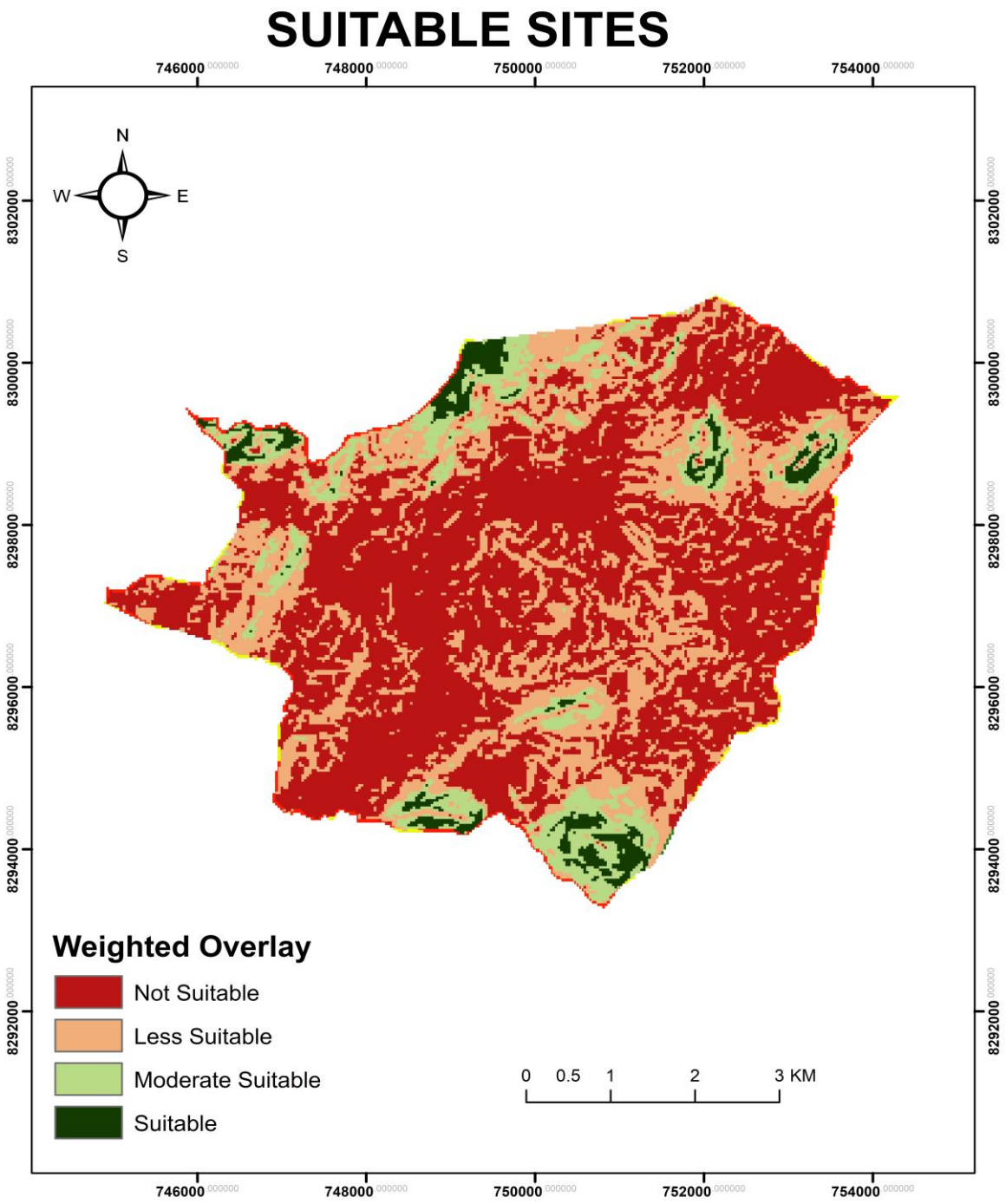


Figure 27: The Map of Suitable Sites for Dumpsite

4.1.2 Criteria's used to propose additional waste collections stations

4.1.2.1 Population density

Acted as the fundamental layer upon which high-priority zones were determined. In order to visualize the places with the largest potential for trash generation, ward-level population data was converted into a heatmap using Kernel Density analysis. With populations of more than 1,000 people per km2, wards like Chinamwali and Chikanda have been crucial targets for more infrastructure because of their disproportionate waste production.

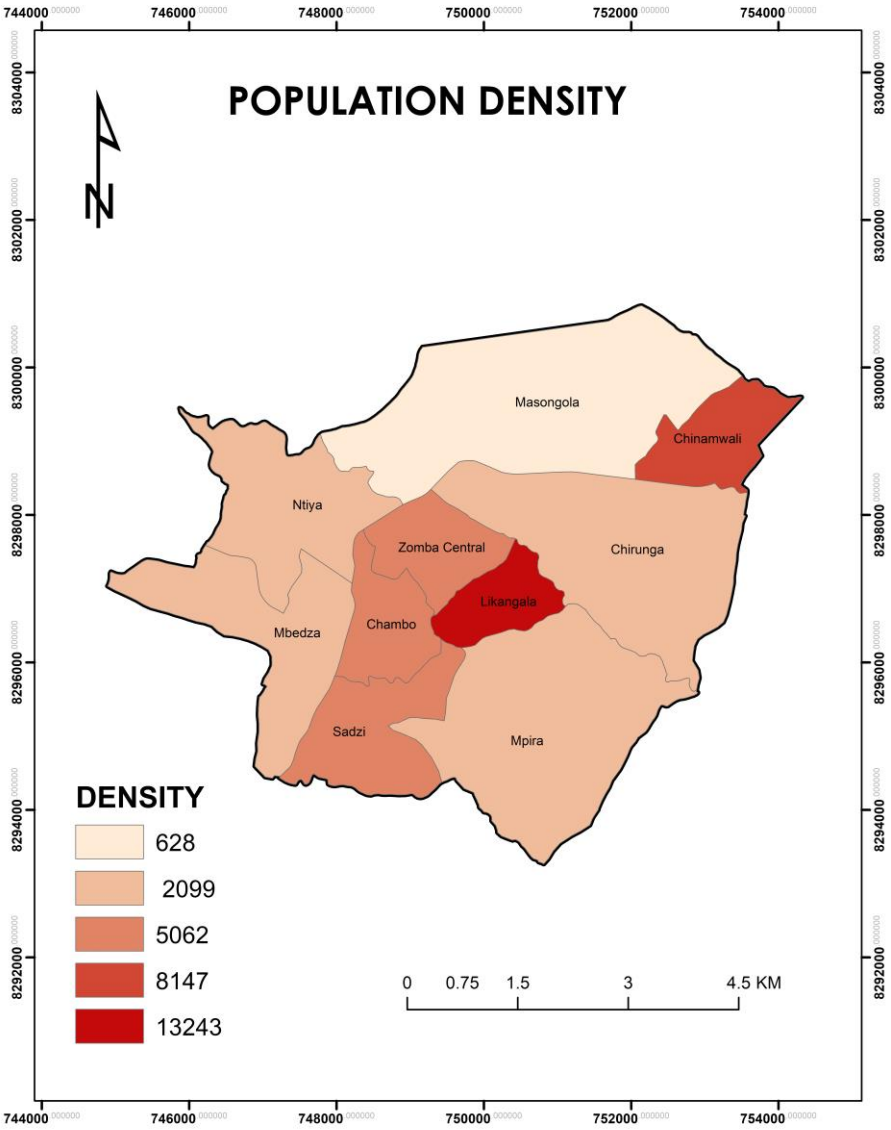


Figure 28: Zomba City Population Density

4.1.2.2 Markets and existing waste collection points

Markets and existing waste collection points were examined in order to evaluate the coverage of present services. Accessibility gaps were found, especially in peri-urban regions, when a 300-meter buffer was placed around each WCP, which is a comfortable walking distance for inhabitants. Markets were identified as areas with high activity levels and given priority for the installation of extra bins to accommodate both sellers and customers.

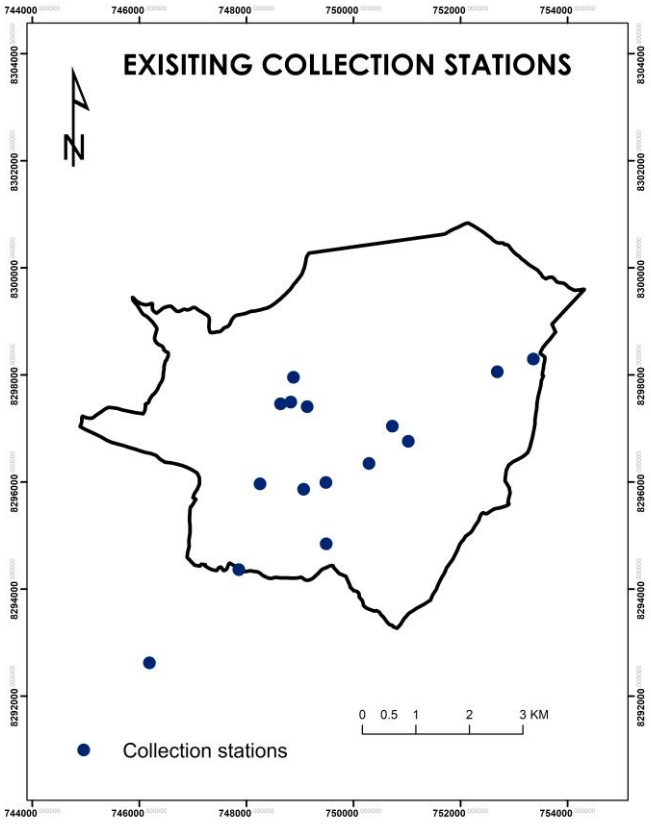


Figure 29: City Waste Collection Stations

4.1.2.3 Roads

Road networks had two purposes: they provided inhabitants with pedestrian access and ensured that collection vehicles could operate logistically. In order to retain walkability and conform to trash truck routes, candidate locations were connected to roadways 20–50 meters away. WCP deployment was denser on major arterial roadways because of increased foot traffic.

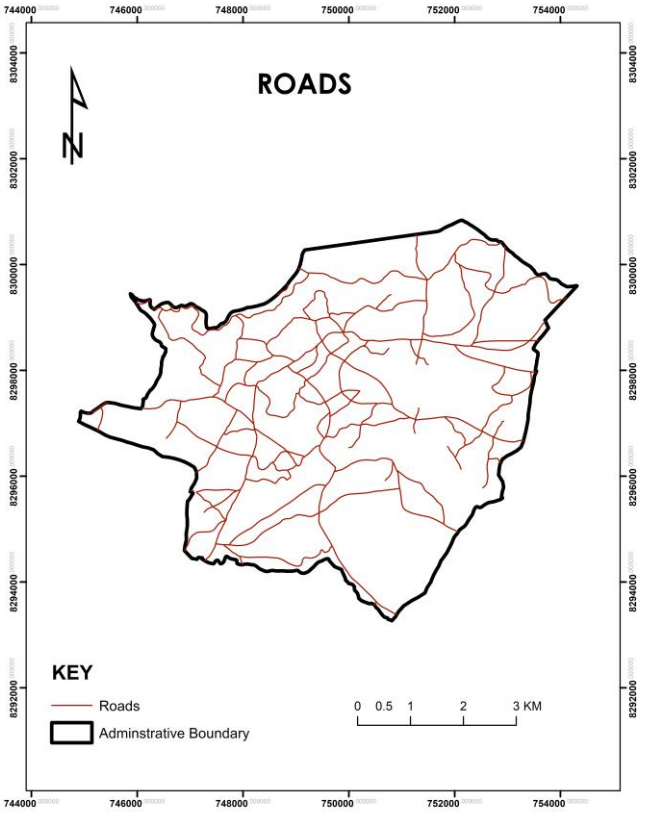


Figure 30: The City Roads networks

4.1.2.4 Rivers

A 200-meter buffer around waterways prevented pollution risks, while similar buffers around schools minimized public health concerns. These zones were erased from candidate areas using overlay tools.

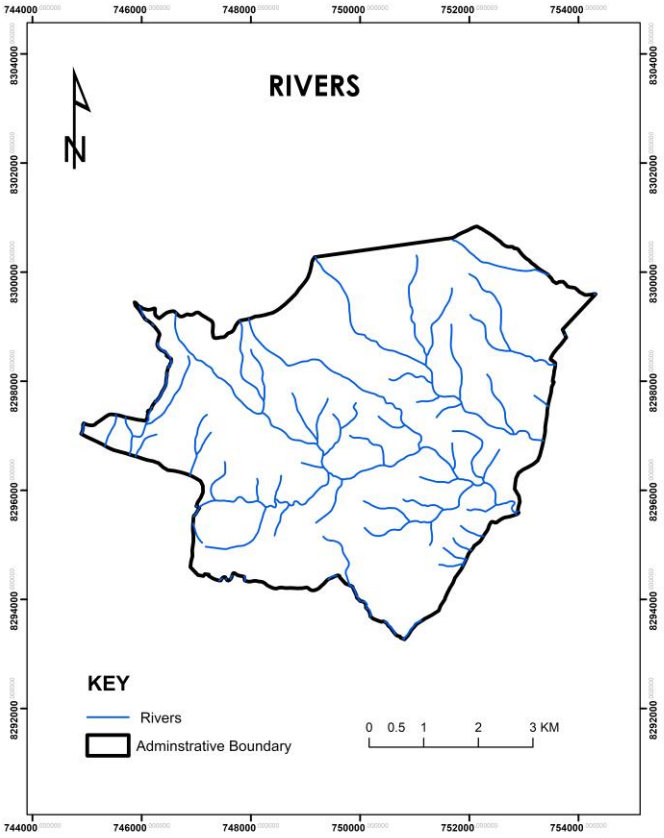


Figure 31: The Map of Zomba City Rivers

After taking into the considering all the factors above here the map showing the proposed waste collection station around the city.

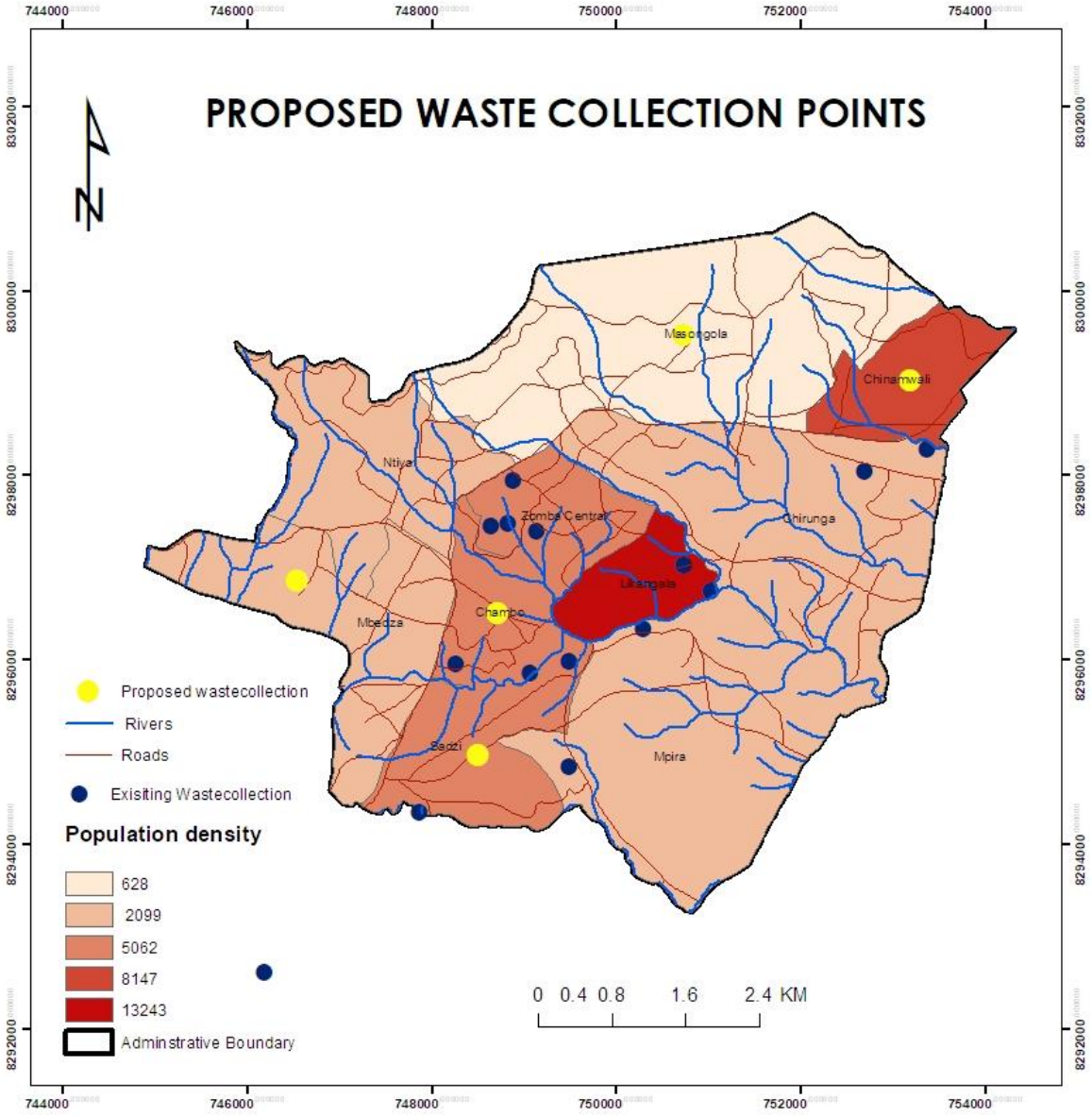


Figure 32: The Map of Waste Proposed Stations

1.2. DISCUSSION

According to the initial set of findings from the site suitability analysis, residential, commercial, and institutional developments currently occupy around 78% of Zomba City's area. There are fewer environmentally and socially appropriate locations for dump site construction due to the increasing level of urbanization. The quality of life in the surrounding communities would eventually be jeopardized if a dumpsite were developed in such densely populated areas since it would provide major environmental dangers, including air pollution, groundwater contamination, and public health hazards (UNEP, 2010). These results are in line with comparable urban case studies that show social opposition and land constraints deter landfill siting in the urban core (Mbulaje et al., 2022).

Just 6.5% of the entire research area was deemed to be highly appropriate for dumpsite construction, according to the multi-criteria evaluation methodology. These places are mostly found around the southern and eastern urban peripheries of Mbedza and Mpira Ward, on the far side. These areas received higher ratings for non-sensitive land use, low settlement density, safe separations from roads and waterways, and slope (usually less than 10%). This is in keeping with recommendations made by the Malawi Environmental Protection Authority (2021), which support the placement of landfills in areas with a low population density and stable environmental conditions. The landfill's placement in such outlying areas also supports Malawi Vision 2063's objectives, especially Pillar 3 on environmental sustainability (NPC, 2020).

Over **60%** of the central urban zone was classified as strongly unsuitable for landfill development. These areas are characterized by intense built-up land use, proximity to major roads and rivers, and high population density. Furthermore, environmental sensitivity in these zones is high and these may result in increasing the risk of contamination. Constructing a dumpsite in these central areas would not only violate zoning regulations but also escalate community health risks (Zomba City Council, 2023). This supports Sustainable Development Goal (SDG) 11, which calls for sustainable, inclusive, and safe urban settlements (UN, 2015).

An analysis of kernel density and service area allocation showed that about 40% of residential areas, mostly in Chinamwali, Sadzi, Mbedza, Mtiya, and Masongola, are outside of the current garbage collection service zones. Illegal waste disposal in rivers, roadside drains, and open spaces is largely caused by this service gap, which results in poor environmental cleanliness and issues with public health. The city's waste collection system would be far more inclusive and efficient if five additional waste collection locations were added to these underserved wards, increasing collection coverage by 27%. In line with Malawi's Vision 2063 commitment to ecologically safe infrastructure, these initiatives also support SDG 11 (NPC, 2020; UN, 2015).

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, using GIS and multi-criteria evaluation approaches, the study effectively evaluated the appropriateness of waste disposal locations and the spatial distribution efficiency of waste collecting stations in Zomba City. The majority of the city is already substantially developed, according to the results, and 78% of the area is unsuitable for dumpsite development because of urbanization and environmental restrictions. The majority of the extremely favorable locations found are found along the edge of the city and on the far side of Mbedza Ward, where there are little environmental hazards.

Significant spatial gaps in waste collection services were found by the investigation, especially in Chinamwali, Sadzi, Mbedza, Mtiya, and Masongola, where almost 40% of residential zones lack adequate service.

Priority zones for the construction of more collection points were identified by the study through kernel density estimation, buffer analysis, and service area allocation. These measures would immediately reduce unlawful garbage dumping and increase the effectiveness of waste management, which is in line with SDG 11's advocacy for inclusive, safe, and sustainable cities and Malawi Vision 2063's environmental sustainability targets.

5.2 Recommendations

To address the challenges caused by poor management of solid waste in Zomba city and to align with SDG 11 and the Malawi 2063 vision, the following recommendations are proposed:

1. **Expand Waste Collection Services**

   The Zomba City Council should expand solid waste collection services to Chinamwali, Sadzi, Mbedza, Mtiya, and Masongola, areas that were identified as significantly underserved. This expansion will reduce illegal dumping, close service gaps, and improve environmental hygiene.

2. **Get the city dumpsite moved quickly**

   Considering the unsuitability of the current dumpsite at Chikumbeni and the risks posed by encroaching settlements, it is recommended that the city relocates the main dumpsite to the far eastern side of Mbedza Ward or preferably outside the city boundary in the same direction. This location offers favorable slope, geology, soil type, and minimal risk to public health.

3. **Establish Strict Exclusion Zones.**

   The city should designate and enforce exclusion zones in areas identified as strongly unsuitable for waste disposal and infrastructure development—such as steep slopes, river buffer zones, and high-density settlements like Chikanda, Chinamwali, and Sadzi. These zones should be legally protected to prevent unregulated land use that may exacerbate environmental degradation.

4. **Integrate Suitability Data in Urban Planning**

   The land suitability maps and service coverage analyses from this research should be integrated into Zomba City's urban planning and policy formulation processes. This will ensure that future infrastructure, including

waste management systems, align with environmental and spatial suitability considerations.

5. **Promote Community Awareness and Participation**

   The success of waste management interventions relies heavily on public cooperation. It is recommended that the City Council conducts community sensitization campaigns to promote responsible waste disposal practices, enhance compliance, and increase support for new infrastructure developments.

6. **Invest in Data-Driven Monitoring Tools**

   The city should continue using GIS-based tools for monitoring waste generation trends, service coverage, and environmental impact. This will provide real-time data for decision-making and help in achieving long-term sustainability goals.

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