

SITES SELECTION FOR SOLIDS WASTE DISPOSAL BY USING GIS AND REMOTE SENSING A CASE STUDY OF BLANTYRE CITY, MALAWI

RESEARCH PROJECT DISSERTATION SUBMIITTED IN PARTIAL FULLFILLMENT FOR THE REQUIREMENTS FOR THE AWARD OF THE BARCHELOR OF SCIENCE DEGREE IN GEO INFORMATION AND EARTH OBSERVATION SCIENCE

MALAWI UNIVERSITY OF SCIENCE AND TECHNOLOGY

NDATA SCHOOL OF CLIMATE AND EARTH SCIENCES

ALLAN GUNDA (GIS-008-20)

THYOLO, MALAWI

SUBMISSION DATE: 29 April 2025.

RESEARCH PROJECT APPROVED BY

SUPERVISOR: S. Gondwe SIGNATURE: __ 

ASSESSOR SIGNATURE: _____

DISCLAIMER

this document describes work undertaken as part of a programme of study at ndata school of climate and earth sciences of the malawi university of science and technology. all views and opinions expressed therein remain the sole responsibility of the author(s), and do not necessarily represent those of the school.

ACKNOWLEDGEMENTS

first and foremost, I would like to extend my deepest gratitude to Dr. Chikondi Chisenga, Head of Department of Climate and Earth Science at Malawi university of Science and Technology, for his invaluable support and mentorship. Teachings in Geological Remote Sensing has contributes to me critical skills in interpreting subsurface Geological features. His guidance has been a pivotal role in this research project

I m also grateful to Dr. Jabulani Nyengere for his exceptional instruction in machine learning and its application in GIS. I developed skills in supervised classification technique particularly use of Random-forest algorithm for land use and land cover Mapping, which prove crucial processing satellite imagery and optimizing classification accuracy for this project.

Special thanks to Mr. Steven Gondwe, my project supervisor, for his constant encouragement, expert advise and unwavering support throughout the research process. His mentorship during web mapping course was instrumental in equipping me with technical expertise needed to develop a fully functional web-based GIS application. Through his instructions I mastered skills in spatial data visualization and interactive map creation. These skills significantly enhanced presentation and communication of spatial analysis in this study. His feedback and high expectation continuously challenge me to refine my technical work and strengthen my academic writing.

I would like to acknowledge Mr.D Mbeya who taught me Multihazard Mapping and cartography. His course imparted essential cartographic skills like effective map design, thematic map production and spatial risk assessment. These skills were vital for accurate representation and visualization of multiple environmental factors considered in this project, especially in developing suitability maps.

My sincere appreciation goes to Mr.Billy Kachingwe, who was working alongside Dr Nyengere in Machine Learning course. Mr kachingwe`s practical insight on optimization and classification model evaluation refines my approach toward ensuring classification precision and validation technique. His contribution fosters my deeper understanding of integrating Machine Learning tools within the Google Earth Engine platform.

A heartfelt thanks to Madam Agness Hamis, who was instrumental in delivering Drone Technology Course. Through her expertise, I acquired important skills in drone flight operations, missions planning, image acquisition and Ortho mosaic generation. The drone data collection knowledge she imparted allows me to appreciate the role of high-resolution imagery data for environmental monitoring and spatial analysis.

TABLE OF CONTENTS

CHAPTER 1 10
ABSTRACT 10
INTRODUCTION 11
PROBLEM STATEMENT 12
MAIN OBJECTIVE OF THE STUDY 13
SPECIFIC OBJECTIVE OF THE STUDY 13
RESEARCH QUESTIONS 13
SIGNIFICANCY OF THE STUDY 14
CHAPTER 2 16
LITERATURE REVIEW 16
CHAPTER 3 25
RESEARCH DESIGN 25
DATA SOURCES 26
MATERIALS AND METHODS 26
METHODOLOGY STRUCTURE 31
DATA ANALYSIS 32
STUDY LIMITATIONS 33
RESUITS AND DISCUSSION 34
CHAPTER 5 47
CONCLUSION 47
APPENDEX 49
REFERENCES 54

ACRONYMS / ABBREVIATIONS

GIS: Geographic Information and Earth Observation science

GEE: Google Earth Engine

AHP: Analytical Hierarch Process

BCC : Blantyre City Council

RS: Remote Sensing

SVM: support vector Machine

LULC: Land use and Land Cover

FAO : Food and Agriculture Organization

CNN: convolutional Neural Network

DEM: digital elevation model

GSD: Geological Survey Department

OSM: Open Street Map

list of figures

Figure 1 study area, Blantyre City 25
Figure 2 weights graph, derived from AHP 30
Figure 3 Blantyre city terrain characteristics 34
Figure 4 Residential, trunk, primary, secondary and tertiary road 35
Figure 5 Blantyre City, Rock types 36
Figure 6 active faults in Blantyre City 38
Figure 7, Current City Dumpsite, still in operation as of April 25/04 2025 39
Figure 8, active railway, as of 25/04/2025 40
Figure 9, river and streams within Blantyre City 41
Figure 10, active borehole, sourced from GSD North 41
Figure 11, BT soil type, sourced from FAO 43
Figure 12, subsurface soil type.....43
Figure 13, land use and land cover derived from GEE 45
Figure 14, suitability map indicating potential sites 46

Table 1, data types and data sources with spatial resolution 26
Table 2, weights derived from AHP template 30
Table 3, sites and possible proximity to borehole and river 42

CHAPTER 1

ABSTRACT

Solid waste are now becoming a growing environmental and public health challenge in both developed and developing Nations, with urban centres in Africa experiencing particularly acute impacts due to rapid population growth, unregulated waste disposal practices, and insufficient infrastructure. Blantyre City exemplifies this crisis. It produces approximately 192,720 metric tons of waste annually, of which only 28% is collected and safely disposed of. The rest is often dumped in undesignated locations, including riverbanks such as Naperi river and open fields like in Mlambala. The city's only official waste disposal facility Mzedi dumps is currently in bad state and poorly located, with its surrounding areas densely populated with kachere residents, and road access nearly impassable during the rainy season.

This study applies an integrated approach using Geographic Information Systems (GIS), Remote Sensing (RS), and the Analytic Hierarchy Process (AHP) to identify suitable locations for waste disposal in Blantyre City. Ten key criteria were considered, including slope, geology, soil type (surface and subsurface), land use/land cover (LULC), proximity to water points, fault lines, roads, railways, and existing dumpsites. These parameters were carefully selected due to their relevance in determining environmental vulnerability and operational efficiency. Using ArcGIS software and Google Earth Engine (GEE), each criterion was mapped, standardised, and weighted based on its relative importance through AHP pairwise comparison. The study employed Euclidean distance analysis to determine optimum buffer zones from critical features. Land suitability was categorised into five classes: highly suitable, suitable, moderately suitable, less suitable and unsuitable.

The results of the spatial analysis reveal that most areas in Blantyre are unsuitable for waste disposal due to factors such as steep slopes, proximity to residential areas, and high soil permeability. However, five sites across Mapanga, Masamba, Michiru, and Nacholi wards emerged as optimal locations. These areas are located on bare land, with

no current developments, and are situated over clay-rich or sandy clay loam soils known for their low permeability and effectiveness in minimising leachate infiltration. Furthermore, all selected sites lie at a safe distance over 1,000 metres from critical features such as water bodies, residential zones, and existing dumpsites. Notably, the identified Mapanga sites exhibited particularly favourable terrain and proximity to major roads, making them logistically efficient for waste transport and disposal. The geological analysis confirmed that most proposed sites lie on granitic and hornblende-rich formations, which are stable and less susceptible to underground water contamination. Additionally, all sites are outside the fault lines and railway buffer zones, ensuring minimal disruption to infrastructure and natural aquifer systems.

INTRODUCTION

solid waste either in form of E-waste or scraps or plastics are becoming a Global challenge in both developed and developing countries, in 2018 world bank report known as What a Waste indicate 2.0 (What a Waste 2.0, n.d.) recognizes plastics as a key waste problem, the report shows that amount of waste by 2050 will increase up to 3.5 billion tons if no any strategic management is taken into action. In 2016 plastics made up of 12% of all solid waste an amount that is equally to 242 million tons of waste. Urbanization and population growth in most of the cases it associates with rapid generation of waste. The World E-waste is rising much faster than the rate at which they are recycled, it accounts that about 62 million tons of E-waste was generated in 2022 of which only 22.3% of it was properly documented to have been collected and recycled and annually more than 2.6 million tons E-waste is produced, it expected that by 2030 it will increase up to 83 million tons about 33% increase from 2022 (Bonn, n.d.).

Africa rapid Population growth, increase in economic activities and expanding urbanization has resulted into uncontrollably production of waste. It is projected that by 2050, the volume of waste in Africa will be triples to approximately of 516 million tons (High-Level Panel on Emerging Technologies (APET) and the Calestous Juma Executive Dialogues (CJED), n.d.). More than 90% of waste in Africa is disposed at the

uncontrollable dumpsites. These has resulted into water and air contamination as well as affecting the well-being of the African communities.

Malawi is currently facing challenges related to poor management of solid wastes, Nearly-all the cities lack adequate waste collection services, treatment and disposal facilities. Blantyre City faces the same challenges, Industrialization as well as Urbanization has influence waste production than the rate at which BBC can collect and Dump them into designated waste disposal sites.

PROBLEM STATEMENT

As of 2018 Blantyre City had a population of 800 264 people (National Statistical Office, 2019) and in 2024 the population rise up to 1 ,114, 000 people (Blantyre-Limbe, Malawi Metro Area Population 1950-2025, 2010). This rapid increase facilitates waste production which exert pressure on already fully Mzedi dumpsite, the capacity to provide waste management services is severely limited and this problem is expected to intensify as population increase, waste production is currently at a significant level with a large amount of waste accumulating into the environment. Blantyre city produces an approximately of 158,775,000 amounts of wastes annually of which 300 to 400 metric tons of waste is produce per day and only 28% is collected while the rest is left in undesignated places such as roads or river. Mzedi dumpsite is currently surrounded by Kachere settlements and the road is almost impassable especially in rain seasons (Kalina & Tilley, 2020) . Poor waste management pose a threat to both public health and environment. Blantyre city is one of the Areas which was affected by Cholera outbreak that was characterized by unsafe water and poor sanitation in March 2022, the outbreak claims about 1,724 lives from 56,876 confirmed cases (Cholera in the Midst of a Floods Emergency _ UNICEF Malawi, n.d.).Additionally there exist some illegal dumpsites such as along the Naper river and in Mumbalala according to the known data, this project focuses on using GIS and Remote in identifying most suitable sites for waste disposal which cannot pose health threats and environment as well as reducing cost in term of transportation of the waste hence respond to sustainable development Goal number 12, which emphasize responsible consumption and production.

MAIN OBJECTIVE OF THE STUDY

The main objective of the study is to identify suitable sites for waste disposal in Blantyre city by using GIS and Remote Sensing.

SPECIFIC OBJECTIVE OF THE STUDY

i. To determine and evaluate suitability factors for waste disposal sitting in Blantyre City.
ii. To determine and allocate waste disposal site on suitable topography in Blantyre City.
iii. To determine safe distance between waste disposal sites and residential areas in Blantyre City.

RESEARCH QUESTIONS

i. What are the factors that can be used to determine suitable waste disposal sites in Blantyre City.
ii. What is the required terrain suitable for landfill site and how it influences site selection for waste disposal.
iii. What is the optimum distance thresholds for waste disposal sites from the roads distance and residential areas, which can ensure cost efficiency and prevent air pollution to the residential areas respectively.

SIGNIFICANCY OF THE STUDY

1. It enhance-waste to energy and circular economy

These is an important strategy in waste management-service, it transforms waste which could have been in environment into useful products. (Jiang et al., 2022)it is concerned with non-hazardous waste that can be combust into energy and another form of encouraging waste to energy strategy is anaerobic digestion, in these form bacteria break down organic materials in absence of oxygen and the end result is biogas which can be used for energy hence encouraging circular economy, waste to energy approach is line with Malawi Sustainable goal number 7 which emphasizes access to affordable, reliable, sustainable and modern energy for all.

2. Environmental protection

A proper disposal of waste is crucial for protecting the environment, it prevents pollution and conserve natural resources which helps to maintained ecosystem. Unmanaged waste can end up in local water sources, or any other undesignated places hence reading to water, air and land contamination and other health problems. Industries sector generates more waste and is important to make sure that waste is properly disposed to prevent negative impact to the local ecosystem. Environmental protection is vital in promoting Malawi`s sustainable development -goals especially goal number 3 which emphasizes health lives and promote well being for all at all age, by reducing number of deaths and illnesses from hazardous chemicals, air, water pollution and other form of contamination by 2030 (Sustainable Development Goals, Targets and Indicators, n.d.).

3. It promotes sustainability Development

Proper wastes disposal is an essential component of sustainable living, by managing waste effectively environmental impact are reduced such as occurrence of disease related to waste like cholera, pollution of both water and air hence it conserves resources for future generation, these benefit the communities in such a way that the communities remain healthy and safety. Integrating waste management into sustainable development goals enables a well-being of the current and future generation by preserving resources (10 Reasons Why Waste Management Is Important, n.d.)

4. It can promote route optimization which reduces cost

This is important component in waste management it focuses on identifying most efficient routes for waste collection and disposal vehicles. The algorithms consider roads condition, distance, time, fuel consumption and traffic patten to evaluate the optimal routes to travel to the dumpsites. Suitable waste disposal sites within Blantyre city can enables BCC to develop best routes optimization by using various algorithms such as mixed integer linear programming which is the mathematical approach for optimizing problem with linear relationship, simulated annealing and ant colony optimization that can enhance real time tracking of the waste collection vehicles thereby by allowing efficiency dispatching and monitoring processes beside saving and influence efficiency and quality of waste management services (Karadimas & Doukas, 2008)

5. Mitigate climate change

Unlegalized or unregulated dumpsites are considered as a major source of Greenhouse-gas such as Methane gas, one way of dealing with greenhouse gases is through proper dumpsites facilities which minimises emission of gas into atmosphere(Cristóbal et al., 2022) and that automatically engages BCC in achieving Malawi development Sustainable Goal number 13 which influence urgent action to combat climate change and its implications.

CHAPTER 2

LITERATURE REVIEW

According to the world bank report it indicates that the major cause of waste production is urbanization, population growth and industrialization, amount of waste Globally is expected to reach up to 3.4 billion tones over the next 30 year from 2.01 billion tons , for example East Asia and pacific region is responsible for generating close to a quarter or 23 percent of the total Global waste, and it is expected that by 2050 sub Sahala Africa waste generation will be more than triple from the current level while South Asia will double its waste stream. all type of waste is a problematic even if they are collected, they contaminate and affect the ecosystem for hundreds of the years.

Most of the solid waste management are not enhanced or tackled in Developing Countries, the report also emphasizes the need for proper waste management system that are essential for building circular economy, where the products are designed and optimise for reuse and recycling, World bank has funded more than 340 solid waste management programs across the Global with an amount of more than $ 4.7 billion. (2050, unless urgent solution). The first Global waste Management Outlook (GWMO) which was published in 2015, provide a pioneering scientific Global assessment of the state of the waste management and emphasizes on international communities to recognise waste and resources as a significant contributor of the sustainable development (Beyond an Age of Waste Turning Rubbish into a Resource, 2024) it indicates that access to collection services varies significantly with within and between the regions for example high income regions almost all the waste is collected while in lower income Countries about 40 percent is collected while in the sub Sahala Africa there is lowest collection rate as it the very critical step in waste management.

Another important field which needs to addressed that is a form of solid waste is E-waste these are items with a battery or power cord such as computers and lap tops and mobile phones. They are varying estimation as to the amount at which domestic,

regional or global E-waste are produced, according to (O'mahoney et al., n.d.) in 2012 global E-waste generation was 45.6 million metric tons, China was reported to generate about 11.1 million metric tons and United national about 10 million metric tons, the major concerning is the rapid increase of this E-waste because consumer demand is relatively higher in both developed and developing Countries, for example new cell phone models are released at highly intervals and some accessories such as chargers often change due to new model hence this short innovation cycle and low recycling rate contribute to accumulation of E-waste within the Environment (Perkins et al., 2014), as of 2024 the global E-waste generation was about 62 million billion kilograms of electronic waste, in developing countries there a little or no effort being made which target E-waste management and it more problematic in recent years, because they have high levels of contaminating or toxic materials such as mercury, lead and arsenic in them once in a landfill these toxic materials seep out into environment contaminating land, water and air , as of 2020 within the EU countries E-waste recycling rate was on average which was less than 40 percent while on the global scale was only 20 percent and the remaining 80 percent is often incinerated and dumped into undesignated places. In 2018 a record of the amount to 53.6 million metric tons of E waste was produced consisting of phones, computers, appliances devices and other gadgets (O'mahoney et al., n.d.) and global volume of E-waste is expected to grow by 33 percent in the next four years

This E-waste material are mostly comprises of the mobile phones and computers which have a short lifespan. The current E-waste globally is about 20- 25 million tones per year, with most of E-waste being produced in Europe, the United states and Canada and in Easten Europe China is the major producer. E-waste are different from any form of the municipal or industrial waste, they contains hazardous material which need special handling and recycling method to avoid contaminating the environment due to high labour cost or lack of incinerators these materials accumulate into the environment than the rate at which they are recycled (E-waste assessment). The most fastest growing solid waste is E-waste around the world today this is due to rising demands for information and advanced new design of the electronic products, disposal of computer

and phones in other parts of the global may not necessarily mean that they are non-functional so as to replaced it, but they opt to keep up with rapid changing technologies (Perkins et al., 2014). though these waste may comprise of hazardous or non-hazardous material both of the them have the ability to contaminate the environment. Due to improper re-processing of these materials high level of heavy metal and other pollutants have been reported in New Delhi, Bangalore, Kolkata and Gaziabad and Children are most vulnerable to the harmful effects of these improper recycling activities (environmental pollution of electronic). most of the developing countries they do not have proper regulation and policy for e-waste management. A number of global agreements and framework have been established for the collaboration and management of the E-waste for example Bassel convectional which was established in 1989 it monitor every materials including E-waste between or among the nationals, it also emphasizes nationals to reduce hazardous waste production and prioritise environmental management.

The Circular Electronic partnership is also another global agreement and framework it was established in 2021 is emphasizes on circularity of the electronic sector through policy reform, good practices and industrial collaboration, it brings together non-governmental organisations, industries and electronic companies to create ecosystem for electronic devices in order to mitigate hazard which might be associated with E-waste in the environment (International Collaboration for E-Waste Management: A Global Endeavor towards Sustainability The Power of Global Agreements and Frameworks, n.d.). Ministry of natural resources and climate together with Wildlife and Environmental society of Malawi joined together in launching of the Malawi's National E-waste Management policy which was conducted at Bingu stadium on 3rd December 2024 (Malawi Takes Bold Step Toward Sustainable E-Waste Management with Launch of National Policy - WESM, n.d.) and these policy focuses on E-waste collections as well as proper recycling of such materials within Malawi even though in most of the African countries there is no effective infrastructure of the E-waste management which can sort, store or separates these waste as a result they are dumped into the environment without any consideration of the surrounding impacts

Plastic waste is also major problem in both developing and developed countries these waste they accumulate in the environment faster as most of them they can only be used once, they do not degrade easily as compared to other waste for example plastic papers or bottles. These types of waste often have negative impact on human health, ecosystem and wildlife especially marine species. Thes increase in waste production currently is due to high consumption rate which is associated with population rate. Waste production has double since the beginning of the century to almost 400 million metric tons per year as of 2011, lifespan of plastic products averages around 10 year and plastics can take up to 5000 year to decompose (Global plastics as of 2023 s). There has been mismanagement of waste worldwide as they are disposed at illegal places or open pits, between 1970 to 2019 an estimation of 30 million tons of waste is suspected to be dumped in ocean, such huge amount of waste can cause a devastating damage to the marine life and ecosystem

According Statistic research Department, China is considered as one of the country with higher plastic waste records and it contributed 33% globally as of 2023, following by Asia which account for 17% and North America and a total of 413 million metric tons of plastic waste recorded in 2023. It expected that if no any strategy is taken as for now amount of waste globally will increase up to 3,40 billion tons by 2050, despite the technologies use worldwide a total of 20% only is recycled while 80% is dump in an undesignated places (News Stream, n.d.) In Africa for several years waste production has been rising steadily due to demographic growth and urbanization as well as changing of consumption habit, in 2016 for example Sub Saharan African generate about 174 million tons of waste though most of them were recyclables only a total of 4% was actually recycled and in 2025 Africa is expected to generates 244 million ton of waste, these is a challenge for the continent because a lot of waste accumulates into the environment even though there international policies for waste management, the most important policies and strategies are being implemented across the content , for example Africa union agenda 2063 , (In Africa, Greenhouse Gas Emissions from the Waste Sector Increase, despite Efforts from Various Actors Analysis Note by the

Observatory of Climate Action in Africa, n.d.) a strategy framework for social economic and political transformational of the Africa continent , it emphasize on waste transformation sector with a recommended target

Mult attribute or Criteria is a Decision-Making process which is the most well-known branch of decision making. It deals with decision making problems under the presence of the number of a number of criteria. According to Saaty this model is divided into multi-objective decision making and multi-attribute decision making. Basically it is mathematical programming with multiple objective functions.

Recent studies which have been conducted in most of the developed countries indicates that landfill site have been heavily relied on hierarchical analytical approach which is integrated with Geographic Information system and Remote sensing techniques. These processes involve evaluating multiple criteria such as geology, hydrogeology, land use, slope, proximity to road or railway and residential area in order to determine suitability of an area, these process typically it involve assigning score or weight to each criterion based on its relative importance, and weighted overlay analysis can be performed -to find the optimal areas based on the specified score of the criterion. Hierarchy analytical process. AHP is decision making technique which allow prioritization of the factors, it also helps to ensure that more critical criteria are given greater importance than less significant ones and solve complex as well as conflicting criteria. AHP play important role in methodology by prioritizing criteria through pairwise comparison, it uses nine points scale to express relative importance of each factor (Randazzo et al., 2018).

Different land analysis can be integrated with AHP model for example weighted summation approach, it also provides a clear decision framework by incorporating weights derived from AHP model weighted summation accept both integers and decimals unlike weighted overlay which use integers only and sum total of weighted summation is 1 while weighted overlay is 100%. Consistency index (CI) within AHP ensure reliability of the results by the coherence of the pairwise comparison, if the consistency ratio I above an acceptable threshold which 0.1 or 10% the comparison are

revisited. By combining AHP, weighted overlay, GIS and Remote sensing it offers a systematic, transparent and it is an effective approach for site selection in complex decision-making scenarios.

Even in the countries that utilizes waste incineration, landfill sites are needed mostly for disposing of waste after burning them. In Mahawil Qadhaa in Iraq there was no landfill site which meet scientific approach though the region had four disposal sites across the city and to address this challenge GIS and Mult criteria decision making method were integrated to evaluate potential sites (Chabuk et al., 2017) . Analytical hierarchical Process was adopted to evaluates weight of the criteria to find the optimal site for waste disposal which did not pose any challenges to both environment and well being of the peoples.

In Africa, Ghana also adopted the same technique, in Accra the capital city of Ghana there was improper waste management practices which open dumping or undesignated places, increase in waste production was being driven by urbanization, population growth and high consumption rate, in response to the mounting waste management crisis there was a very push by both private and government sectors to convert waste to energy and proper waste disposal management, the choice to chose an optimal site for waste to energy facilities requires a careful evaluation of several factor which might include topography, proximity to road, river, settlement or rail as well as geological aspect of the an area. Decision maker finds if had to balance among the conflicting criteria and multi criteria decision making approach was used known as Analytical Hierarchy Process which highly support the selection of the optimal site for waste to energy facilities and dumping sites (Agbejule et al., 2021) . Analytical Hierarchy Process offers a comprehensive or systematic approach, finding shows that using AHP Accra in Ghana suggest that the incinerator is the most preferred technology, followed by anaerobic digestor and aerobic composting with biogas recovery as being the least favoured option.

In Ethiopia metropolitan area like Dessie also experiences worst solid management which include open dumping or into the water bodies and it create a significant environmental challenge, previous studies shows that waste disposal were being selected based on physical characteristics, but through the integration of GIS and Remote sensing offer a comprehensive approach as all parameter are examine according to their influence. In Dessie though the research involves a mixed research design but all the parameter were examined according to their compatibility for example land use and land over, slope, soil, drainages, urban area and population and weighted in overlay analysis according to the respective values which was obtained from Anlytical Hierarchy Process, the category was classified as follows unsuitable, less suitable, moderate suitable, suitable and highly suitable. According to this research it was found that approximately 71% of the research area was unsuitable, while 29% was suitable for waste disposal site. 40.8% where not suitable, 17.6% less suitable areas, 10% moderate suitable, suitable area were 13% and highly suitable were 18.6% (Kebede et al., n.d.) .

Kitwe area in Zambia also faces the same challenge related to waste disposal, it has an average elevation of 1224 m above the sea level, it is considered as the second city with high population of 661, 901 as 2022 with a projected annual growth of 21%, the lithological unit of Kitwe range from Paleoproterozoic, Mesoproterozoic, Neoproterozoic and Quaternary. Basement complex rocks are also dominant in Northern and Easten part of Kitwe. Functional dumpsites were based on bare land with no any development taking place on it, which later on exerts health hazards to people, and contaminating both ground water and air quality. Due to this circumstances it engages a hybrid GIS and multicriteria decision approach to find suitable sites for waste disposal, several factors were considered for example slope, land use and land cover, lineaments, railway, roads, protected areas and geology. Thise factors were weighted using Analytical Hierarch Process (AHP) developed by Saaty and finally a weighted linear combination analysis was performed, AHP proved to the most reliable in decision making, the results indicates that 333.24 km square represent 41.69% of the study area was unsuitable, 140.41 represent 17.57% was suitable for landfill and 325.63 km square

representing a total of 40.74% was most suitable. According to Kitwe City Council, the city generates about 303.44 tons of waste per day and an estimated waste to be generated over 20 years of operational is 8.64×10^6 M3 with a projected waste

population growth of 21%. Hence a landfill capacity to hold amount of waste to be generated for 20 year is about 0.54km2 of more, and the results indicate 7 suitable sites for waste disposal in Kitwe City. (Mvula et al., 2023a)

In Morocco GIS and Remote Sensing coupled with Analytical Hierarch Process (AHP) was used for selecting appropriate area for waste disposal in the province of Quarzazate, the parameters for selecting a landfill site ware based on environmental factor, economic and social factor, hydrological and geological factor hence making the process more complex and challenging. They adopt AHP in weight assigning of the criteria, this approach has been used by a lot of researchers for suitability analysis, for example it has prove to be significant in northeastern Greece, konya in Turkey, Qom in Iran, Sao Paulo in Brazil and Srinagar in India (Abdelouhed et al., 2022). AHP in landfill site selection is commonly used because it integrates qualitative and quantitative criteria which minimise inconsistency of judgement. Different criteria such as elevation, Lineament density, Lithology, wind direction, Soil type, Distant from road and river and population density were assigned weights based on their importance and weighted overlay process which combine multiple raster dataset into a single output was performed in ArcGIS and a total of 1600 hectares was considered to suitable for waste disposal because it has good terrain characteristics and impermeable soil, no surface water and it was located at a good distance from the national road.

Libya also uses analytical Hierarch process in evaluating waste treatment system which include anaerobic digestion, landfilling, incineration and composting. The evaluation was based on four main criteria namely environmental impact, social cultural aspects, technical aspects and economic aspects with other 22 sub criteria. This method was

considered to more flexible and understandable in analysing complex problems, and it is more used than other method of Muit-Criteria-Decision Making. The results indicates that anaerobic digestion ranks the highest overall, followed by composting, which outperforms landfilling and incineration (Badi et al., 2019).

Google Earth Engine has emerges as a transformative platform for land use and land cover classification because it handle vast amount of dataset and integrates with advanced tools, GEE is more important than tradition classification because it can access vast amount repository satellites imagery including Landsat, sentinel and MODIS satellite and another significancy of GEE is that it can integrate with machine learning algorithms for various classification, Machine learning models such as Random forest algorithm, support vector machine and Neural network can be deployed directly within the GEE platform, there by improving land use and land cover accuracy (Kumar et al., 2025).

This cloud-based computing platform, can be used to solve most significant problems related Land cover mapping of the large Area, Users can analyse all the available remote sensing images using a web based integrated environment (IDE) code editor without downloading the data into the local machines, hence it facilitates easily accessibility of satellites data (Noi Phan et al., 2020)GEE unlike tradition method which might not reliable for spatial analysis not only that GEE provide real time or updated data hence classification reflect true surfaces features, an algorithms under given good training samples, the output of the is a complete classification of the define features

CHAPTER 3

RESEARCH DESIGN

This study employs a multi-Criteria-Decision Analysis approach integrated with GIS, Remote Sensing and Geology for selecting suitable sites for waste disposal in Blantyre city. It also involves primary and secondary data source, on primary data source the main alms were to evaluates waste management problems, impacts of wastes and to determine if the current dumpsites were scientifically selected or based on availability of land and secondary source was data acquisition through various GIS platforms. It involved key phases such as data collection, data processing, criteria definition and weighing them.

STUDY AREA

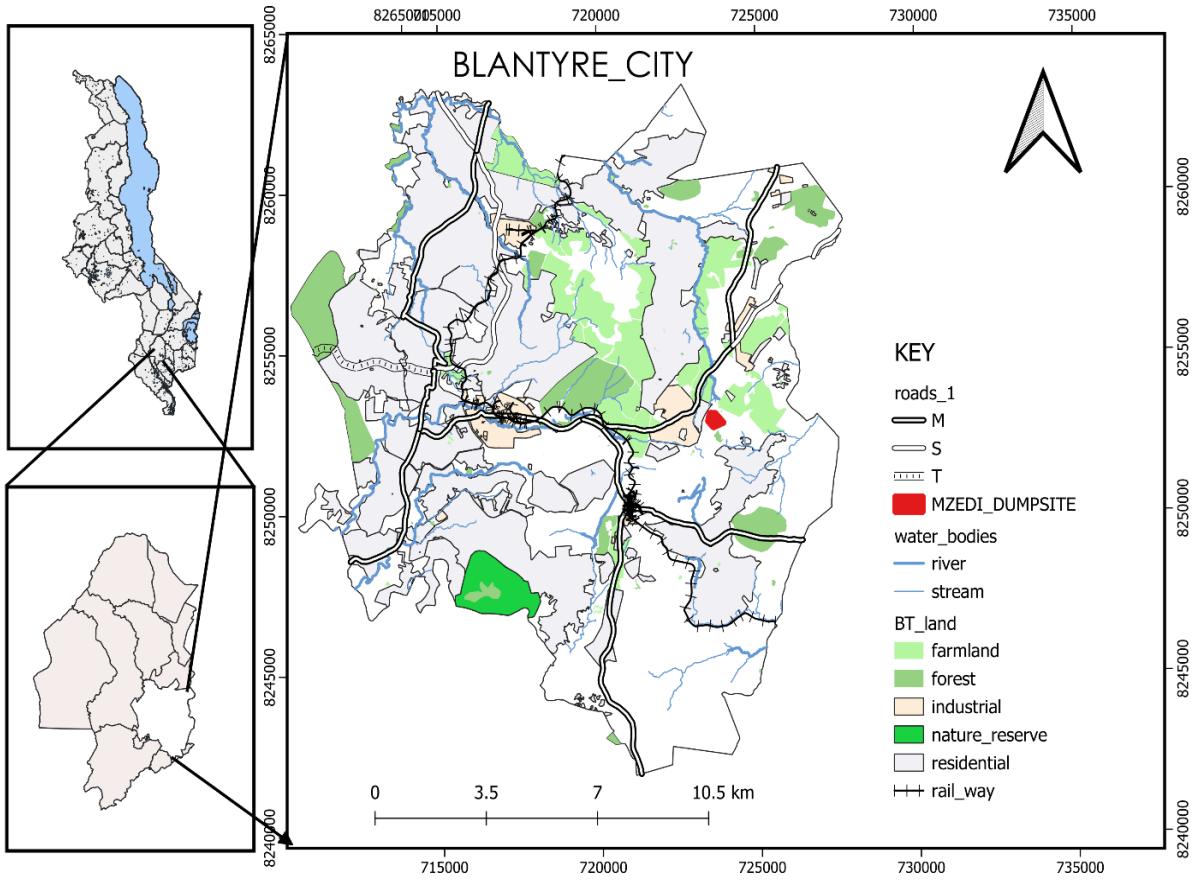


Figure 1 study area, Blantyre City

DATA SOURCES

Table 1, data types and data sources with spatial resolution

Data	Data source	Resolution (Metres)
Land use and land Cover	Google Earth engine (SENTNEL, 2 L2A)	30
Geological data	Geological survey Department	52.33
Soil data	Food and Agriculture Organisation	70
Digital elevation model	Africa Geo portal (Malawi STRM 30 M)	30.65
roads	Humanitarian Data exchange	61
Borehole data	Geological Survey department	52.13
Railway	World Bank databank (Africa infrastructure: railways Data-Bank)	41

MATERIALS AND METHODS

Slope is a crucial factor when selecting suitable sites for waste disposal, as it directly influences environmental impact, operation efficiency and overall safety. Digital Elevation model (DEM) derived from Malawi STRM dataset was used to generate the slope map of Blantyre City. The slope values were classified into five categories, 0-12%, considered as Highly suitable for landfill, 12-16%, regarded as suitable, 16-20%, classified as moderate suitable, 20-30% deemed as less suitable and slope greater than

30%, it is identified as unsuitable for landfill development. This classification provides a systematic approach to evaluating land suitability, with the lower values offering a better condition for effective waste management by minimising runoff. Reducing soil erosion and ensuring operational efficiency.

In site selection for landfill location, optimum distance is also a critical component which influences operational cost. A suitable landfill site should be positioned at an appropriate distance from the Main roads to ensure operation efficiency and situated at far from the residential areas to mitigate harmful effects of ardours and air pollution which can lead to various health issues. A distance of greater than 1000 metres is generally considered as appropriate for landfill in general. Euclidean distance was performed to the following classes of the road suitability, distances ranging from 0-200 metres are deemed as unsuitable due to their proximity to residential areas , 200-400 metres is considered as les suitable, 400-600 metres is it classified as moderate suitable, and 600-800 metres is regarded as suitable while distances greater than 1000 metres are highly suitable for landfill site hence optimal distance offers the balance between the accessibility and environmental protection.

Geological parameters such as faults and fractures form key factor for site selection, Blantyre city is characterize by a complex mixture of Precambrian basement complex rock, primarily consisting of metamorphic and igneous intrusion, the area is a part of the Shire Highlands, situated on southern end of the Malawi Rift valley which is an extension East African Rift valley system, granites and Gneisses are common with low primary permeability, Euclidean distance was performed to the fault that lies within the Blantyre city because they have greater impact on subsurface water contamination, 200-400 metre it is classified as unsuitable, 400-600 metres is considered as moderate suitable while 600-800 metres is less suitable and distances greater than 800 metres is highly suitable for site selection of the waste disposal.

Proximity to railway is the important component to consider in selecting suitable site for waste disposal, Railways are sensitive infrastructures and waste disposal sites being

located closer it may pose a risk such as structural damage due to ground instability and unnecessarily odour. Euclidean distance of 200, 400, 600, 800 and greater than 1000 metres were used to classify areas into highly unsuitable, not suitable, moderate suitable, suitable and highly suitable respectively. Maintaining a safe distance ensure safety and minimise environmental and public health concern.

Proximity to current dumpsite, considering current dumpsite is essential to avoid environmental degradation and over concentration the waste in a single area. Areas closer to the current dumpsites may experience cumulative negative impacts such as pollution, by categorising distance with the same Euclidean metric, areas which are far from existing dumpsites are rated as more suitable hence promoting better environmental management and reducing the risk of underground water contamination.

Proximity to the well points is the critical parameter because of the risk of underground water contamination through leachate percolation, and it can severe health implications.in the classification system, the distance closer to 200 metres is it highly unsuitable, while distances greater than 1000 metres are highly suitable.

Soli type plays a pivotal role in waste disposal site selection due to its influence on leachate infiltration and soil stability. Different soli types such as sand, clay loam, and sand loam has a varying permeability level. Clay loam with its low permeability it is an ideal because it minimises leachate percolation thus classified as highly suitable in contract to sand soil with higher permeability and it allows fast flow of leachate into subsurface, hence it is regarded as unsuitable for waste disposal.

Land use and land cover data derived from Google Earth Engine play a critical role in waste disposal site selection. This dataset provides detailed information on vegetation, bare soil, built up areas and water bodies, vegetation areas in most of the cases are considered as not suitable due to their ecological values, built up areas are avoided to prevent human health hazards, while bare soil areas depending on the environment parameters are often favourable for waste disposal , areas closer to water bodies are

highly unsuitable, incorporating LULC data ensures that site selection is both environmentally responsible and social accepted.

The Analytic Hierarchy Process (AHP) is a widely used multi-criteria decision-making method that supports the systematic evaluation of various factors involved in site selection for waste disposal. In this study, AHP was employed to assess and prioritize multiple environmental and infrastructural criteria, including proximity to rivers and water points, railway lines, land use and land cover, proximity to the current dumpsite, geology, and the presence of faults and joints. Each of these factors plays a significant role in determining site suitability. For instance, rivers and water points are critical because of the risk of groundwater and surface water contamination; thus, sites should be located at a safe distance to prevent pollution. Similarly, proximity to railways is considered to avoid interference with transport infrastructure, while land use and land cover data help in avoiding ecologically sensitive or densely populated areas. Proximity to the existing dumpsite may reduce operational costs, whereas geological features influence the site's permeability and structural stability. Faults and joints, if present in large numbers, can increase the risk of leachate migration, thus reducing site suitability. Using AHP, these criteria were compared pairwise to determine their relative importance, and weights were assigned accordingly.

Table 2, weights derived from AHP template.

N	CRITERIA	COMENT	RGMM	+/-
1	FAULTS		7.6%	
2	GEOLOGY		13.9%	
3	SLOPE		8.2%	
4	RAILWAY		8.9%	
5	ROADS		9.7%	
6	CURRENT DUMPSITE		5.3%	
7	SUBSURFACE SOIL		12.5%	
8	SURFACE SOIL		12.6%	
9	LULC		16.7%	
10	WATER POINTS		4.8%	

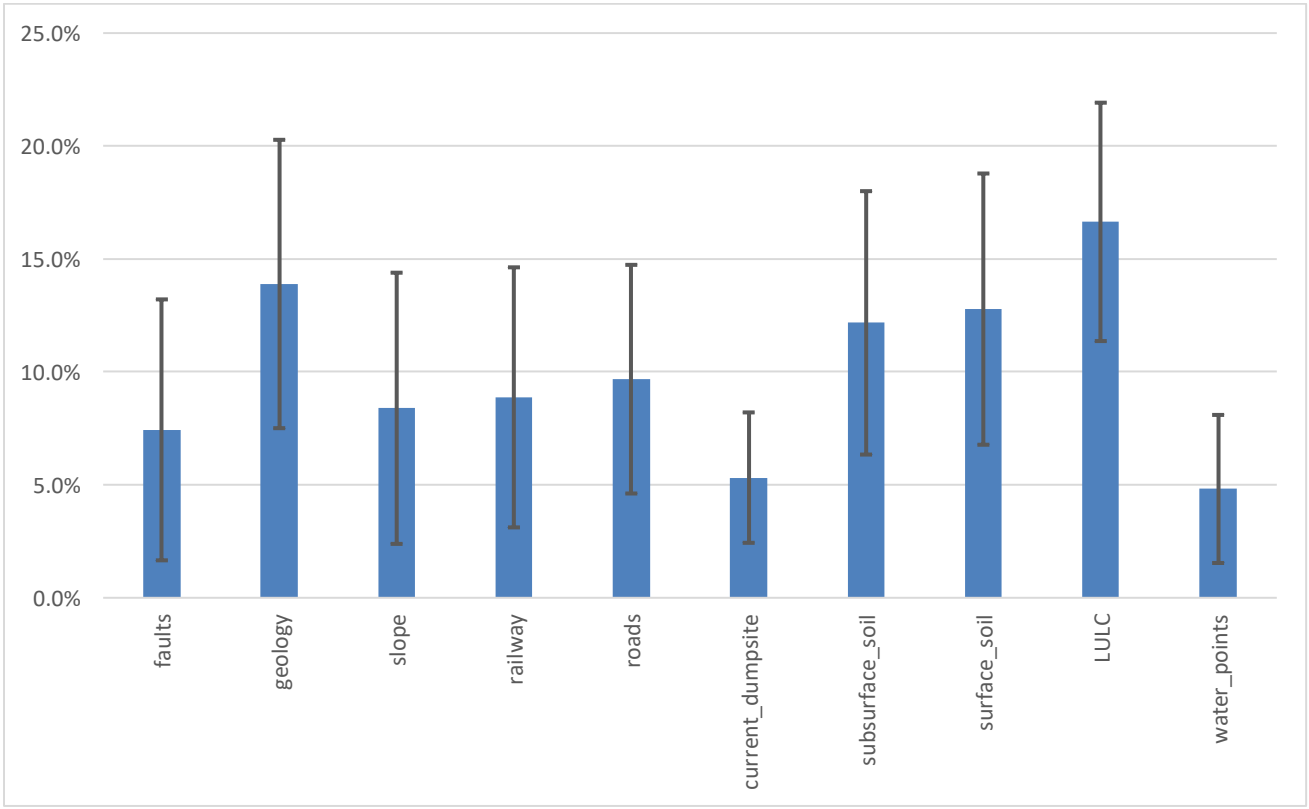
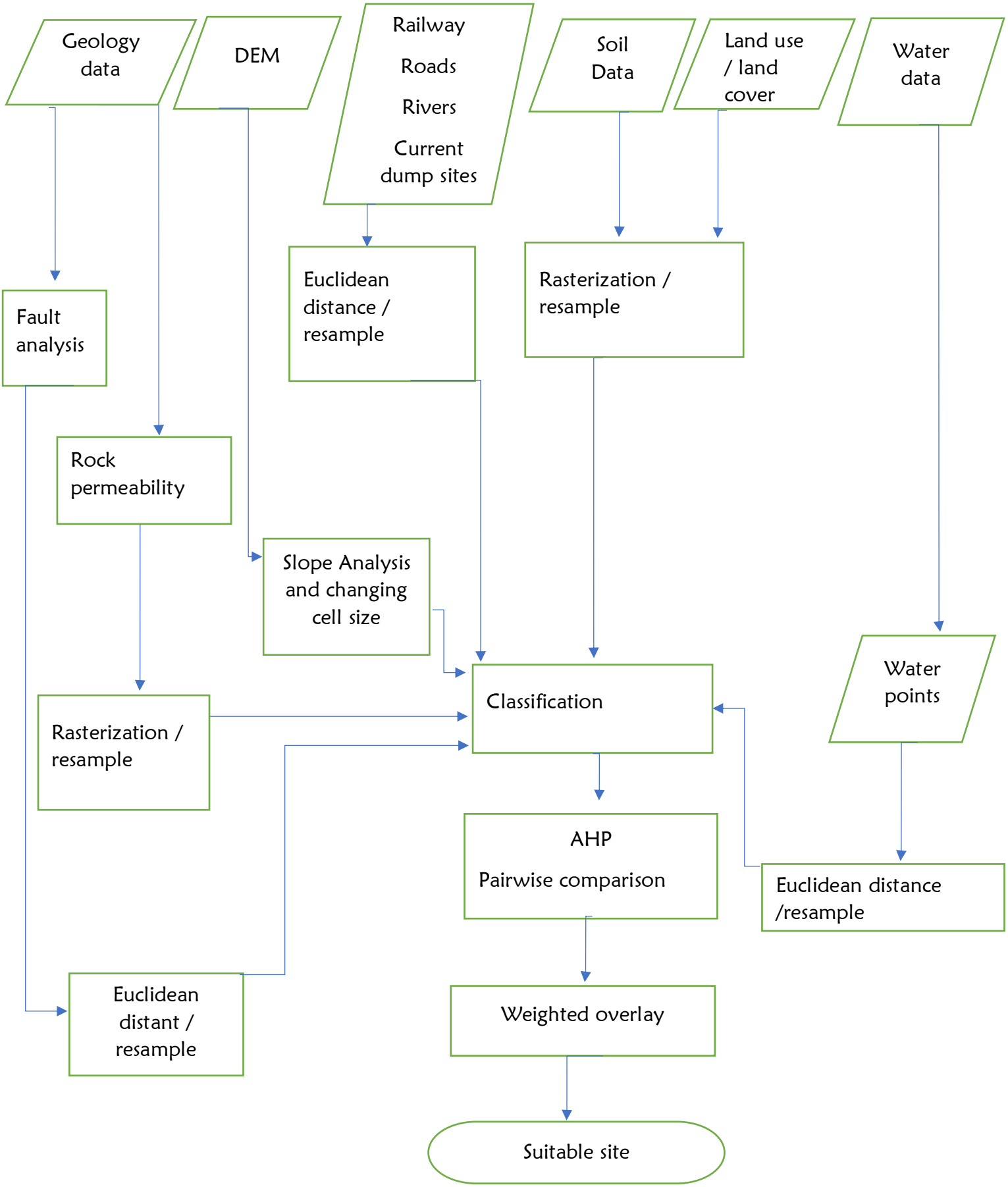


Figure 2 weights graph, derived from AHP.

METHODOLOGY STRUCTURE



DATA ANALYSIS

Slope is considered to be a very critical component in site selection for waste disposal, it was classified into five classes of which 0-12% is proved to be good slope for waste disposal because it ensures effective leachate management, stability of waste piles and minimum environmental degradation, in general lowers values can provide a better condition for effective waste management as they minimise run off as well as enhancing operation effectively.

By analysing distance which was classified into five classes after performing Euclidean distance, a safe distance from the residential and waste disposal sites was established, a good dumpsite should be at least greater than 1000 metres away from the residential areas these helps to reduces health impacts due to pollution and a considerable distance from the roads is also important, a dumpsite should be located not too far from the main roads to reduce cost to the waste collectors. Desirable distance from the current dumpsite was also considered and a distance of more than 1000 metres is suitable.

Geology forms a key factor for site selection, it can consist of soil, joint and fractures, Blantyre City is located within shire highland, which is a part of Africa rift valley system in hence due to geological events folding, joints and fractures are common, some of the features they act as recharge zone for underground water. Euclidean distance was performed to the joints and faults, a good dumpsite should not contaminate underground water. Soli data was used which was also classified into their classes, both surface and subsurface soil type was used to determine the require soli type which can support various activities within the dumpsite

STUDY LIMITATIONS

One of the major limitations encountered during the project was inadequate of land use and land cover data that was obtain in OpenStreetMap (OSM). The dataset lacks sufficient data points in many areas, which resulted into gaps where land cover type were not properly represented. The limitation posed a challenge for accurate site suitability analysis as absence of important land cover information could lead to incorrect classification of the areas for waste disposal. To address this issue, Google earth Engine was utilized to classify land cover into key categories such as vegetation, bare soli area, water bodes and built-up areas, GEE provide to be more advanced and reliable platform, it offers up to data satellite imagery and it is a powerful tool for cloud based processing, unlike Esri shapefiles which requires manual updates, GEE provide continuously provide near real time data , this made it possible to achieve a better classification accuracy and fill in missing datapoints.

Another challenge encountered during was poor resolution of the spatial data which greatly affected the quality of the overall output, when low resolution dataset were overlayed other high resolution dataset, the inconsistence in spatial details became clear making it difficult to accurately analyse land suitability, this was so because of using different GIS Spatial portals to download the shapefile, the dataset had varying resolutions which led to incompatibility when performing weighted overlay analysis. This was overcome by performing resampling technique to standardise the cell size across all the dataset, these techniques enhance easily integration of the data for accurate analysis because all the distortion were removed from the data.

Limited resource, insufficient financial resource hinders data acquisition especially high resolutions dataset which are offered at a cost and access to advance GIS software licenses such as ArcGIS pro, these resulted into the use of free available but low resolutions dataset from various GIS platforms and it compromise the precision of the suitability analysis.

CHAPTER 4

RESUITS AND DISCUSSION

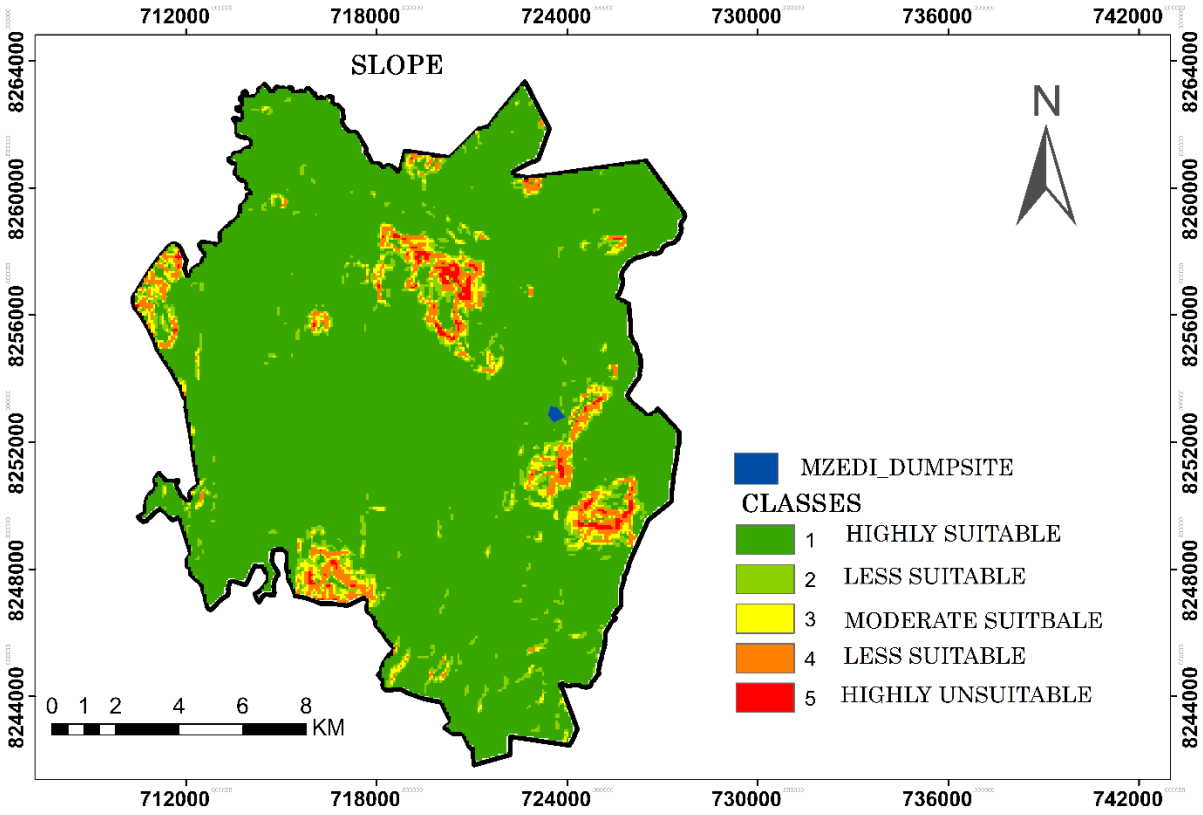


Figure 3 Blantyre city terrain characteristics

Slope is considered as Major factor in site selection for waste disposal, as it significantly influences the potential for environmental contamination, especially through run off, this study finds that the current dumpsite at Mzedi is located relatively in a hilly area thereby increasing the risk of waste being washed into nearby water sources during heavy rainfall. Using ArcMap the slope of the study area was classified into five suitability classes namely highly suitable, suitable, moderate suitable, less suitable and not suitable, the most suitable sites for waste disposal were identified and ranked as follows the Michiru ward, Mapanga ward having 3 potential sites, third one in Masamba ward, fourth site along the edge of part of Nacholi, Although all these locations possess ideal terrain characteristics for waste disposal, Mapanga sites, particularly favourable due to their designation as a farming-areas with minimal or no current development. And ideal slope for dumpsite is 0-12%.

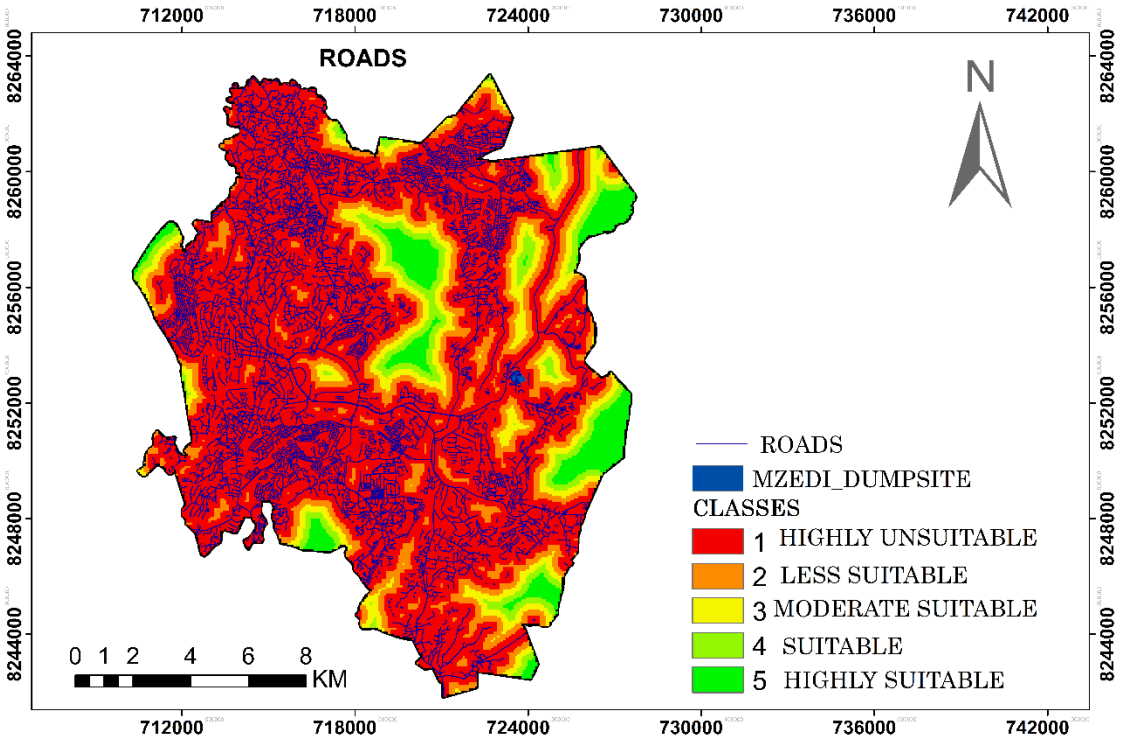


Figure 4 Residential, trunk, primary, secondary and tertiary road

Road accessibility is another crucial component which needs to be considered in site selection process, as it directly affects the efficiency and cost of transporting waste from collection points to the disposal sites. Ideally, dumpsites should be located at a reasonable distance of more than 500 metre from the major roads particularly in highly urbanised areas (Ezeah & Eng, 2010) , this helps to minimise operation cost for waste collectors while ensuring ease access. This research finds that current Mzedi dumpsite is advantageous in terms of accessibility due to its proximity to M3 Zomba road though in rain season the roads to Mzedi is almost impassable. The proposed dumpsites identified in this study were also found to be at safe distances from residential areas, thereby minimizing health and environmental risks. Specifically, Mapanga sites were found to be located at an approximately of 612 metres and 517 metres, site 1 and site 2 respectively. The Mapanga site 3 is located at 3,190 metres from Midima road and lastly Nacholi site is situated 1,811 meters from Victoria road. Thise distances are considered optimal, as they support cost-effective operations and can enhance the

overall productivity of waste management efforts to the Blantyre City Council and other waste collection stakeholders.

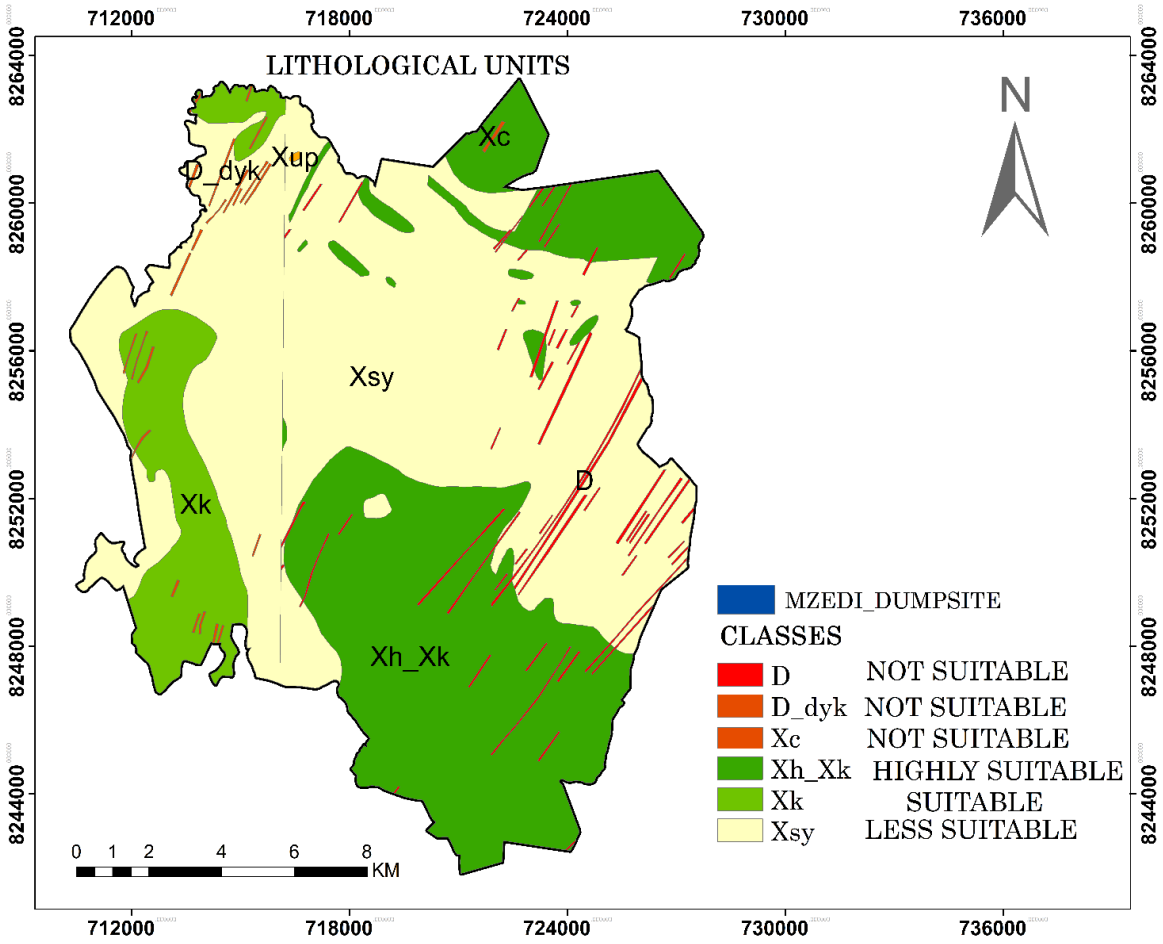


Figure 5 Blantyre City, Rock types

Blantyre City comprises of various lithological units such as D, XC, XK, XK_XH and XSY. This study finds that the current dumpsite Mzedi is located within the XSY unit, which consist of syenite or associated igneous rocks. These rock are characterised by low permeability, making the site geological suitable for waste disposal in contrast, Unit D refers to unconsolidated deposits, which exhibit high permeability and are therefore unsuitable for waste containment due to the potential risk of leachate infiltration into the groundwater system. The XUP Unit is composed of sandstone and shale, materials

which possess moderate permeability, thereby offering limited suitability for waste disposal.

The XC unit represent the crystalline basement complex, which is generally iss considered to have low permeability and relatively suitable for waste disposal purposes similarly XK and XK_XH units consist of primarily of granitic and hornblende-rich rock which are classified as having low to moderate permeability.

This study finds that Nacholi site is located on less suitable XSY lithological unit, Mapanga sites, Michiru site as well as Masamba sites are located within the XK_XH lithological unit, which offers a favourable geological setting for waste disposal due to its permeability and this characteristic minimises the risk of underground water contamination.

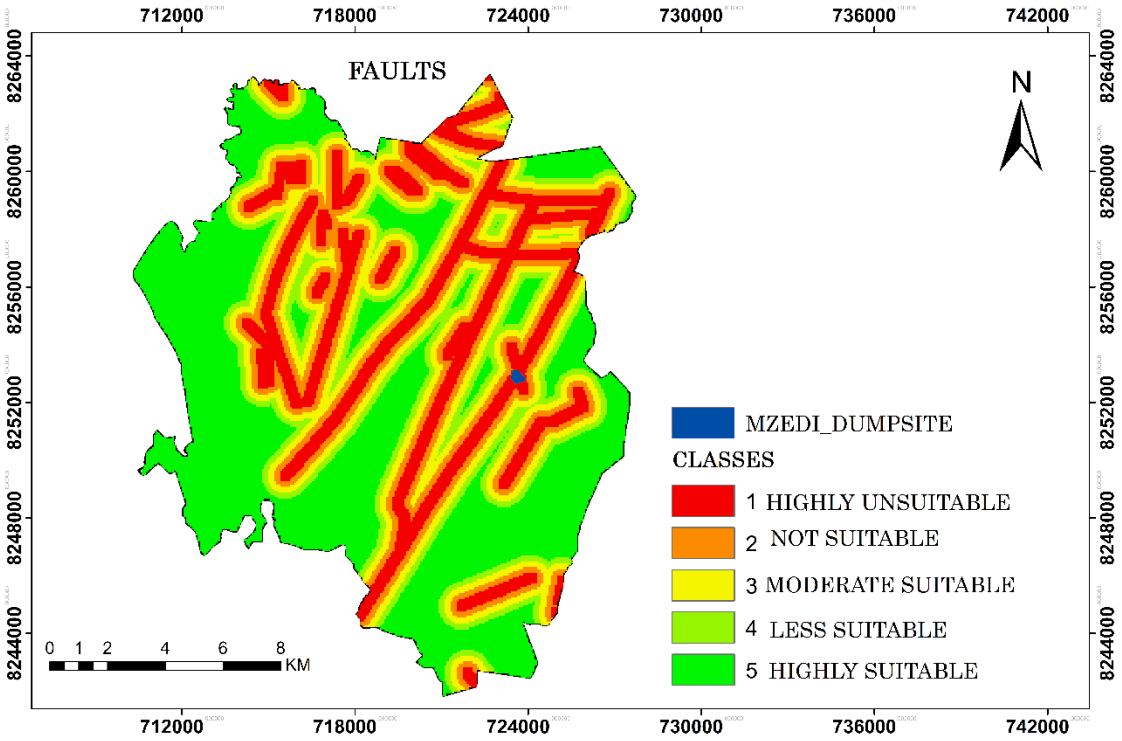


Figure 6 active faults in Blantyre City

Blantyre City has also a lot of faults and joints due to geological positioning system within the southern segment of the East Africa Rift system. This rift system is an active tectonic boundary where Africa plate is undergoing extensional forces, leading to formation of numerous faults and fractures in the earth crust, bedrock primarily consist of crystalline formations , such as granulite gneiss and syenitic gneiss when subjected to tectonic stresses tend to fracture resulting in numerous faults and joins (Castaing, 1991).All the site were found to away from faults and joins which is vital to prevent underground water contaminations as some faults can act as recharging zone for underground water , and this study also found Mapanga site has a distance of 1,202 metres, 871 metres and 1029 metre from site 1,2 and 3 respectively , Mapanga site was found to be at 1, 615 metre , Nacholi site 4,915 metres while Michiru 593 metres from active fault , this study also finds that the current dumpsite is within fault zone.

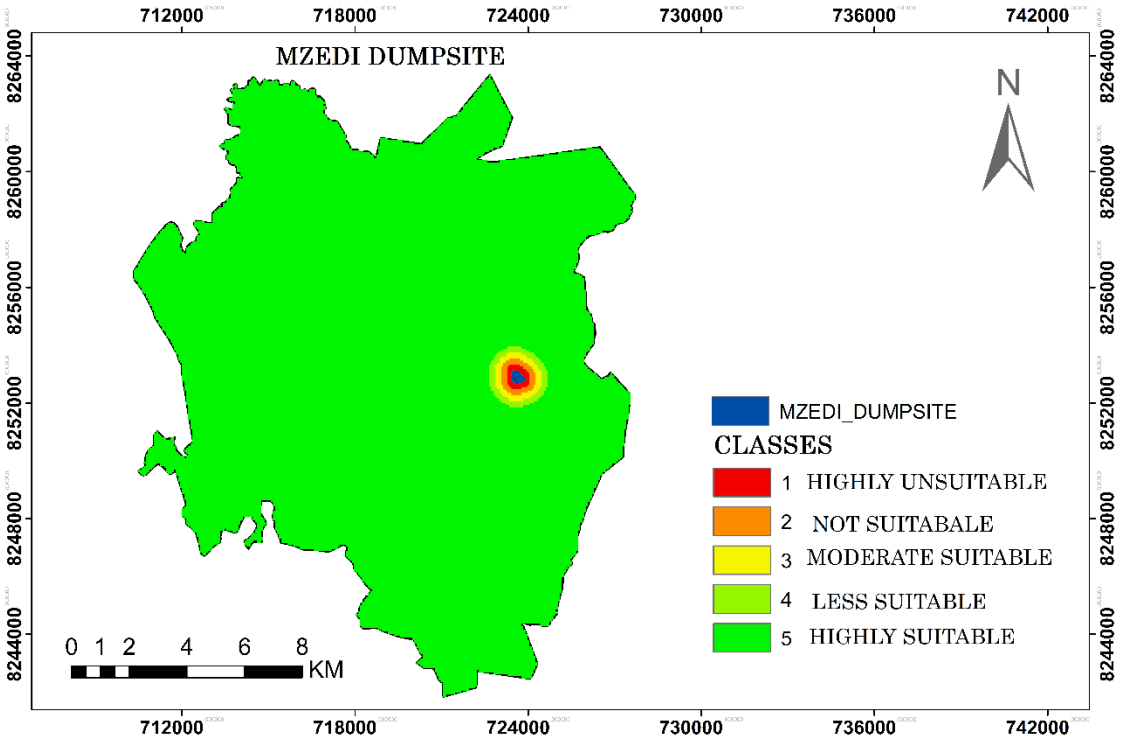


Figure 7, Current City Dumpsite, still in operation as of April 25/04 2025

In the process of identifying suitable sites for future waste disposal, it is crucial to consider the spatial relationship between potential sites and existing dumpsites. A key criterion applied in this research is a minimum distance threshold of 1000 metres from existing dumpsites. This buffer distance was established to mitigate the risk of environmental degradation, particularly the contamination of underground water resources, which may result from leachate infiltration if sites are located in close proximity to one another. By applying this threshold, the study ensures that the siting of new dumpsites does not pose additional environmental hazards, especially in areas with permeable soils or shallow groundwater tables. Spatial analysis using GIS tools revealed that all the proposed suitable sites fall outside the 1000-metre buffer zone of the current dumpsites, Mapanga site 1, 2 and 3 were found to be 7,203 metres,6,694 metre and 4,905 metre respectively, Masamba site was found to be at a distance of 8,113 metres and Michiru site 10,165 metres while Nacholi site 12,870 metres from the current dumpsite Mzedi. This spatial compliance indicates that the selected sites meet

the essential environmental protection standards and are spatially distributed in a manner that minimizes cumulative ecological impacts.

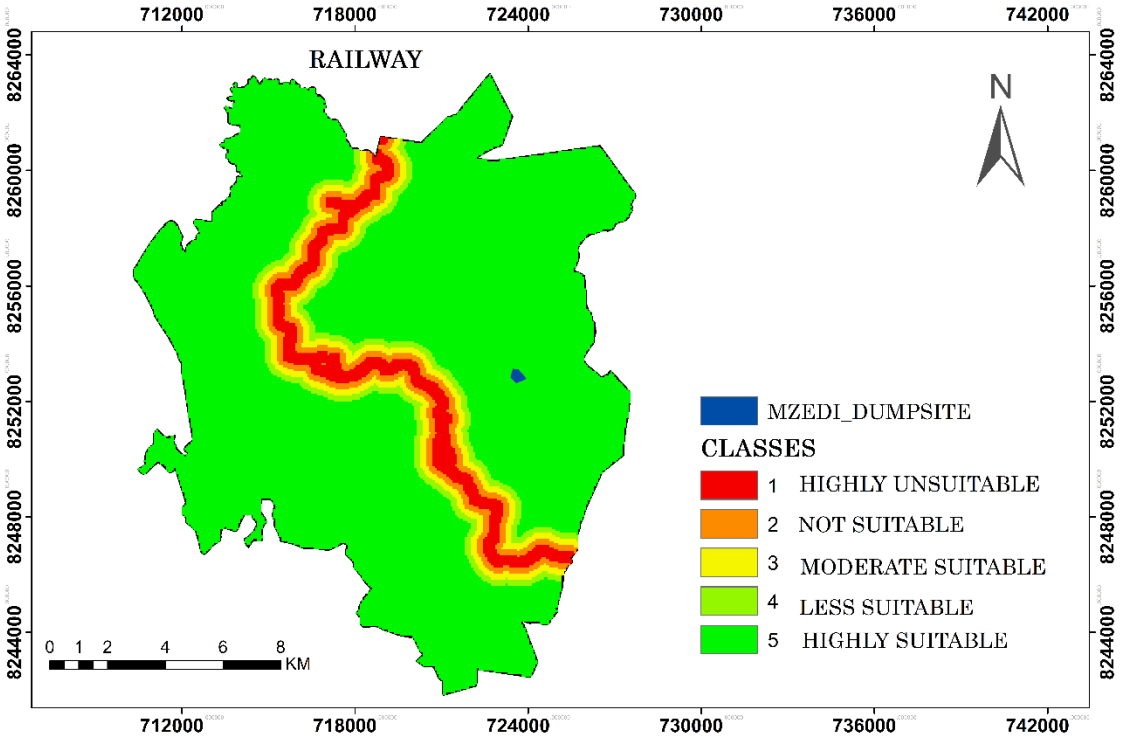


Figure 8, active railway, as of 25/04/2025

Blantyre City is served by an active railway network, which plays a vital role in transportation and logistics. In this study, the railway was considered an important factor in the site selection process for waste disposal. A Euclidean distance analysis was conducted in ArcGIS, with distances classified into five categories ranging from Class 1 to Class 5. A distance of more than 1,000 meters is considered as distance threshold for railway suitability (Mvula et al., 2023b). All the identified potential waste disposal sites exceeded this threshold, indicating minimal risk of interference with railway operations. Specifically, Mapanga sites are located at approximately of 7 346.12 and 6,082 meters site 1 and 2 respectively from the railway while site 3 is located at an approximately of 7,347 metre away from the railway and Masamba site is situated 1,776.12 meters from the railway and Michiru is located at a distance of 1,573 metre. Additionally, this research also highlight that current Mzedi dumpsite also lies within the recommended buffer zone, at a distance of 2,949.55 meters from the railway. These distances suggest that all proposed and existing sites meet the safety and operational guidelines concerning proximity to the railway infrastructure.

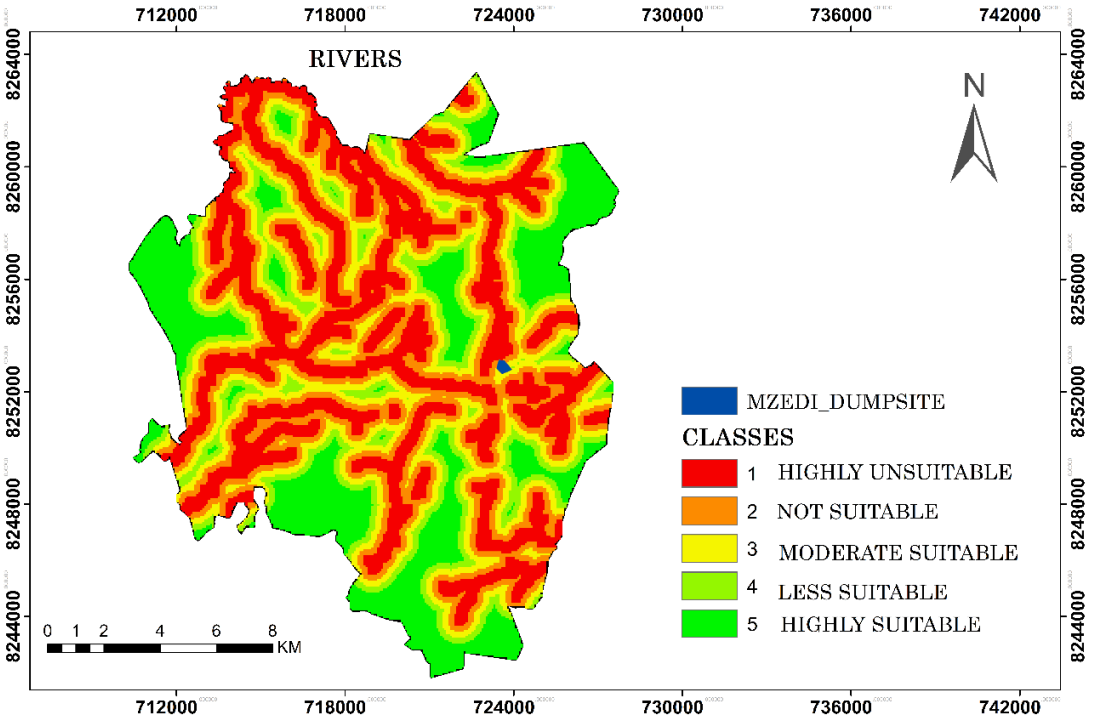


Figure 9, river and streams within Blantyre City

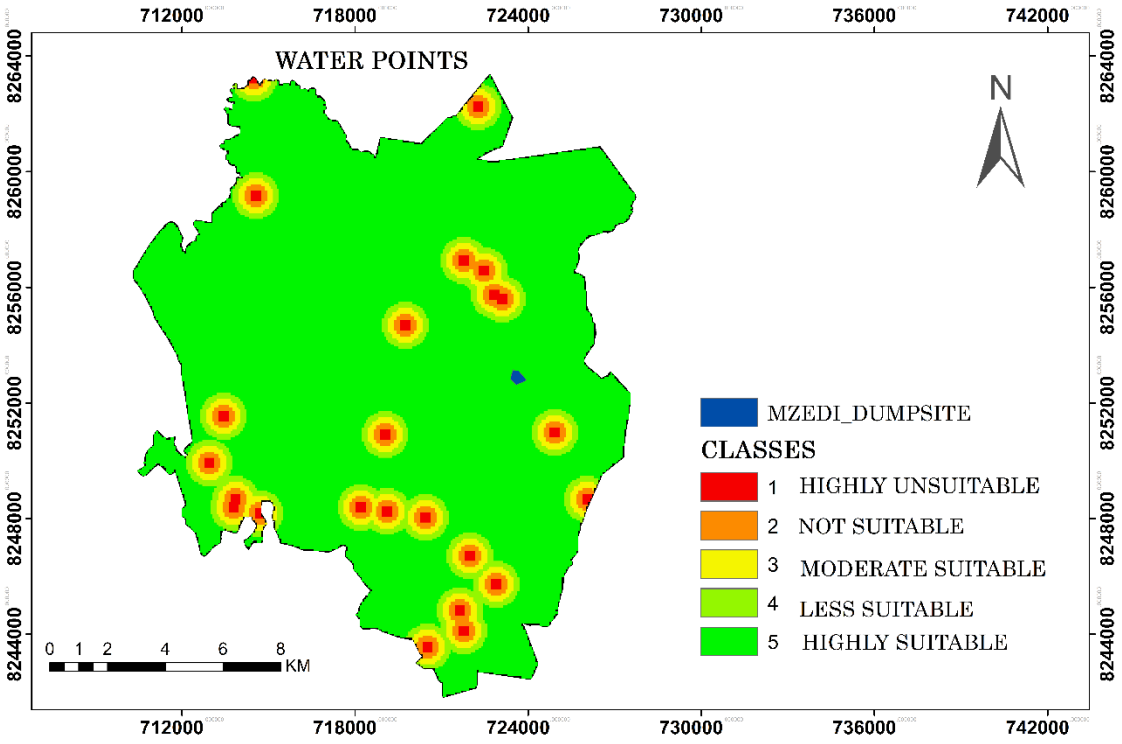


Figure 10, active borehole, sourced from GSD North

The study also incorporated proximity to waterbodies such as rivers, it is important factor to consider. Euclidean distance analysis was conducted using a buffer zone ranging from 200 metres to 1,000 metres in order to assess the spatial relationship between potential dumpsites and nearby water bodies. The importance of considering water bodies in waste disposal sites section lies in the need to minimise the risk of surface and ground water contamination and all had more than 1000 metre from water bodies as distant threshold (Kabite et al., 2012) .

The findings of this study indicate that the current dumpsite is situated at a considerable distance from major rivers, which is favourable in terms of reducing direct contamination, all the newly identified potential sites were found to be at safe distances from water bodies, making them more suitable for waste disposal.

Table 3, sites and possible proximity to borehole and river

SITE	NEAREST RVER	DISTANCE (M)	NEAREST WATER POINT (ACTIVE WELL)	DISTANCE (M)
Mapanga site 1	Nangafuwe river	1,123	Mapanga ward	4,885
Mapanga site 2	Nangafuwe river	326	Mapanga ward	4,014
Mapanga site 3	Nangafuwe river	1,053	Mapanga ward	3,195
Nacholi site	Mudi stream	1,152	Nacholi ward	1,961
Masamba site	Bangwe stream	210	Masamba ward	1,449
Michiru site	Lunzu stream	307	Michiru ward	349

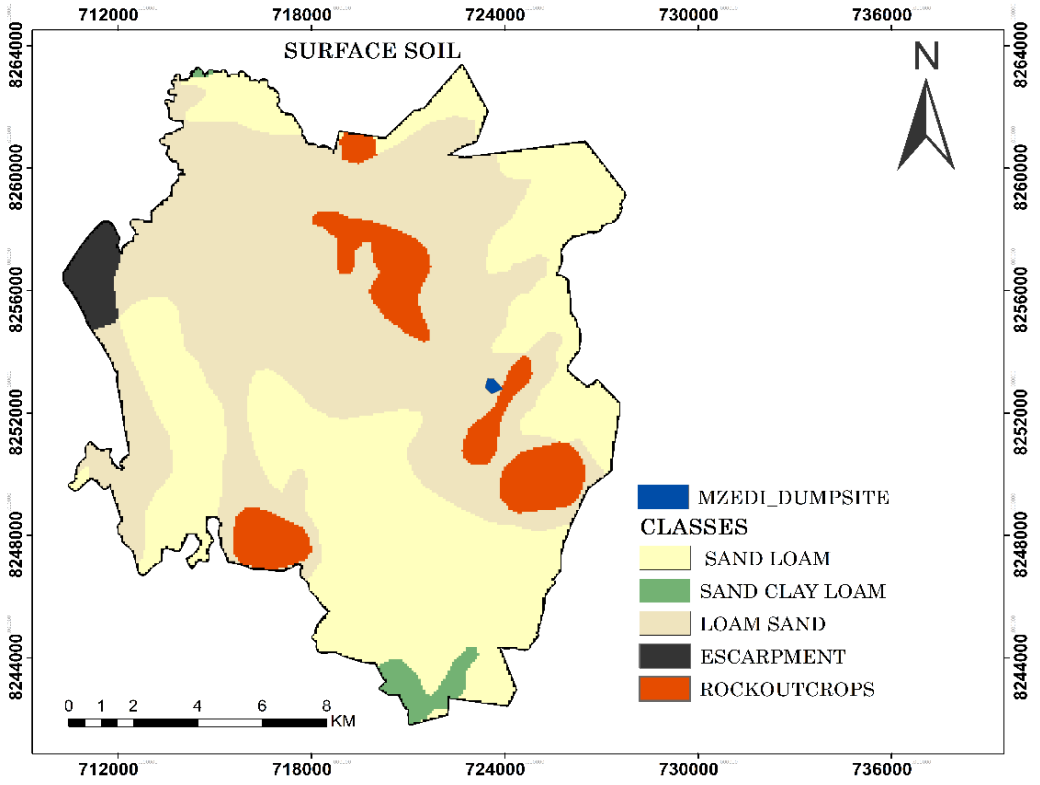


Figure 11, BT soil type, sourced from FAO

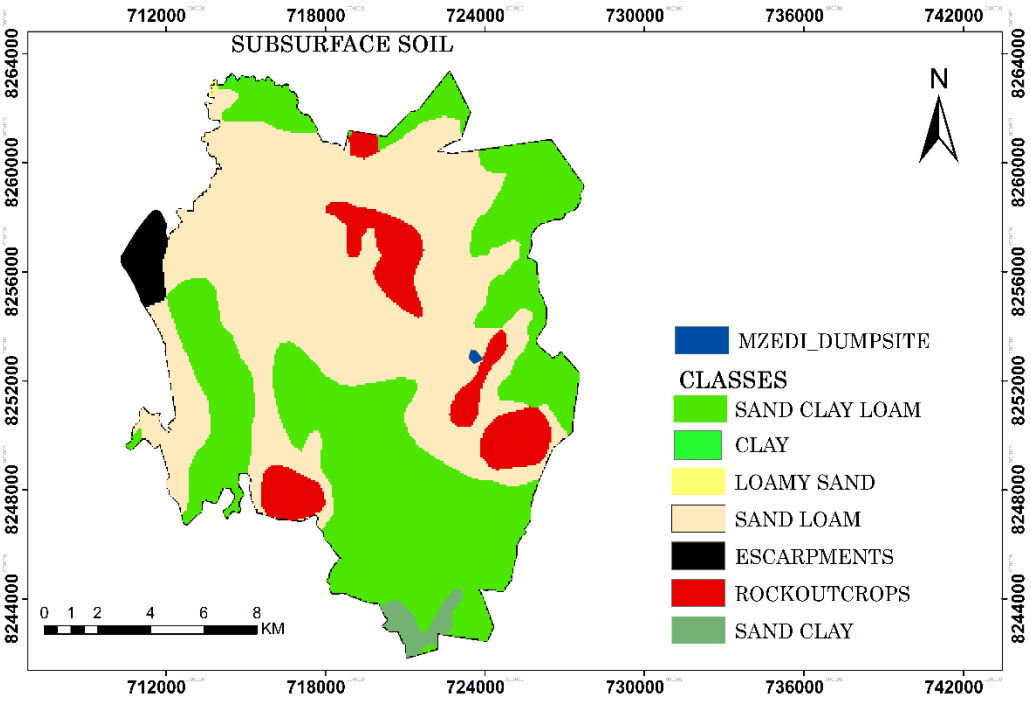


Figure 12, subsurface soil type

The study also considered the types of soil present within the city of Blantyre, considering both surface and subsurface layers. The findings indicate that the current dumpsite in Mzedi is situated on sand loam, a soil type characterized by poor water retention capacity. This makes it less suitable for waste disposal, as it facilitates leachate percolation into the groundwater system. In contrast, clay soils are deemed more appropriate for dumpsite development due to their high water-holding capacity and low permeability, which help to prevent leachate infiltration into the subsurface aquifers.

The study area is composed of the following notable soil types, sandy loam, sandy clay, sandy clay loam, and loamy sand. In the suitability analysis, a weighted overlay approach was employed to identify and prioritize suitable areas for waste disposal. Escarpment zones were classified as restricted areas due to their steep slopes and high susceptibility to erosion. Although these zones were included in the analysis, the algorithm assigned them restrictive weights, thereby effectively excluding them from the final selection of suitable sites.

The newly identified potential dumpsites were located on a variety of soil types. At the Michiru site, the subsurface soil was identified as sandy clay loam, which is favourable for retaining moisture, while the surface layer consisted of sand. Mapanga Site 1 exhibited sandy clay loam as the subsurface soil type and sand as the surface layer. Similarly, Mapanga Site 2 had sandy clay loam subsurface soil and sandy loam at the surface. Mapanga Site 3 and Masamba Site both featured sandy clay loam in the subsurface and sandy loam at the surface. In contrast, the Nacholi site had loamy sand as the surface soil and clay as the subsurface layer, a combination considered more suitable for waste containment due to the impermeable nature of the clay.

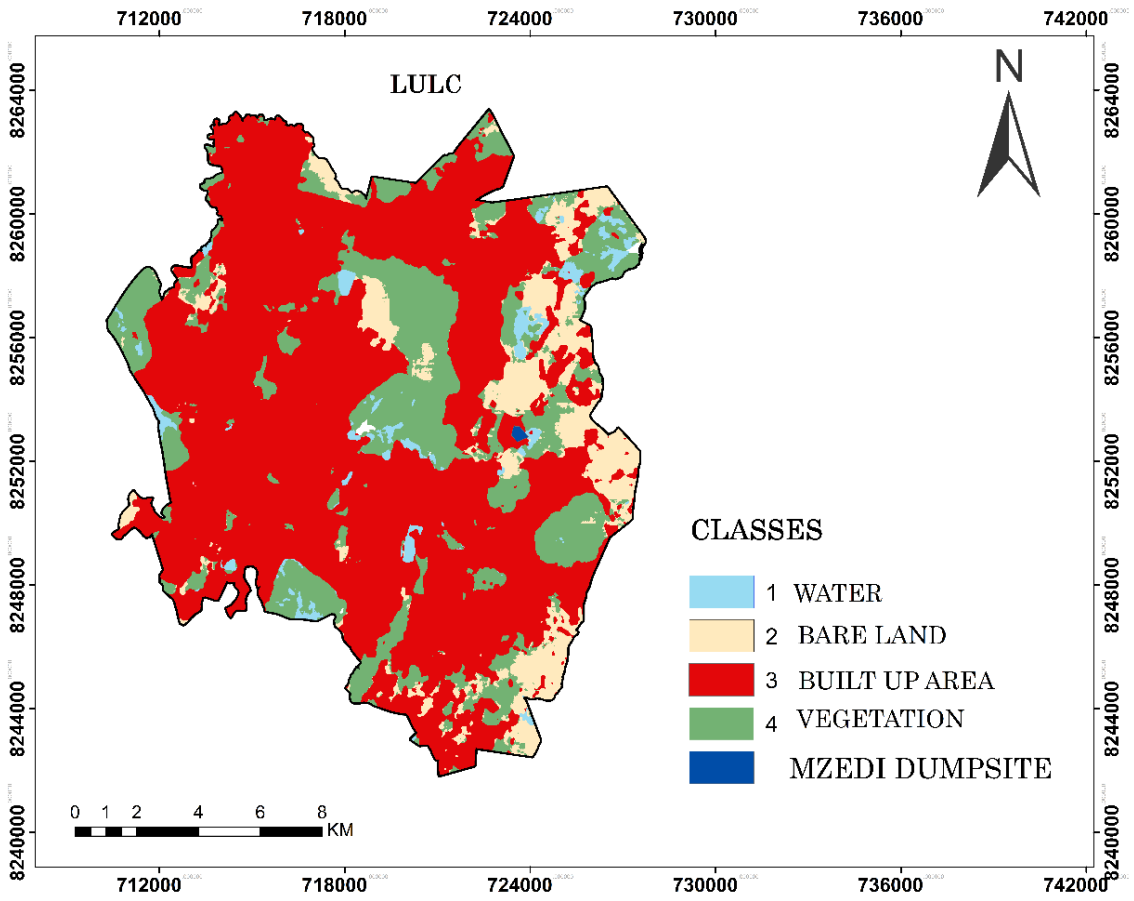


Figure 13, land use and land cover derived from GEE

Land use and land cover (LULC) data used in this study was derived from Google Earth Engine (GEE) and categorized into four classes, bare land, water, vegetation and built up area. The analysis reveals that Blantyre City is currently densely populated, with limited areas of bare land. The current dumpsite at mzedi is situated in close proximity to built up areas, which pose a significant health risks due to air pollution. In the weighted overlay Analysis the LULC was assigned a weight of 16.7, derived using Analytical Hierarch Process (AHP). Within this framework, bare land was prioritized with a score of 5, indicating it as a highly suitable area for waste disposal. Water bodies were restricted from the analysis, built up area was assigned a lower suitability score of 1, reflecting its unsuitability for waste disposal while vegetation was given a moderate suitability score of 3

All the identified potential waste disposal sites were located on the bare land with no any existing development on it, making them a viable option. Approximately three identified sites in Mapanga were located at a distance of 308 metres, 228 metres and 361 metres from the nearest residential areas, corresponding to site 1, site 2 and site 3 respectively. The Nacholi site was found to be situated at a distance of 146 metres away while the Masamba site was at an approximately distance of 459 metres from the nearest residential zone.

SUITABLESITES SITES

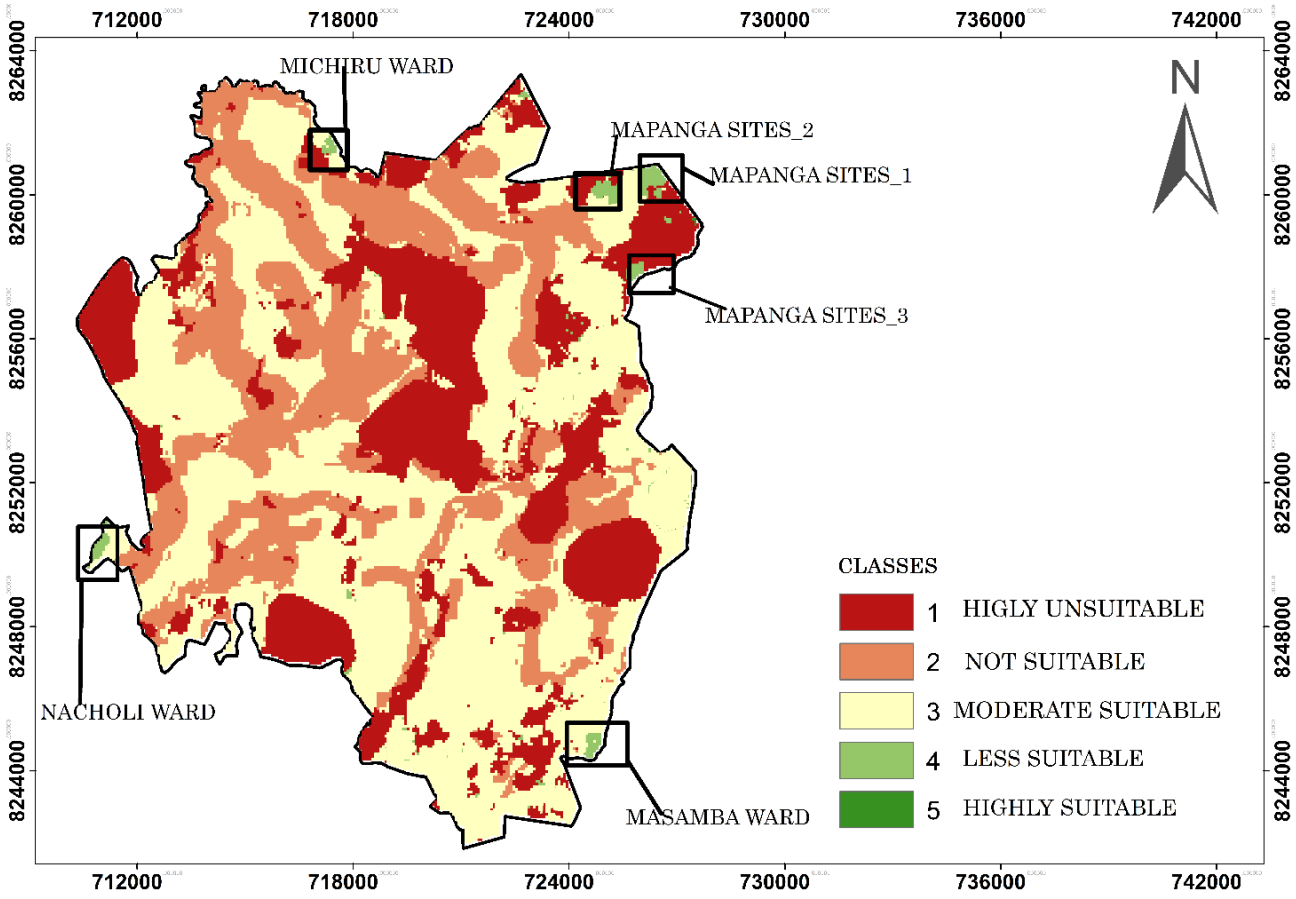


Figure 14, suitability map indicating potential sites

CHAPTER 5

CONCLUSION

This study successfully applied Geographic information Systems (GIS), Remote sensing and Hierarch Analytical process to identify suitable sites for waste disposal in Blantyre City. The research was necessitated by increase in waste generation in the city, coupled with inadequate capacity and environmental concern surrounding current Mzedi dumpsite. By integrating multiple criteria such as slope, geology, land use and land cover, proximity to roads, river, faults and residential area the study presents a scientifically results

The findings also indicates that existing dumpsites at Mzedi is poorly located, being surrounded by densely kacheri settlement and situated at loam soil, Through the AHP-weighted overlay analysis, new potential sites were identified in Mapanga, Masamba, Nacholi, and Michiru wards. These sites were found to possess highly suitable physical and environmental characteristics for waste disposal. Notably, all selected locations were on bare land with no current economic development, and most were underlain by sandy clay loam and clay soils both ideal for minimizing leachate infiltration. Additionally, all proposed sites met or exceeded the recommended distance thresholds from residential areas, major roads, fault lines, water bodies, and the existing dumpsite, thus minimizing potential environmental and social conflicts.

The study underscores the value of integrating GIS and RS tools with decision-support frameworks like AHP to achieve sustainable urban waste management. The identified sites not only offer spatially and environmentally options but also provide a basis for future infrastructure development, route optimization, and climate resilience.

RECOMMENDATION

1. Integrating of high-resolution remote data

To improve land use and land cove (LULC) classification accuracy, future studies should utilize higher resolution satellite dataset, such as Landsat 8 via Google Earth Engine (GEE). This enhances complete classification of different features, particularly in areas with a mixed of land uses, it helps to improve the precision of spatial analysis outcome.

2. Incorporating proximity and buffer analysis using Euclidean distance

Conducting proximity for sensitive features such residential zones, water, roads, rivers and fault lines, it is important to establish scientifically justified buffer zone based in wate disposal siting to avoid environmental impacts

3. Use of Machine Learning for LULC Classification and Change Detection

Classifiers such as Random Forest, Support Vector Machine (SVM), and Convolutional Neural Network (CNN) within the GEE platform is recommended for future LULC analysis. These algorithms they have a higher classification accuracy and can support time series change detection critical for long term waste management planning.

4. Incorporating GIS, Remote Sensing and Geology in site selection for waste disposal

The most overlooked component in site selection for waste disposal in Geology, different lithological units have different permeability capacity, Geological structures such as faults and joints can as recharge zone for underground water.

APPENDEX

```
var blantyre = ee.FeatureCollection('projects/ee-mmymmap/assets/blantyre');
print('blantyre Shapefile:', blantyre);
function maskClouds(image) {
  var qa = image.select('QA_PIXEL');
  var cloudMask = qa.bitwiseAnd(1 << 3).eq(0);
  return image.updateMask(cloudMask);
}
var imageCollection = ee.ImageCollection('LANDSAT/LC09/C02/T1_TOA') // Use Landsat 9
            .merge(ee.ImageCollection('LANDSAT/LC08/C02/T1_TOA')) // Merge with Landsat 8
            .filterBounds(blantyre)
            .filterDate('2024-05-01', '2024-12-31')
            .filter(ee.Filter.lt('CLOUD_COVER', 5))
            .map(maskClouds)
print('Filtered Collection Size:', imageCollection.size());

// Compute the median image and clip to the study area
var finalImage = ee.Image(imageCollection.median()).clip(blantyre);

// Ensure a valid image is returned
var emptyCheck = imageCollection.size().gt(0);
finalImage = ee.Image(ee.Algorithms.If(emptyCheck, finalImage, ee.Image(0).clip(blantyre)));

var vizParams = {
  bands: ['B4', 'B3', 'B2'], // Landsat 8/9 equivalent of RGB
  min: 0,
  max: 0.3,
  gamma: 1.4
};
```

```
Map.centerObject(blantyre, 10);
Map.addLayer(finalImage, vizParams, 'Preprocessed Landsat 8/9 (2024)');
var waterSamples = water;       // Value 1
var vegetationSamples = vegetation;     // Value 2
var buit_up_areaSamples = buit_up_area;     // Value 3
var bare_landSamples = bare_land;     // Value 4

// Merge all training samples
var trainingSamples = waterSamples
  .merge(vegetationSamples)
  .merge(buit_up_areaSamples)
  .merge(bare_landSamples)
print('Training Samples:', trainingSamples);



var trainingData = finalImage.sampleRegions({
  collection: trainingSamples,
  properties: ['LC'],  // Use 'LC' as the class property
  scale: 30
});

print('Training Data:', trainingData);

var classifier = ee.Classifier.smileRandomForest(50).train({
  features: trainingData,
  classProperty: 'LC',
  inputProperties: ['B2', 'B3', 'B4', 'B5', 'B6', 'B7']
});

var classifiedImage = finalImage.classify(classifier);

var classVis = {
```

```
  min: 1,
  max: 4,
  palette: ['blue', 'green', 'gray', 'brown']
};

Map.addLayer(classifiedImage, classVis, 'Land Cover Classification (2024)');
print('Classified Image:', classifiedImage);
var areaImage = ee.Image.pixelArea().addBands(classifiedImage);

var classAreas = areaImage.reduceRegion({
  reducer: ee.Reducer.sum().group({
    groupField: 1,
    groupName: 'classification',
  }),
  geometry: blantyre,
  scale: 30,
  maxPixels: 1e13
});

var areasList = ee.List(classAreas.get('groups'));

var areaInHectares = areasList.map(function(obj) {
  obj = ee.Dictionary(obj);
  return ee.Feature(null, {
    class: obj.get('classification'),
    area_ha: ee.Number(obj.get('sum')).divide(10000)
  });
});

print('LULC Class Areas (Hectares):', areaInHectares);
var sample = trainingData.randomColumn();
var trainingSet = sample.filter(ee.Filter.lt('random', 0.7));
```

```
var validationSet = sample.filter(ee.Filter.gte('random', 0.7));

var trainedClassifier = ee.Classifier.smileRandomForest(50).train({
  features: trainingSet,
  classProperty: 'LC',
  inputProperties: ['B2', 'B3', 'B4', 'B5', 'B6', 'B7']
});

var validated = validationSet.classify(trainedClassifier);
var errorMatrix = validated.errorMatrix('LC', 'classification');
print('Confusion Matrix:', errorMatrix);

print('Overall Accuracy:', errorMatrix.accuracy());
print('Kappa Coefficient:', errorMatrix.kappa());
print('Producer Accuracy:', errorMatrix.producersAccuracy());
print('Users Accuracy:', errorMatrix.consumersAccuracy());
Export.image.toDrive({
  image: classifiedImage,
  description: 'blantyre_Classification_2024',
  region: blantyre.geometry(),
  scale: 30,
  maxPixels: 1e13,
  fileFormat: 'GeoTIFF'
});

Export.table.toDrive({
  collection: ee.FeatureCollection(areaInHectares),
  description: 'blantyre_LULC_Areas_2024_Hectares',
  fileFormat: 'CSV'
});

Export.table.toDrive({
```

```
  collection: ee.FeatureCollection([ee.Feature(null, {
    'Overall Accuracy': errorMatrix.accuracy(),
    'Kappa Coefficient': errorMatrix.kappa()
  })]),
  description: 'blantyre_Accuracy_Assessment_2024',
  fileFormat: 'CSV'
});

print('Exporting Results...');
```

REFERENCES

10 Reasons Why Waste Management is Important. (n.d.).

Abdelouhed, F., Ahmed, A., Abdellah, A., Yassine, B., & Mohammed, I. (2022). GIS and remote sensing coupled with analytical hierarchy process (AHP) for the selection of appropriate sites for landfills: a case study in the province of Ouarzazate, Morocco. Journal of Engineering and Applied Science, 69(1). https://doi.org/10.1186/s44147-021-00063-3

Agbejule, A., Shamsuzzoha, A., Lotchi, K., & Rutledge, K. (2021). Application of multi-criteria decision-making process to select waste-to-energy technology in developing countries: The case of ghana. Sustainability (Switzerland), 13(22). https://doi.org/10.3390/su132212863

Badi, I., Shetwan, A., Abdulshahed, A., & Eltayeb, W. (2019). Evaluation of solid waste treatment methods in libya by using the analytic hierarchy process. Decision Making: Applications in Management and Engineering, 2(2), 19–35. https://doi.org/10.31181/dmame1902038b

Beyond an age of waste Turning rubbish into a resource. (2024). https://wedocs.unep.org/20.500.11822/44939

Blantyre-limbe, Malawi Metro Area Population 1950-2025. (2010). https://population.un.org/wpp/

Bonn, G. /. (n.d.). The global E-waste Monitor 2024-Electronic Waste Rising Five Times Faster than Documented E-waste Recycling: UN D O W N L O A D E N D O W N L O A D E S D O W N L O A D F R.

Castaing, C. (1991). lost-Pan-Af~can tectonic evolution of South Malawi in relation to the Karroo and Recent East African Rift Systems (Vol. 191).

Chabuk, A. J., Al-Ansari, N., Hussain, H. M., Knutsson, S., & Pusch, R. (2017). Landfill Sites Selection Using Analytical Hierarchy Process and Ratio Scale Weighting: Case Study of Al-Mahawil, Babylon, Iraq. Engineering, 09(02), 123–141. https://doi.org/10.4236/eng.2017.92006

Cholera in the midst of a floods emergency _ UNICEF Malawi. (n.d.).

Cristóbal, J., Vázquez-Rowe, I., Margallo, M., Ita-Nagy, D., Ziegler-Rodriguez, K., Laso, J., Ruiz-Salmón, I., Kahhat, R., & Aldaco, R. (2022). Climate change mitigation potential of transitioning from open dumpsters in Peru: Evaluation of mitigation strategies in critical dumpsites. Science of the Total Environment, 846. https://doi.org/10.1016/j.scitotenv.2022.157295

Ezeah, C., & Eng, B. (2010). ANALYSIS OF BARRIERS AND SUCCESS FACTORS AFFECTING THE ADOPTION OF SUSTAINABLE MANAGEMENT OF MUNICIPAL SOLID WASTE IN ABUJA, NIGERIA.

High-Level Panel on Emerging Technologies (APET) and the Calestous Juma Executive Dialogues (CJED). (n.d.). https://www.nepad.org/microsite/work-

In Africa, greenhouse gas emissions from the waste sector increase, despite efforts from various actors Analysis note by the Observatory of Climate Action in Africa. (n.d.). https://www.climate-chance.org/en/comprehend/blog-observatory-global/africa-greenhouse-gas-emissions-waste-sector-increase/

International Collaboration for E-waste Management: A Global Endeavor towards Sustainability The Power of Global Agreements and Frameworks. (n.d.). https://ecircular.com/international-collaboration-for-e-waste-management/

Jiang, B., Zhou, F., Qu, H., & Xia, D. (2022). Industrial waste heat recovery: A helix-weaved convection-radiation converter for heat transfer enhancement in gas heat exchanger. Chemical Engineering and Processing - Process Intensification, 173. https://doi.org/10.1016/j.cep.2022.108853

Kabite, G., Suryabhagavan, K. V, & Sulaiman, H. (2012). GIS-Based Solid Waste Landfill Site Selection in Addis Ababa, Ethiopia. In International Journal of Ecology and Environmental Sciences (Vol. 38, Issue 3).

Kalina, M., & Tilley, E. (2020). 'Bad' trash: Problematising waste in Blantyre, Malawi. Detritus, 12, 187–200. https://doi.org/10.31025/2611-4135/2020.13994

Karadimas, N. V, & Doukas, N. (2008). Routing Optimization Heuristics Algorithms for Urban Solid Waste Transportation Management. https://www.researchgate.net/publication/228714142

Kebede, H. A., Wondim, □ □ •, & Ayenew, A. (n.d.). Solid waste disposal site selection analysis using geospatial technology in Dessie city Ethiopia. https://www.cell.com/heliyon/fulltext/S2405-8440

Kumar, P., Choudhary, M. P., & Mathur, A. K. (2025). Exploring spatial dynamics of urbanization and solid waste generation in Kota city using the Google Earth Engine. Environmental Monitoring and Assessment, 197(2), 212. https://doi.org/10.1007/s10661-025-13659-6

Malawi Takes Bold Step Toward Sustainable E-Waste Management with Launch of National Policy - WESM. (n.d.).

Mvula, R. L. S., Mundike, J., & Nguvulu, A. (2023a). Spatial suitability analysis for site selection of municipal solid waste landfill using hybrid GIS and MCDA approach: The case of Kitwe, Zambia. Scientific African, 21. https://doi.org/10.1016/j.sciaf.2023.e01885

Mvula, R. L. S., Mundike, J., & Nguvulu, A. (2023b). Spatial suitability analysis for site selection of municipal solid waste landfill using hybrid GIS and MCDA approach: The case of Kitwe, Zambia. Scientific African, 21. https://doi.org/10.1016/j.sciaf.2023.e01885

National Statistical Office. (2019). Malawi Population and Housing Census Main Report (Issue May).

News stream. (n.d.). https://www.developmentaid.org/news-stream/post/158158/world-waste-statistics-by-country

Noi Phan, T., Kuch, V., & Lehnert, L. W. (2020). Land cover classification using google earth engine and random forest classifier-the role of image composition. Remote Sensing, 12(15). https://doi.org/10.3390/RS12152411

O'mahoney, M., Santos, S., Riedewald, F., & De Sousa Gallagher, M. (n.d.). Solving The Global Problem Of E-Waste.

Perkins, D. N., Brune Drisse, M. N., Nxele, T., & Sly, P. D. (2014). E-waste: A global hazard. In Annals of Global Health (Vol. 80, Issue 4, pp. 286–295). Elsevier USA. https://doi.org/10.1016/j.aogh.2014.10.001

Randazzo, L., Cusumano, A., Oliveri, G., Di Stefano, P., Renda, P., Perricone, M., & Zarcone, G. (2018). Landfill site selection for municipal solid waste by using AHP method in GIS environment: Waste management decision-support in sicily (Italy). Detritus, 2(June), 78–88. https://doi.org/10.31025/2611-4135/2018.13656

Sustainable Development Goals, Targets and Indicators. (n.d.).

What a Waste 2.0. (n.d.).