University of Nairobi

School of Engineering

DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY

USING GIS IN DUMPING SITE SELECTION: A CASE STUDY OF HOMA BAY TOWN

BY

KOTONYA KILIMIS JAMES

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Declaration

I, Kotonya Kilimis James, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

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Name of student Date

This project has been submitted for examination with our approval as university supervisor(s).

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Name of supervisor Date

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Name of supervisor Date

Dedication

This project is dedicated to my loving parents Mr. Kenneth Ochieng and Mrs. Caren Kenneth, my siblings Evans, Raegan, Rinter, Millicent and Elijah Ochieng who remained supportive and understanding till the end. Without their cooperation, I would not have been able to attain this degree. Thank you.

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Abstract

This study explored solid waste management and suitable dump site selection using GIS in Homa-Bay town. Solid Waste management (SWM) is an environmental global issue which is a major problem in the world today. Many towns and urban centres that have rapid urbanization and population growth inevitably face the challenges of selection of suitable solid waste dumping sites Rapid technological development, which has increased consumption, is also a contributing factor to rapid solid waste generation. The project focused on the following areas of solid waste management in Homa-Bay town: efficient and economical collection methods, identification and allocation of proper dumping sites and relocation of dumping bins for users. To achieve optimal waste management system, GIS was used as an effective tool in selecting suitable disposal sites in Homa-Bay town.

Key Words: Solid Waste Management (SWM), waste bin allocation, Geographical information System (GIS).

CHAPTER 1: INTRODUCTION

1.1 Background

Waste generation is presently becoming an alarming issue globally. Large population in the world is increasingly being exposed to danger due to the increase in the rate of waste generation. According to the World Bank (2012), 1.3 billion tonnes of solid waste is being generated from major towns and cities across the world per year, translating to 1.2 kilograms per person per day. Municipal waste generation is expected to rise to 2.2 billion tonnes by 2025 because of the rapid increase in population and urbanization. 2025 (UN- HABITAT, n.d.).

Ogra (2003) conducted a research about dump site selection in Malaysia with the purpose of using Effective government guidelines have been established to help in the decision-making process using Geographic Information System (GIS) as a tool. The government guidelines are used as parameters in the criteria for doing solid waste dump site selection. “Solid waste is the term used to describe non-liquid waste materials arising from domestic, trade, commercial, agricultural, industrial activities and from public services” (Minale, 2011, p. 72). “The ‘Municipal Solid Waste’ includes commercial and residential wastes generated in municipal areas in either solid or semi-solid form excluding industrial hazardous wastes but including treated bio-medical wastes” (UN-HABITAT, 2004, p. 21). As far back as 900 to 800BC, people had learned to dispose their waste outside their settlements, to escape or avoid the nuisance of vermin, odour insects and wild animals.

During the United Nations Conference on Environment and Development (UNCED). The Earth Summit in Rio De Janeiro, Brazil, came up with a policy framework for development in the 21st century. This is the Agenda 21, which is a far-reaching document in environmental protection. This agenda was to address the problem of solid wastes.
Most of local Kenyan authorities are unable to cope with the solid waste problems including collection, treatment and disposal of wastes due to inadequate capacity and financial constraints as highlighted in the Kenya National Development Plan of 2002-2008. Despite the efforts by County governments in Kenya and private garbage collectors to manage solid waste, they are still struggling with most solid waste left uncollected.

According to the World Bank (2012) report on solid waste management, cities and towns in least developed countries are more affected by waste problems compared to those in developed nations. This report also indicates that, there have been promotion of urban violence, global climate change through methane generation which have created serious health, safety, and environmental consequences. In developing countries, especially the urban poor, residents are more severely affected by unsustainably managed waste. In low and middle-income countries, waste is often disposed in open space, free land or unregulated dumps burned. (World Bank, 2004).

1.2 Problem Statement

In Homa-Bay town, the disposal of solid waste products, for instance, waste papers, metal tins, plastics of all kind, fruit peels, food left-overs, vegetable wastes, rags and other forms, occurs practically everywhere; on the streets, open spaces, parks, and open drainage (UN- HABITAT, n.d.). Solid waste has been a threat to the society. Getting rid of solid waste in Homa-Bay town has been challenging to the residents and to the County Government due to poor planning and policies put in place to control the disposal of solid waste (UN-HABITAT, 2010). There is lack of individual commitment to controlling and managing waste, resulting in the spread of the solid wastes all over the town and its environs.

There has been also a problem in the management of solid waste in the Homa-Bay town and particularly in the low-income residential areas such as Makongeni and Shauri Yako estates. The solid waste problem is an eye-sore in Homa-Bay since there are several open dumping sites for wastes in the town.

According to Musembi (2012) and Njoroge et al. (2014), there are several problems associated with waste management in a town like Homa-Bay, and these include:

1. There have been spread of diseases and some epidemic more so during rainy seasons like cholera and malaria around dumping areas since they are breading grounds for bacteria, insects, flies, fungus and many such micro-organism.
2. The environment around dump site is unbearable due to bad odour caused by garbage.
3. There have been threat to public health caused by poor waste pickers.
4. Garbage have been spread from the bins and dump site by cats, goats, dogs, cows and other non-domestic when they are in search of food.
5. Property values are adversely affected by the poor solid waste management in various areas as a result of poor aesthetics.

1.3 Objectives

The main objective of the project is to identify most suitable solid waste dumping site using GIS technology in Homa-Bay town.

Specific Objectives

1. To determine the various types of solid wastes emanating from Homa-Bay town.
2. To determine suitable dumping site using GIS technology in Homa-Bay Town.

1.4 Justification of the Study

Solid waste problem is mainly common in low income areas in towns and cities. Most local authorities in general and Homa-Bay County in particular, have been unable to cope with the collection, treatment, and disposal of wastes due to inadequate capacity, financial constraints and poor management (UN-HABITAT, 2010). Waste can cause degradation of freshwater, unsanitary and pollution of the land and environment when it is not controlled (Mwanzia, Kimani & Stevens, 2013). Some solid wastes do not decompose or break down easily causing stagnant water where mosquitos can breed, such wastes includes; plastics, cans and bottles (Government of Kenya, 2006).

The open dumping of wastes in Homa-Bay town encourages flies, and rats, leading to the spread of diseases such as cholera and typhoid (Musembi, 2012). Metallic wastes, such as iron sheets and metals, can cause injury, like cuts on people, when exposed to the environment Njoroge et al (2014). There is also air pollution and respiratory ailments to living organisms in environments where open and uncontrolled burning of wastes is done as it is common in Homa-Bay town (Government of Kenya, 2006). Leachate from dumps can contaminate surface and underground waters used for drinking and other uses (Mwanzia, Kimani & Stevens, 2013). These are just but a few examples of how waste and their poor disposal can cause environmental degradation.

From the foregoing, it is imperative that wastes be managed properly to avert the possible negative effects that are associated with their management. These wastes need to be properly collected and dumped at correctly selected points for effective and easy management to avoid the scenario that currently characterizes towns in Kenya, especially low-income residential. While traditional techniques of selecting dumping sites for solid waste have been instrumental, this paper posits that the use of GIS will significantly help address inadequate capacity and financial constraints which are often the main challenges that hamper waste management in Kenyan counties, especially, Homa-Bay County. GIS has the ability of analysing and displaying information in accordance with user-defined specifications and also allows for a relatively easy presentation of findings for quick decision making (Mwangi, 2007). The use of GIS for this study in Homa-Bay is backed up by the current level of technological advancement that has made planning for solid waste management easy and efficient in other cities around the globe. Thus, GIS employment in Homa-Bay town waste management will improve its urban and regional planning performance.

1.5 Scope of Work

This project focuses on the solid waste management in Homa-Bay town and the importance of GIS technologies in waste management. This study explores how wastes are collected, separated, and transported in Homa-Bay town. It also discusses how GIS technology is used in planning of towns and how the technology can be employed in planning waste management in Homa-Bay town. Similarly, the paper discusses the types of wastes that are generated in Homa-Bay and how GIS can be used to determine suitable dumping sites in the town. While the interest is on how wastes can effectively and efficiently be managed, this study is limited to the selection of solid waste dumping sites. This is because the whole process of waste management is too broad for a detailed coverage in this project. As such, the project will primarily focus on selection of dumping sites and not on other waste management stages. Additionally, the study only focuses on Homa-Bay town.

1.6 Limitations of the Study

Lack of up to date records at the municipal council of Homa-Bay and Community Based Organizations (CBOs) that are tasked with the duty of gathering waste in the town was a great challenge during the research time constraint was a great limitation to the whole research process. Since it was difficult to meet some of the town officials who could provide important data to waste management in Homa-Bay, the researchers had to visit their offices severally in vain, causing them to lose a lot of time. Some study participants were also not able to share their views candidly due to unknown fears. Unresponsive respondents were a great limitation to the quality of data that was gathered. The dawn of Covid-19 also made it impossible to fast-track the research's processes, since there was restriction on inter-region travels. With restriction on movement and gatherings of people, it was difficult to have one-on-one interviews with stakeholders who could inform this study's objectives. Similarly, financial constraints were also pronounced during the study. Lastly, the study's findings cannot be used for generalization purposes for other towns since the focus was only Homa-Bay.

1.7 Area of Study

Homa-Bay town lies at an altitude of approximately 4000 feet (at 1330 meters) above sea level. It covers an area of 17 square kilometres. Estates within Homa-Bay town include Makongeni, Shauri Yako, Milimani, and Site. Homa-Bay was once South Nyanza District's headquarters See Figures 1.1 and 1.2 for a pictorial illustration of the location of Homa-Bay town its surroundings there are a number of activities taking place in Homa-Bay town such as small scale business and fishing.

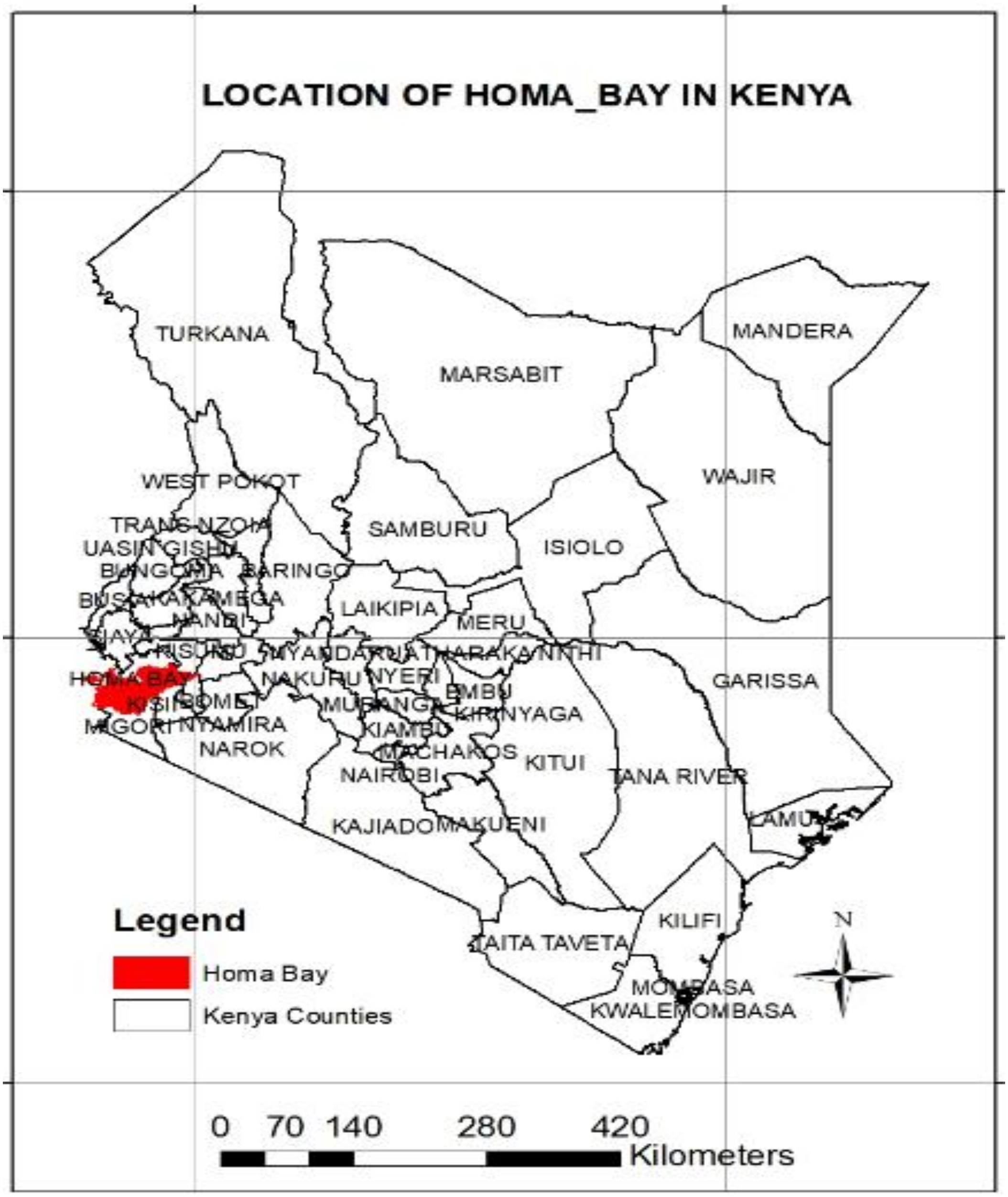


Figure 1.1 Location of Homa-Bay County in Kenya

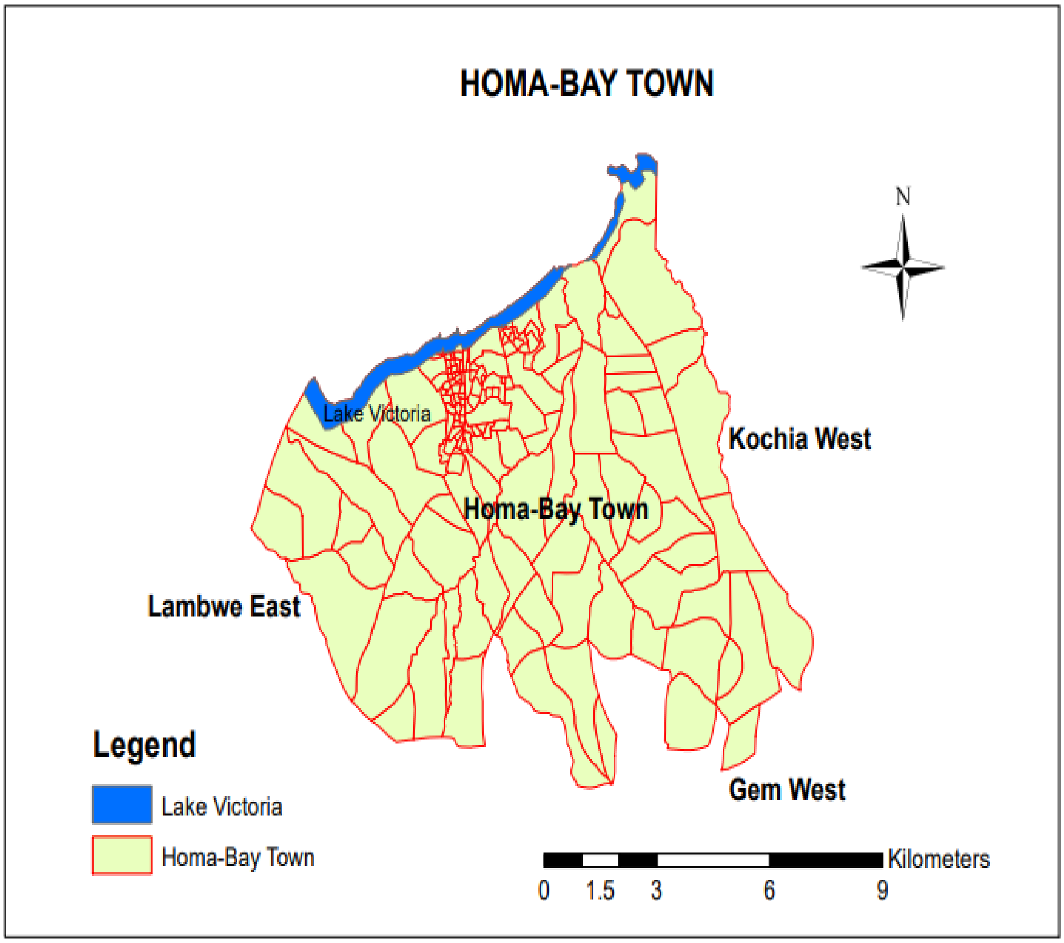


Figure 1.2 Map of Homa-Bay Town

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Article 42, the Constitution of Kenya, provides that; *every person has the right to a clean and healthy environment,* every person in Kenya should have an access to healthy environment and clean and safe water, it is government mandate to protect and enhance environment. The policies protecting the environment are put forward to guide and control methods of dumping solid waste by the citizens or an individual.

2.2 Waste Separation and Collection

Feinbaum and Gehr (1995), in their study to test the logistics of source separation of waste, found out that in 1990, California's Alameda County's waste management estimated that about 4.7% of the County's waste was food residues from commercial and industrial sources. If half of that material could be kept out of dumping site, the impact of diversion would be as great as from all the County's residential curb side programs. They contend that the first step in assessing the feasibility of diverting commercial and industrial organics was to survey existing composting programs taking soiled paper. The focus was on programs that collected materials from a variety of sources. Typically, solid waste generators in these programs separated organics at the source. In general, the programs reported positive experiences with separation, collection and processing of food and soiled paper. Solid waste generators found out that source separation added little. Contamination proved to be controlled, and collection logistics were improved. Composting, even with very low technological methods, yielded a product that could be sold in the market place.

Kaluli et al (2017), in a study, found that the application of composting to municipal refuse has been very limited. The main reason is the large quantity of biologically non-degradable materials (e.g. plastics, and at times, toxic heavy metals) in municipal refuse, which seriously restricts the use of the compost product (See Figures 2.1, 2.2 and 2.3). They noted that although mechanical removal of the objectionable materials can be tried in the composting operation, complete separation of the objectionable materials from the product might never be achieved mechanically. On the other hand, separation by hand is certainly uneconomically feasible. Therefore, source separation, which is a more economical approach, may be the only satisfactory answer for complete separation. However, with source separation, many difficult problems may arise. Solving this uncertainty will require a courageous decision on the part of the planning authorities.

Figure 2.1 Burning waste on open space

Figure 2.2 Waste components in Homa-Bay

Figure 2.3 Waste dumping on bushes

2.3 Waste Transportation and Disposal

Sonesson (2000) argues that less developed countries (LDCs) have often failed to solve the waste problem issues in their major cities and towns. A large number of people today are becoming aware of the need for carrying out waste management program in cities, towns and villages (Siddiqui, Everett & Vieux, 1996). According to Sener, Suzen and Doyuran (2006), following two steps waste management effort to be successful. First step is to determine the composition of raw waste. Second is to ascertain not only the amount of raw waste available, but also whether or not the continued access to the waste is assured and at a reasonable cost. A clear idea of the producer's economic and manpower resources so as to be able to determine their adequacy in terms of the need of the undertaking waste management is also needed. Sener, Suzen and Doyuran (2006) added that since the management of the solid waste is difficult there is no need to make it more difficult by using complex and high technology.

Kaluli, Mwangi and Sira (2017) outline various steps to go about the planning process for an integrated waste management plan in the small island developing in the Pacific region. The steps as outlined are:

1. For better planning and waste management it is essential to know and understand what one is dealing with for example the source of the solid waste, the quantity, nature of the material generated and how it enters the country.

2. Consulting widely, sensitization, and training people on the importance of solid waste management will help in gaining the support of people hence will help in achieving your goals. This is done at inertial stage in the development of the waste management plan, for instance, seeking the views of people and organizations currently involved in waste management. The input from these organizations and people will help in identifying concerns and establishing objectives which everyone supports in Homa-Bay town.
3. The plan should be clear, explaining what is trying to provide, achieve and target against which its success can be measured and assist in providing priorities for action. It is therefore important to set objectives of the waste management plan.
4. To achieve the objectives and overcome some of the obstacles actions should be identified.
5. Prioritization of the actions. The implementation of the actions or plan will depend on the priority, benefits arising from objective and the availability resources and money whereby most important will be implemented first. Ideally it would be important to implement the actions at once but this cannot be easy due to constraints of money and labour required in the implementation of plan.
6. The next step is the agreement plan. All stakeholders should come to consensus of the plan. In this stage both social and cultural issues will be addressed and the solutions proposed might not be only technical for instance requiring new equipment.
7. Implementation of the waste management plan.
8. Reviewing the progress to ensure it is working. This requires periodic reviewing and updating. This can be done by National Government or by the County Government of Homa-Bay.

2.4 Application of GIS Technology in Waste Management

GIS can efficiently analyse and display information according to user-defined specifications. Some of its advantages is easy presentation of GIS results to people. There are number of software packages including GIS that are used in waste management. The Arc-GIS applications are engineered for ease of use and powerful geographic display, query, and analysis.

With advancement in technology, particularly the information technology (IT), it is important that this technology is also applied in any planning, including planning for waste management. Siddiqui, Everett and Vieux (1996) note that the implication of information system for planning has often been studied and debated, but has less often been explored in a rigorous and coherent manner that integrates both conceptual and empirical aspects including the use and application of information system for urban and regional planning.

Information systems are the operational ‘keystone’ of the urban and regional planning process. Without an effective information system, such a process is impossible since information system will improve urban and regional planning performance (Haregu et al., 2017). An information system may be defined as the organization of data relevant to understand, planning for, and monitoring and evaluating urban and regional development (Okalebo, Opata & Mwasi, 2014). Information systems serve various needs, such as increasing planning capability and providing information on which to base the delineation and evaluation of alternatives courses of action (Haregu, Ziraba & Mberu, 2016). Specifically, Haregu et al. (2017) point out that information systems perform three essential functions:
(1) They identify the information required for planning, implementation and monitoring and evaluation;
(2) They utilize methods of collecting, processing, analysing and disseminating data that meet standards of accuracy, timeliness, and cost; and
(3) They provide organizational structure, which bring users and suppliers of information in constant dialogue.

In developing countries, very few large cities and sub-national regions have adopted modem information technology. In organizations which have started to use computer technology in information handling, it has so far not produced significant change in the setup of city or regional administration, in the structure of decision making, or in the actual work of the planning and decision making agencies (Okalebo, Opata & Mwasi, 2014). McLead (1997), in his study entitled ‘Using Geographical Information System (G1S) to evaluate Decentralized Management of Municipal Food Waste’ noted that the implementation of decentralized waste management is stymied by an inability to communicate the cost and benefit of these plans in the decision making arena.

Towns in developing countries are facing a lot of challenges due the old working methods and lack of commitment, improper work and work negligence. There is also improper solid waste management by the municipality (Sibanda et al., 2017). “Municipal bodies are unable to provide an efficient system and also able to reach the efficiency of 60%” (Haregu, Ziraba &

Mberu, 2016, p. 2879). Municipal bodies have tried their best in some areas to provide better services to people in their cities. They have used several methods and delegate a number of duties to enable them run this system perfectly. Some of the municipal authorities have come up with a better and refined system to help them solve the problem of selecting the most suitable dumping site putting into consideration of all the figures and facts of the situation. Some of the problems have been solved such as handling of different data forms like attributes and spatial using GIS technologies. Solid waste management have got arising challenges time to time which need to be dealt with but since the system might have some loop holes for example in terms of its approaches to maintenance of a clean environment therefore there is need of upgrading and refining of the GIS technologies to help in solving the current situation.

The introduction of new and simplest innovations, studying the existing systems and adoption of these new technologies by introducing innovative and cost effective solutions will helps to bring possible reforms and makes work easier to the authority (Sibanda et al., 2017, p. 393). Some of the datasets required while looking and a suitable dumping site for a city or town such as Homa-Bay will include; data related to the employees involved in the waste management programme, Water bodies such as Bo holes, rivers, streams. Map of the area of study which is Homa-Bay town a long side existing roads and routes used for waste transportation and land use is also needful.

The institutional support on solid waste management, provision planning and financial support have helped many municipalities to manage some of the waste and set up most suitable dumping sites, the institutions have also come up with action plan proposing two elements of the plan; the creation of an efficient management information system (MIS) and GIS. There should be incorporation of different options to help in the improvement of GIS system with less investments this is due to the financial constraints as stated by Okinyi, Omondi and Chelanga (2018) Formation and creation of GIS and MIS has been supported. According to Opiyo and Togogo (2017), it is not easy to find some of the data related to solid waste management and this might affect the results of the findings and decision making regarding planning and management during site selection.

Lack of supervision of county workers, proper spatial planning and logistics management have contributed to poor decision making while selecting most suitable dumping site (Okinyi, Omondi & Chelanga, 2018).

According to Ogra (2003), GIS and MIS can be used to design solid waste collection and dumping methods on a continuous basis. GIS technologies can be used to make different map layers which can be overlaid for final result and to come with the best dump site in Homa-Bay town. It is not easy to stop the planning process since waste generated from cities and service requirements also changes with time. There is need for use of new GIS technologies considering new trend of planning and urban population growth. It is therefore possible to predict future trend and carry out analysis using GIS for long term planning. GIS technology has been used in data capturing, mapping of the dumping site and analysis of the spatial data.

"Better analysis and decision making will highly depend on the number of layers in terms of information, more layers will give better result and decision making '' (Ogra, 2003, p. 13).

CHAPTER 3: MATERIALS AND METHODS

The methodologies used in the research included collection of data and needed information about the past and current waste management conditions in Homa-Bay town. Some of the criteria used in data collection involved the use of maps showing the spatial information of Homa-Bay town, buildings and location of waste bins. The County officials were also interviewed to provide information about waste collection methods and management patterns.

Analysis of present situation was to identify the problems and disavantages of waste management faced in the town. Literature review, discussion and critical analysis of solid waste management (SWM) models presented by other proffesionals on waste management methods using GIS. The last step done was to design GIS model for the implementation of SWM, and problem analysis using GIS. These methodologies are further explained here below.

3.1 Data Capture

I. Most of the spatial information of Homa-Bay town was obtained from satellite imagery. Satellite imagery was most important for this study because it allows for the measuring of elevations (Opiyo & Togogo, 2017). According to Alnakeeb (2007), satellite images help in showing what cannot be seen or measured. Similarly, satellite images are viewed as true. Ground trothing was carried out using the satellite imagery.

II. GPS Essentials device was used to collect some of the spatial data, such as area of interest, waste points and the road network. GPS Essentials provided the researchers with all the information they needed, like waste points, road networks, and other dumping site related information. The use of the GPS Essentials was also informed by the fact that GPS essentials support several common map services, like OpenStreetMap and Google Maps (Bagchi, 1994). The attribute information was also collected to provide more spatial information.

III. Phone call interviews and online sources were also used. Since restrictions as a result of Covid-19 were already beginning to be put to effect, interviews allowed for gathering of some data from some of the study's respondents. Additionally, some of the respondents were often occupied at their workplaces. As such, they would easily avoid techniques like questionnaire. This left the researchers with the option of booking times for structured interviews with them during their leisure times. The interviews were kept brief for this cohort of respondents and would sometimes be conducted via phone calls. The researcher also resorted to online sources to provide insight about the topic of study. Online journals and books were skimmed through and relevant information gathered. This helped minimize the effects of the movement restrictions that came with the dawn of Covid-19.

3.2 Data Types and Data Sources

The secondary data was obtained from the County Government of Homa-Bay under the Department of Lands and Urban Planning and the data included the topographic map and the administrative boundary maps which were obtained in the hard copy form and converted to soft copy and used in the GIS.

3.3 Data Collection

GPS essential was used to collect data including waste points, routes and buildings in the study area. Homa-Bay base map was also used and this was provided by the County Government to help identify the boundary of research area. For purposes of giving the digitized features attributes such as name, size, purpose and any other important information, the attribute table was prepared by the researcher. The enumeration areas' theme had a comprehensive attribute table that gave the number of people and number of households found within each enumeration area/unit. This is important as it will help in the determination of the total amount of waste produced in each enumeration area and hence the overall amount of waste in the study area.

The use of pre-existing information published on dump site selection criteria was also used to identify most suitable area for dumping site in Homa-Bay, use of rules and existing environmental laws were put into consideration before selecting the suitable land site for waste dumping, as well as the prevailing local conditions. Model builder and spatial analysis was done using ArcGIS 10.5 to identify appropriate distance from water bodies and streams, protected areas, distance from transportation routes. Model builder refers to a visual programming language used for building geoprocessing workflows (McLead, 1997). Geoprocessing models functioned in this study to automate and document Homa-Bay town’s spatial analysis as well as data management processes, as supported by Hengl (2003). In ArcGIS Pro, model builder allowed the researcher to:

i. Build a model by connecting and adding tools and data about dumping sites in Homa-Bay town.
ii. Iteratively process raster, file, feature class, or tables in their workspaces.
iii. Visualize their workflow sequence as an easy to comprehend diagram.

iv. Run a model

v. Make their model into a geoprocessing tool that they could share in other models (Kumar, 2011).

The slope was derived at using Digital Elevation Model (DEM 30m resolution). This method was divided into factor and constraints criteria to determine the most suitable area and least suitable dump site selection in Homa-Bay town. As pointed out by Lin (1999), DEMs , which are raster filers with elevation information for each raster cell, were used in this study since they are the most popular tools for manipulation, calculation, and further analysis of an area, and more particularly analyses based upon elevation.

Further, GIS analysis tools and buffering using international and UNEP standards was used to identify unsuitable and most suitable area for dump site. All the constraint criterion maps were overlaid to produce the final factor map. Buffering refers to a GIS procedure by which zones of particular width or radius are defined around chosen raster grid cells or vector features (Minale, 2011). The result was further classified into classes of most suitable, suitable, unsuitable and moderately suitable for being used as site locations. Reclassification and weighting processes was carried out, each map layer was weighted putting into consideration of minimum and maximum distance to features (environmental judgment) and externally weighted using analytical hierarchy process (AHP) based on its relative importance to the waste disposal problem.

Analytical Hierarchy Process (AHP) is a method of organizing and analysing intricate decisions using Psychology and Mathematics. (Cancela, Fico & Arredondo, 2015). AHP is regarded as the most useful tool when finding decisions to intricate challenges that have high stakes (Pecchia et al., 2013). It outsmarts other decision-making tools since it quantifies options and criteria that initially were difficult to gauge with hard numbers (Munala & Moirongo, 2011). As opposed to prescribing a "correct" decision, AHP assists decision makers to find a decision that best suits their understanding and values of the problem (Pecchia et al., 2013). AHP technique looks at a problem in three parts:

(1) The issue that should be resolved.

(2) Alternate solutions available to solve the problem and

(3) The criteria employed to assess the alternative solutions (Cancela, Fico & Arredondo, 2015). The decision tree was developed for the dump site selection as shown in Figure 3.1.

3.4 Data Analysis

ArcGIS 10.5 and QGIS were used to carry out the analysis as obtained from the field. The analysis gave the general trend in the waste distribution in terms of type and the respective quantities. The use of ArcGIS 10.5 for this study was informed by the fact that the software efficiently and effectively delivers scalable, secure, data-propelled mapping about an area, as argued by Ogra (2003). The software is comparatively simpler to install and administer, and furnishes researchers with portal-to-portal collaboration, thus, enhances data sharing and makes it comparatively easy for researchers to access authoritative content (Feinbaum & Gehr, 1995).

The ArcGIS's portal collaboration capability enabled configuration of data about dumping sites in Homa-Bay and allowed updating of accounts of Homa-Bay County (Sonesson, 2000). Other benefits that the researcher enjoyed as a result of using ArcGIS 10.5 included: viewing contents shared with portal, geo-analytics feature analysis, raster analysis, and creation with capabilities of updating the information input. Thus, the ArcGIS 10.5 substantially enhanced problem-solving and analytical capabilities of the researcher.

Similarly, QGIS was used for a number of reasons. First, QGIS offered options for special processing free of charge right from the start. Second, QGIS is faster compared to other software, using only a small amount of time to execute a task (Cancela, Fico & Arredondo, 2015). Third, the software has the capability of reaching and the ability of bringing valid tools to many users in all computers. Fourth, QGIS is compatible with Linux, Android, Windows, and Mac OS. This opened a variety of options with regard to the type of device that could be used at any time during the analysis of data that was collected from the field. QGIS allows for quick study as well as faster update of data. Lastly, the software is free to acquire and less costly to maintain relative to other software.

Additionally, graphic representation and tabulation of the results was also used to determine recycling and composting options necessary for the area.

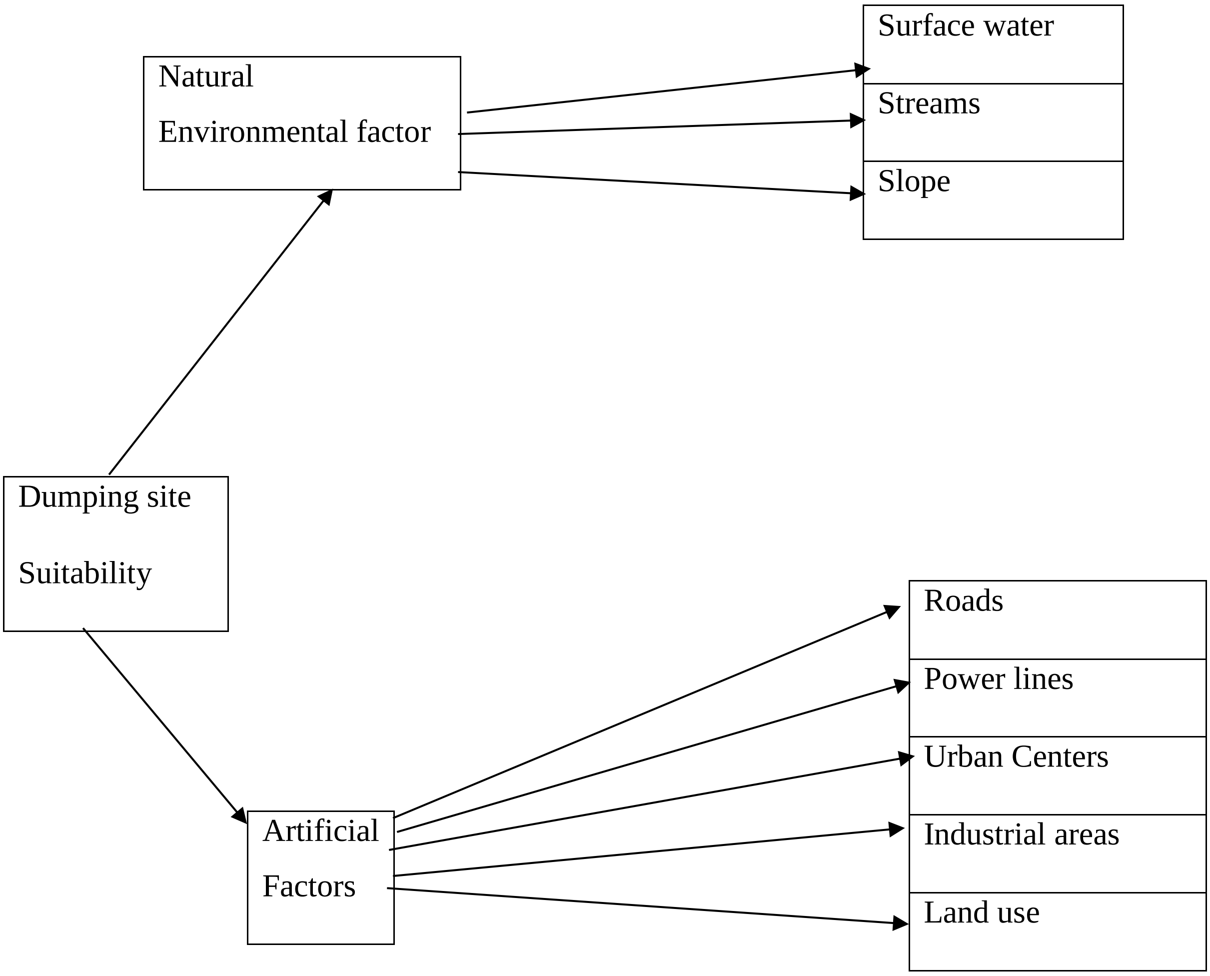


Figure 3.1 The decision tree developed for the dumping site selection

Table 3.2 Dataset standardization for buffer analysis.

Criteria	**Unsuitable**	**Suitable**	**Most Suitable**
Waterbodies	<300 m	300–1000 m	>1000 m
Urban centres	<500 m, >10000 m	3000–10000 m	500–3000 m
Slope	<2%, >15%	10%–15%	2%–10%
Railway line	<1000 m	1000–2000 m	>2000 m
Feeder roads	<100 m	>1000 m	100–1000 m
Highways	<500 m, > 20000 m	2000–20000 m	500–2000 m
Geology	Voltaian and others	Granite	Togo Rocks

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter gives more details on the results as obtained from the field during the field work. It involves the analysis of the results using GIS software, the research findings and discussion into detail.

4.2 Waste Generation in Homa-Bay County

This research found out that there are various sources of wastes in Homa-Bay town as was established by the 2014 Homa Bay Integrated Solid Waste Management Baseline survey and the Lake Victoria region water and sanitation initiative (UN- HABITAT, n.d.). The waste generators found out can be categorised into household wastes, institutional wastes and industrial wastes according to (UN- HABITAT 2016).

4.2.1 Household Wastes

According to the research, Homa-Bay town, which is a low income area with poor housing condition residents, there are no appropriate dumping site of household wastes. There are very few waste bins or none at some area and the residents of the town dump their wastes behind the houses or behind building blocks for the collection by the County Government as shown in Figure 4.1. According to the Homa-Bay town Integrated Solid Waste Management Baseline Survey 2014, site and services estates where majority of the residents are low and medium-income produces 5.12 kgs of waste per household per week as shown in (UN-HABITAT, 2016). See Table 4.1.

Figure 4.1 Household wastes behind the building

Table 4.1 Household waste generation rates

SAMPLING AREA	WASTE GENERATION PER HOUSEHOLD PER WEEK (KGS)	WASTE GENERATION PER PERSON PER DAY
Makongeni Estate (Low-income)	5.12	0.12
Shauriyako Estate (Low-incime)	4.03	0.10
Milimani Estate (High-Income)	6.69	0.16
Average	5.31	0.13

Source: (UN Habitat, 2016)

4.2.2 Institution Waste

There are a number of institutions within Homa-Bay town such as learning institutions, hospitals, financial institutions and hotels, restaurants and food kiosks. Learning institutions are many with a total of 44 public primary schools and 13 private primary schools. Some of these include Homa-Bay Youth Polytechnic, St. Patrick's Makongeni Primary, Bridge International Academy, Makongeni Primary School, Makongeni Hospital, Homa-Bay Hospital and Homa-Bay High school.

It was noted that in these institutions, there were dug pits for disposing wastes, which waste after sometimes were burned. Some hospitals, had incinerators. However, pieces of plastic and other non-biodegradable litter were floating all over the facilities' compounds.

4.3 Waste Management Methods

Solid waste management was seen as a problem in the region during the research with, most of the waste being dumped in open places (see Figure 4.2) and burned during the day, causing air pollution.

Figure 4.2 Makongeni hospital waste

4.4 GIS Map for Homa-Bay Solid Waste Collection/Dump Sites

Some of the problems faced by the people are inadequate bins or no waste bins in some areas at all. There are few dumping sites, for instance, in Makongeni estate, there is only one main dumping site which is also located far away from the residents. Thus, Makongeni residents often dump wastes in the free lands or behind the buildings. Wastes from households are then collected by the County Government and private individuals to main dumping site in Homa-Bay town where they are later picked by the county tractors and tracks to Kaburini in Kaburini estate for recycling and disposal. Most of the waste points within the residential area are less than 10 metres from the buildings (See Figure 4.3).

Figure 4.3 Waste Dumping and Collection point Located in Makongeni Estate

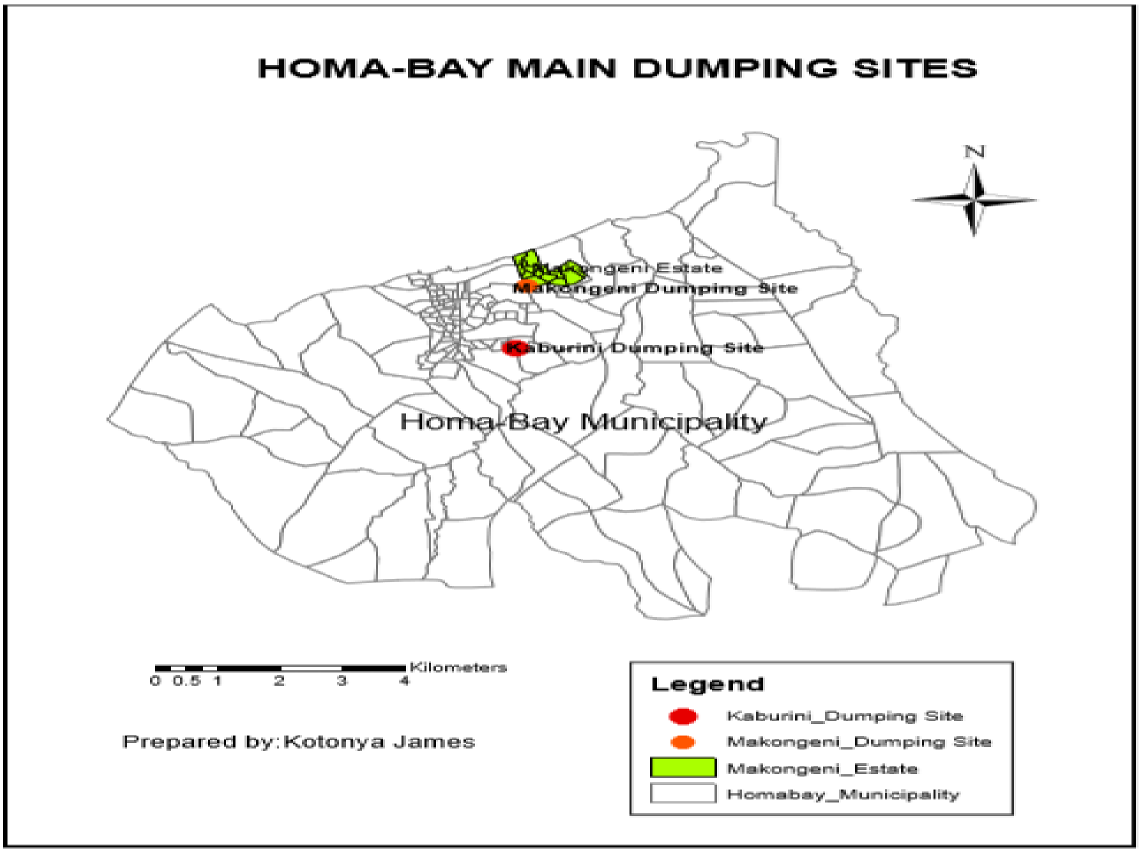


Figure 4.4 Map showing main dumping sites in Homa-Bay Town

4.5. Solid Waste Collection Efficiency and Ground Dumping

According to the research, waste dumping has not been taken proper care of by the local people and even the County Government. Dumping wastes everywhere is seen as a normal activity and there is no action taken against waste dumping more so on the free and open land. For instance, there were only three waste bins identified during the research study among the 32 sampled waste points in Homa-Bay town and one was found within the Makongeni Hospital while the rest were private dumping bins. The Homa-Bay County Government has not provided any waste bins to the residents of the town a part from one main dumping site located some metres far away from the residents (See Figure 4.5).

Figure 4.5 Main dumping site in Homa-Bay town located in Kaburini estate

4.6. Proximity Analysis/Route Analysis

Most of the access roads are in bad condition in Homa-Bay town as shown in Figure 4.6. The bad state of the town's roads makes it difficult during waste transportation from households to the dumping sites. During rainy seasons, tracks find it difficult to move to and from dumping sites, leading to huge amount of waste and bad smell in the area.

After identifying waste dumping sites, including the main dumping site in Makongeni and Kaburini, the study identified the reallocation of the waste collection bins and suggested the optimisation of waste collection vehicle to enable routing analysis using ArcGIS for network analyst modelling. The study came up with the optimal path possible using Dijkstra's (1959) algorithm which is used to solve optimal route selection on indirect routes.

Figure 4.6 Access roads in Homa-Bay Town

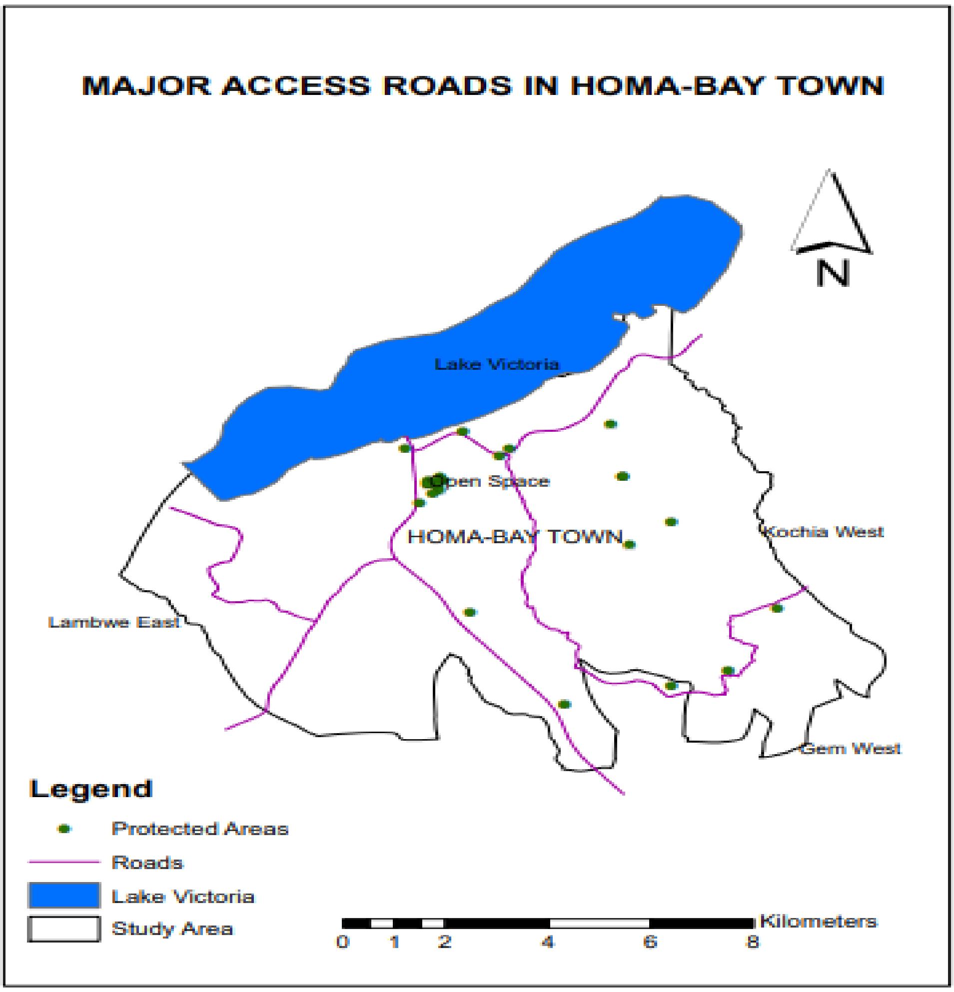


Figure 4.7 Map showing access roads in Homa-Bay Town

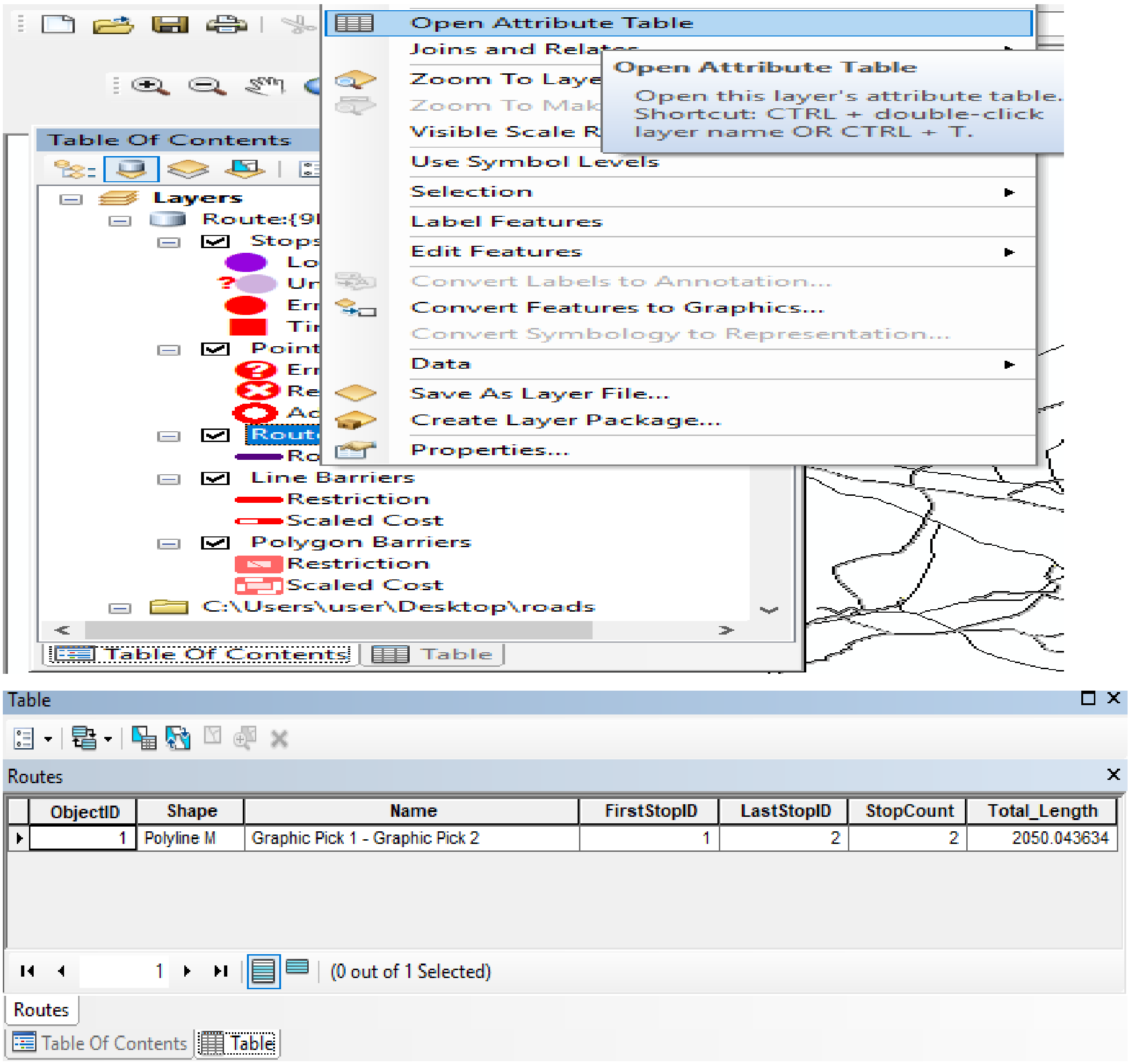


Figure 4.8 Attribute table of major routes from collection to dumping sites

4.7. Dump site Selection

The current dumping site in Homa-Bay town is located in Kaburini, Kaburini Estate. The analysis for the suitable dump site selection was done based on landuse/land cover, distance from water bodies, slope, and distance from roads which led to decision tree for the suitable dump site selection for the Homa-Bay Town.

4.7.1. Distance from Roads

The accessibility for the dump site is a very important issue that should be considered before coming up with the most suitable site for the dumping area. The dumping site location must be easily accessible from both existing roads and routes to avoid expensive cost of constructing connection routes (Lin, 1999). This will also help in the reduction of trasportation costs.

According to Munala and Moirongo (2011), dump site should be located within a 1 km buffer from the roads and other transportation. In the case of Homa-Bay town and for the study, a distance of greater than 1000m from roads is considered best for locating the dump site. This is as shown in Figure 4.9.

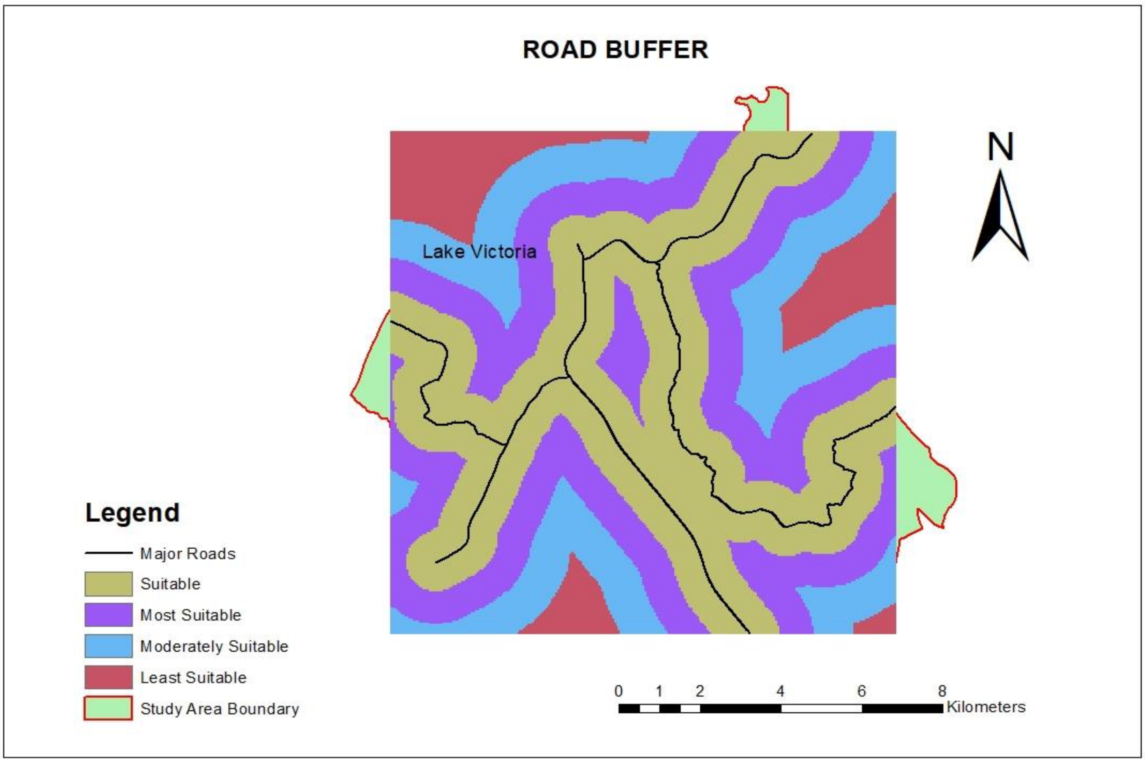


Figure 4.9 Buffer analysis of main roads in Homa-Bay town

4.7.2. Distance from protected areas

A dumping site must not be located close to open space, parks or gazette areas for special protection. Figure 4.10 shows buffering analysis carried out according to the international standard guideline. Multiple Rings of different distance was prepared to identify most preferable site for a dumping site. Multiple Ring Buffers of 0-750, 750-1000, 1000-1500, 1500-2500 m was used to determine areas which are suitable for the dump site. Land away from the protected areas were most preferred as opposed to those nearer these areas. Suitable areas were found to be in distance greater than 2500m away from protected areas.

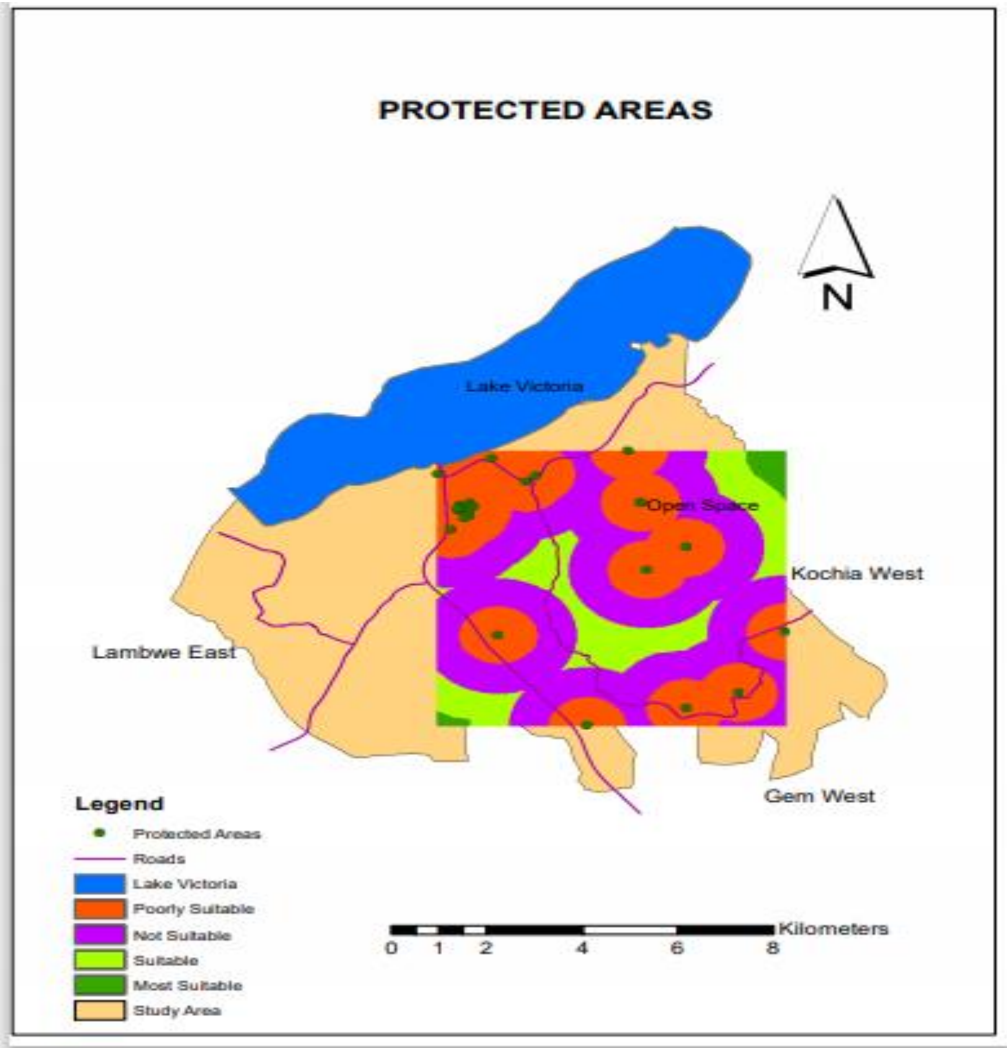


Figure 4.10 Land use/land cover buffer

4.7.3. Land use/land cover

This was mapped using satellite image LANDSAT 8. Some of the land cover found included water bodies, bare land, forest, settlements, and infrastructures such as buildings and road. Dumping site should not be located close to some of the abovementioned land uses, like settlements and water features. Different types of land uses are found in the study area (see Table 4.2). This were further grouped based on the percentage coverage and ranked according to their suitability for a dumping site as most suitable, moderate suitable, least suitable and unsuitable for a dump site by assigning values 0, 5 and 10 respectively. The land use vector map was then converted to a raster map.

Table 4.2 Land use types and their rankings

Ranking	Land use types
0	Streams
0	Residential Areas
0	Industrial Areas
0	Agricultural Areas
0	Surface Water
5	Crops
10	Unoccupied land

Source: (UN-HABITAT, 2016).

4.7.4. Water features/ distance from the water bodies

Some of the water features in Homa-Bay County include Lake Victoria, rivers, streams, dams, and ponds. Dump site location should not be near any water body in order to reduce vulnerability to ground and surface water pollution from contamination. Within Homa-Bay town, the main water body is Lake Victoria and private bore holes. 300 m both side buffering was determined as the most suitable regarding to the international standardization and according to Alnakeeb (2007). There is no stream or river within the town centre. Figure 4.10 shows buffer ring around the Lake Victoria in Homa-Bay town within the following distances: 0-300, 300-500, 500-1000, >1000m.

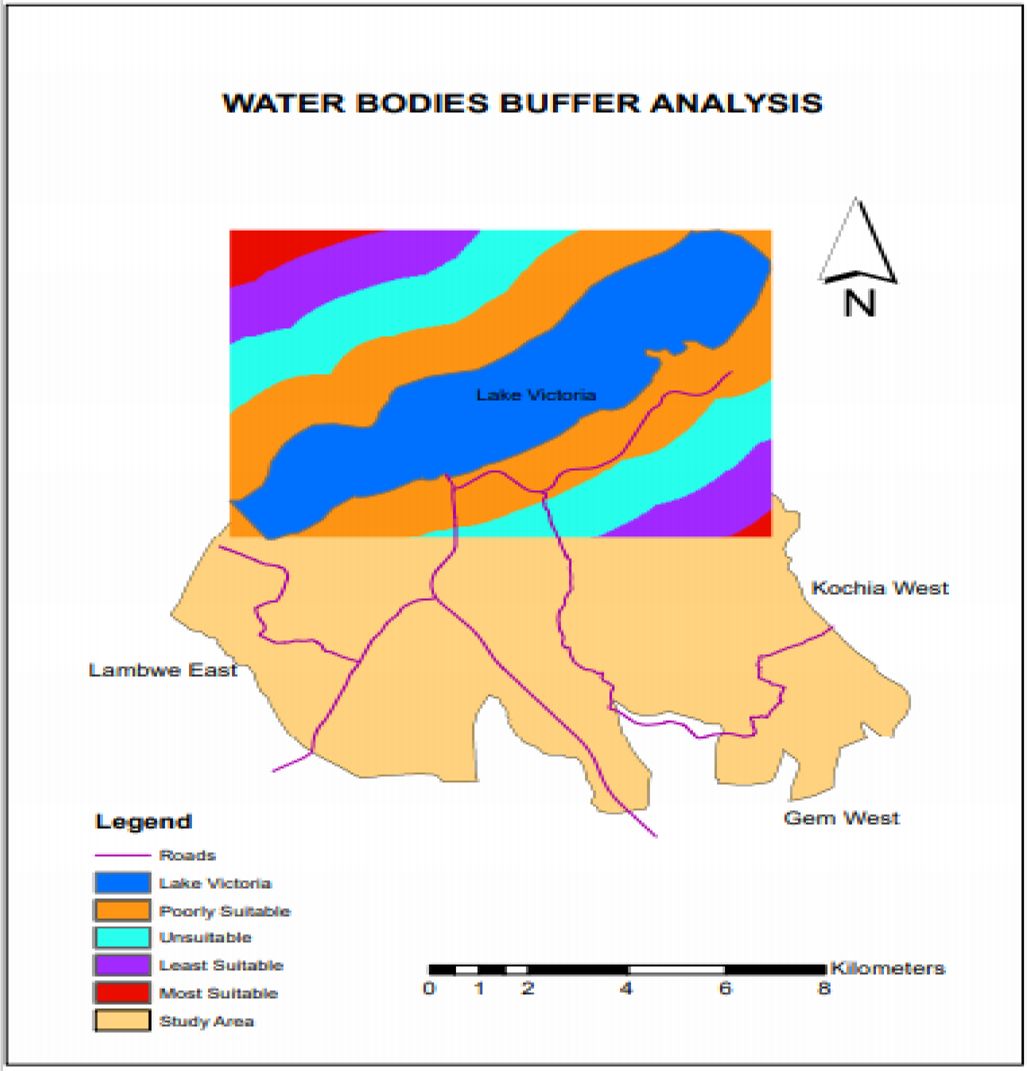


Figure 4.10 Buffer analysis for water bodies in Homa-Bay town

4.7.5 Land use

In Homa-Bay town, there are different land uses such as urban/built land, bare land, and forest and agricultural land. This were ranked and grouped putting into consideration their suitability for dump site as most suitable, moderately suitable, suitable, least suitable and unsuitable area for a dump site by assigning values 0 to 10. The land use vector map was then converted to a raster map (See Figure 4.11).

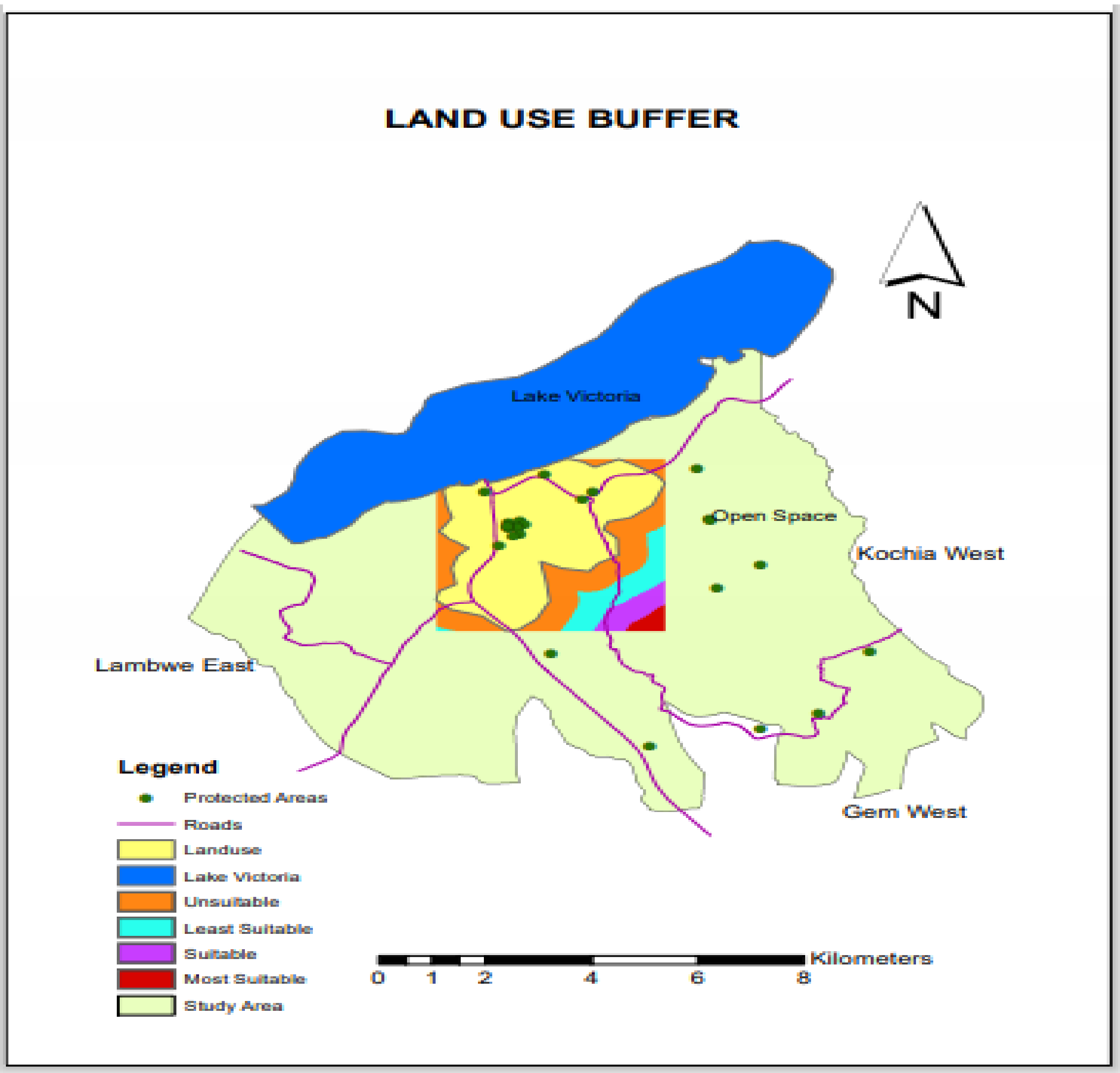


Figure 4.11 Map showing different land use classes buffer

4.7.5 Slope analysis

Digital Elevation Model (DEM), also referred to as the Digital Terrain Analysis, is a digital representation of earth's topography in a continuous way according to Hengl (2003). A slope map was generated from DEM (See Figures 4.12, 4.13 and 4.14). Land with slopes greater than 15% should be considered unsuitable for waste disposal sites as opined by Bagchi (1994).

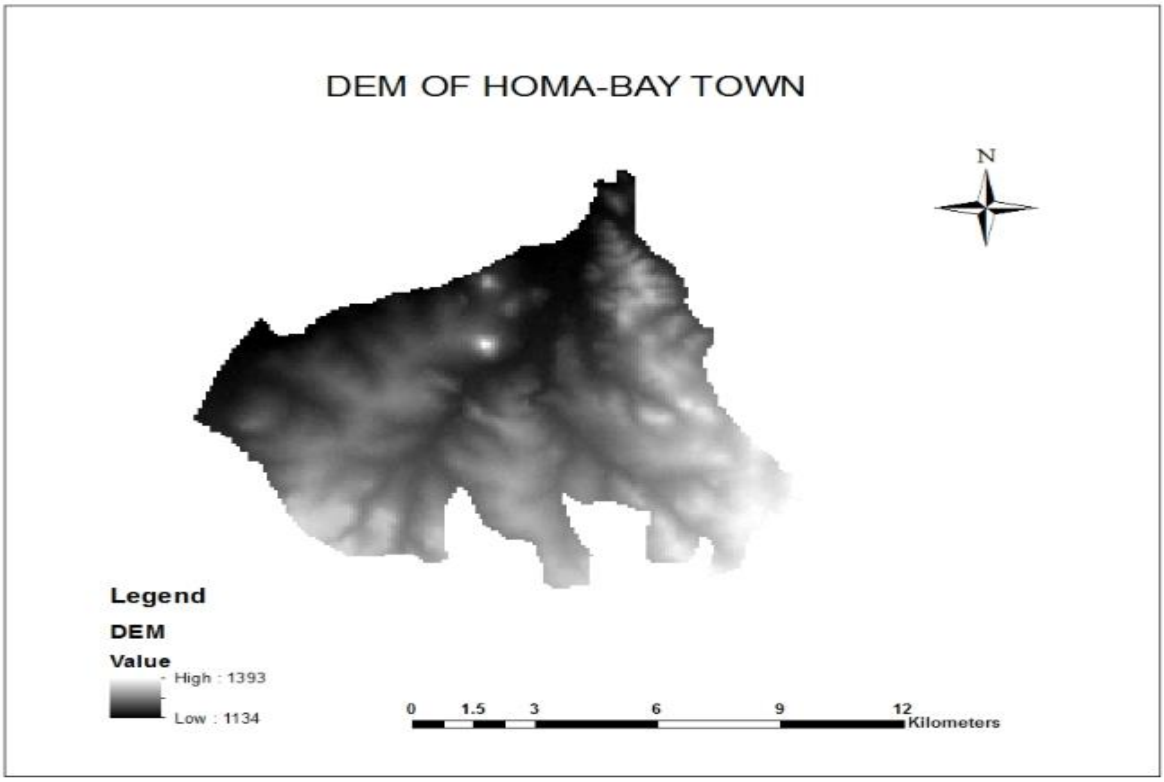


Figure 4.12 DEM of Homa-Bay

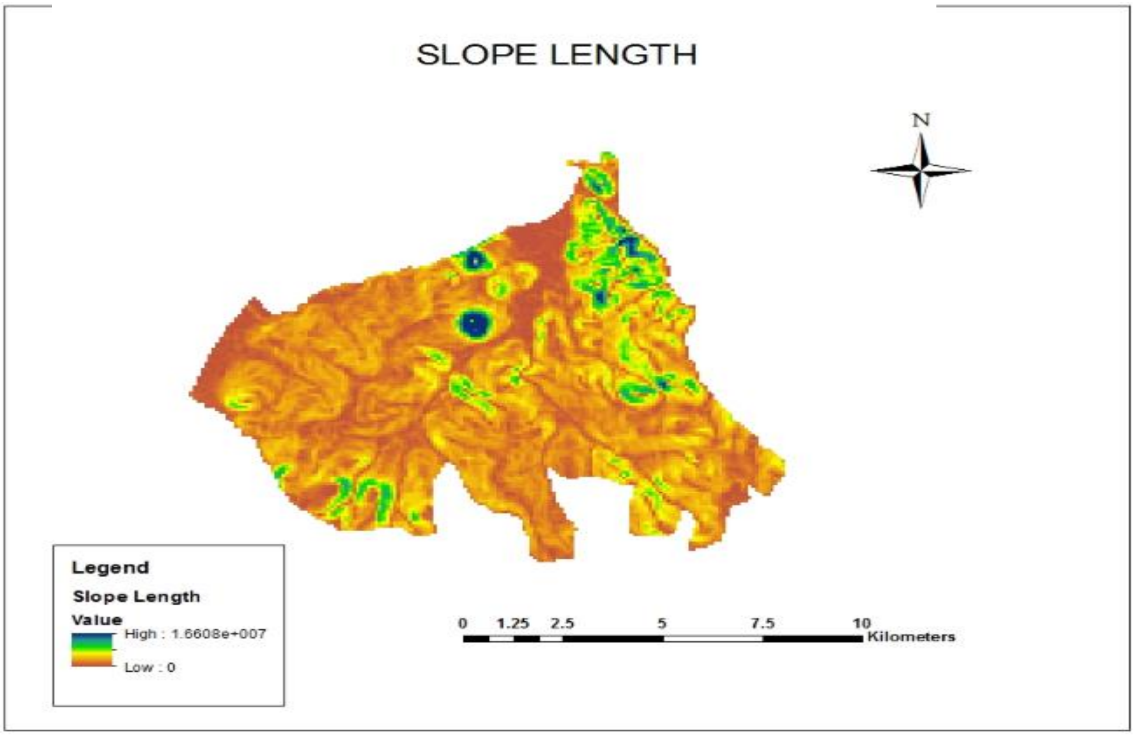


Figure 4.13 Slope Length

4.8 Data Analysis of the Buffer Areas and Results

Table 4.3 shows criteria analysis used for each layer by applying overlay analysis after buffer analysis was carried out. Different map layers were created for each layer with buffer analysis The criteria was used determined for each layer by considering related legal legislations or properties of the buffer area analysis.

In this study, map layers were prepared including land use map, distance from road network, slope, and water bodies. The data sets were collected from different sources and digitized using Arc GIS 10.5. The ranking of the data sets was based on past literature. After the analysis weighted was done considering the percentage coverage of each dataset. Datasets were ranked from point 0 to 10 whereby 0 value indicates the most suitable dumping site and value 10 represents the least suitable land area for dump site as shown in Table 4.3. After the analysis of different datasets suitability map was acquired for the study area and the most suitable areas determined for Homa-Bay town.

Table 4.3 Criteria, variables and the ranking in the site selection process

Criteria	Variable used	Ranking
Settlements	Distance to industrial area (m) 0-250, >250 0-5000 Distance to urban centres (m) 5000 - 10,000 10,000 - 15,000 >15,000	0 1 0 10 5 1
Roads	Distance to Roads (m) 0 - 500 500 – 1000 >2000	0 3 1
Surface Water	Distance (m) 0 - 250 >250	0 1
Powerlines	Distance (m) 0 – 30 >30	0 1
Streams	Distance (m) 0 - 300 >300	0 1

4.9 Slope Analysis

The slope analysis was done using Global Mapper-V13.00. Three different maps were used to determine the most suitable site for dump site. The approach developed by Moore and Burch (1985) was used to compute LS factor.

$$LS= (\text{Slope Length}/22.13)^{0.4} * (0.01745\ \text{Sin}^{\theta}/0.0896)^{1.4} * 1.4,$$

Where

Slope Length is Flow accumulation *Cell resolution (DEM) and $^{\theta}$ is “Slope in Degree

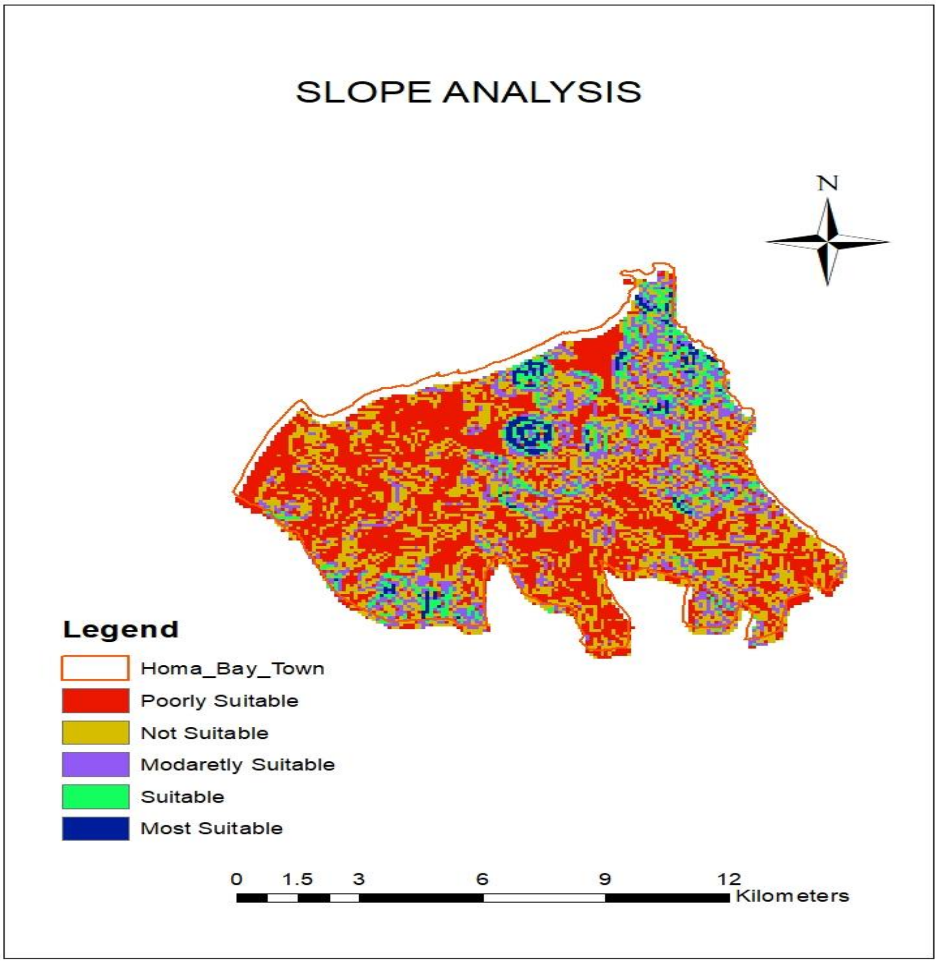


Figure 4.16 Slope Analysis of Homa-Bay Town

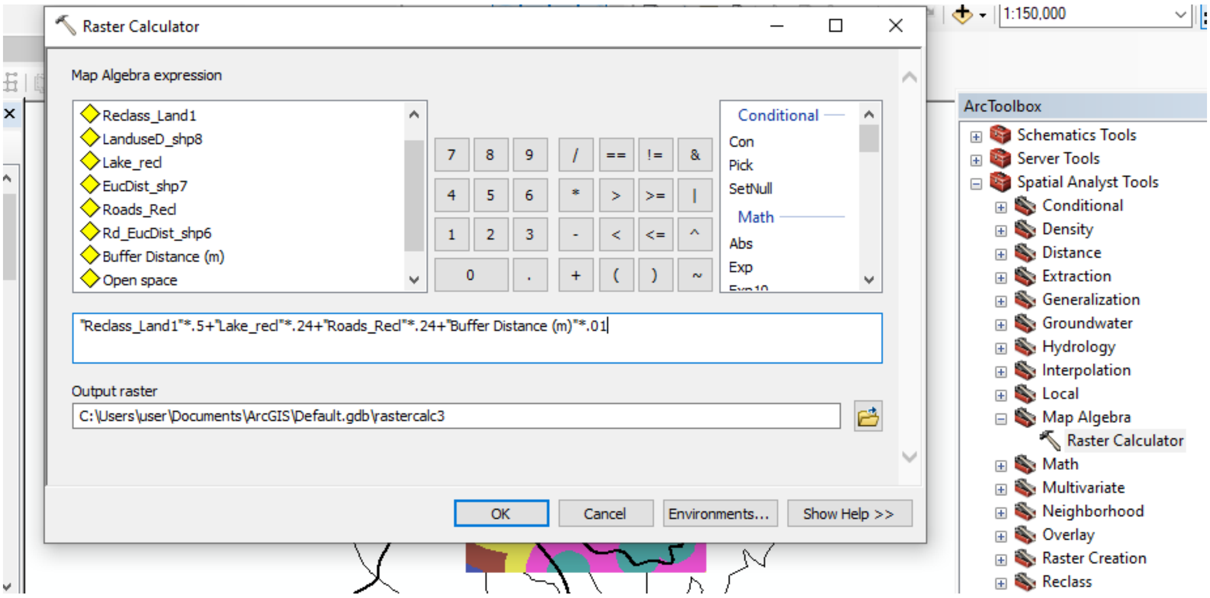
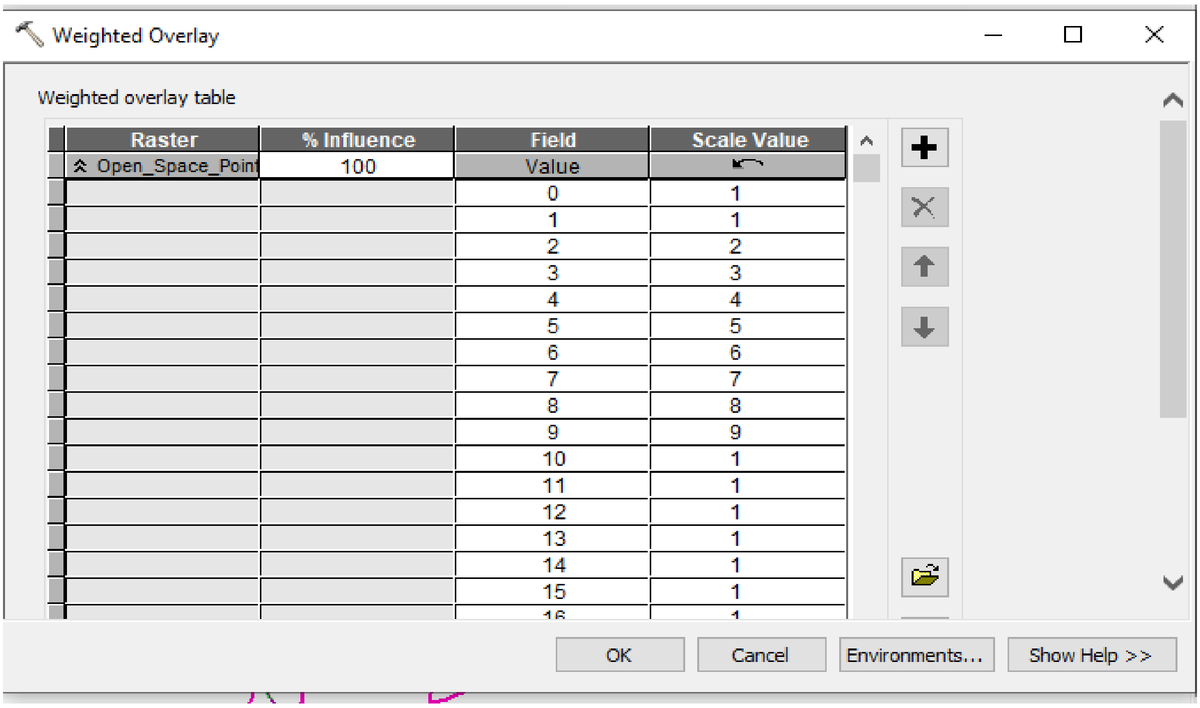


Figure 4.17 Raster Calculator showing method used for analysis

Table 4.4 Weighted overlay



Raster	% Influence	Field	Scale Value
Open_Space_Point	100	Value	
		0	1
		1	1
		2	2
		3	3
		4	4
		5	5
		6	6
		7	7
		8	8
		9	9
		10	1
		11	1
		12	1
		13	1
		14	1
		15	1
		16	1

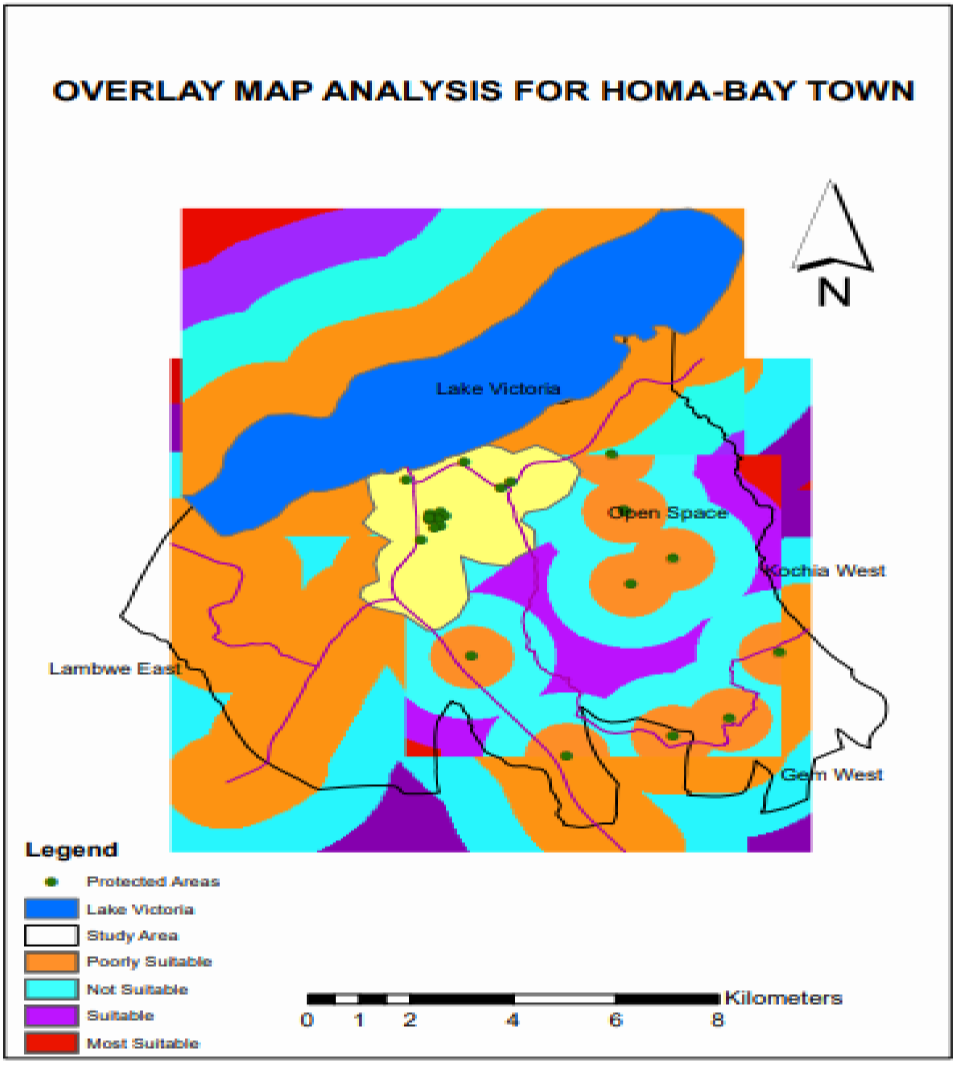


Figure 4.18 Overlay analysis of most suitable dumping site in Homa-Bay town.

The current solid waste dumping site in Homa-Bay town is centrally located in Kburini estate within the residential areas less than 100 meter distance. According to Dataset standardization for buffer analysis most suitable dumping site should be 500-3000 m away from the urban centre. In this research carried out in Homa-Bay town the new dumping site is located in areas >1000 m from residents thus making it most suitable.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Different types and quantities of waste have been identified in Homa-Bay town. A spatial analysis has been established to help in the waste collection. Most suitable solid waste dumping site has also been identified to facilitate waste transportation to the dumping sites or for recycling points for reuse. It would be necessary for the County Government, therefore, to implement the programme. It was also found that most of the wastes could be dealt with at the collection area in appropriate manner rather than burning them and causing air pollution to the area.

5.2. Recommendations

From the study, it is recommended that:

1. There is need to formulate policies by Homa-Bay County Government regarding waste management, starting from waste generation, waste collection, waste transportation to waste disposal. During the study, many issues such as waste collection method, dumping site area, and resources needed were identified concerning solid waste and need to be put into consideration while formulating the policies.
2. GIS for solid waste collection needs to be institutionalized. There is need to introduce the GIS technologies to the town officials and to the contractors. This will make it easy for the updating of information and management for both spatial and non-spatial data. This will further help in decision making and planning.
3. Research on alternative waste collection, transportation, recycling methods should be carried out with the help of national government in collaboration with County Government and other stake holders.
4. Allocation of unique numbers to all the waste bins so that they can easily and quickly be located in case of any complaint registered or planning and maintenance is necessary.
5. The current dumping site (Kaburini) is located within the residential area. This is harmful to the people living around. It is, therefore, recommended that the dump site relocated to some appropriate places, considering residential areas, water features, and slope and road network as shown in the study.
6. The findings of this study can as well be implemented in other counties and towns in Kenya.

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