University of Nairobi

School of Engineering

USE OF GIS IN SOLID WASTE MANAGEMENT IN KENOL MUNICIPALITY

BY

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F56/11053/2018

A Project report submitted in partial fulfillment of the requirements for the Degree of Master of Science in Geographic Information Systems, in the Department of Geospatial and Space Technology of the University of Nairobi

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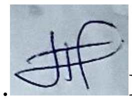
JOSPHAT NGONJO NDUATI: SIGNATURE……..…..…  DATE**24th August 2020**

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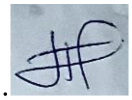

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The project has been submitted for examination with my approval as university supervisor.

Prof. G. C. Mulaku **24th August 2020**

………………………… ………………………………………. …………………..

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DEDICATION

This project is dedicated to my family: My loving Wife Catherine, my children Terry and my twins: Travis and Tracey.

ACKNOWLEDGEMENTS

Without God, it’s all in vain (Psalm 127). I first and foremost thank my maker and enabler, the Almighty God; It has all been possible because of His sufficient grace.

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ABSTRACT

Solid Waste Management is considered as one of the most hazardous environmental problems faced by municipal authorities in developing countries. Various reasons contribute to increase in waste generation rates including rapid urbanization, increasing industrial, commercial and economic development, socio-economic development, and degree of industrialization among others. Kenol Municipality is among the urban areas in Murang'a County that are in dire need of solid waste management facilities. The challenges in solid waste management in the municipality range from reducing generation of waste, separation, change of habits, collection, transport, treatment, reuse and disposal of the waste. The overall objective of this study was to demonstrate how GIS can be used in solid waste management in the Municipality. Specifically, it sought to identify suitable disposal and collection centre sites and to design appropriate routes for transporting waste from the collection centres to the disposal site. To achieve these objectives, GIS and Multi Criteria Decision Making (MCDM) were applied. After carrying out analysis, 36 disposal sites were obtained: 32 sites which were Moderately Suitable occupied a total area of 1499.6Ha and four sites in the Suitable category occupied a total of 107.2Ha. The four suitable disposal sites identified, were further analyzed and Site A was found to be the optimal site due to its size (44.9 Ha) and ease of accessibility. Which means that it can significantly provide some space for future expansion and a buffer for tree planting to serve as barrier for noise, dust and odor screening. Also, a total of 46 collection centres were identified all in the Suitable category and clustered in populated areas which in reality means that these are the waste generation sites. In addition, the appropriate routes were also designed which included optimal and alternative. The optimal route was found to be the one taking the shortest time to complete a trip while an alternative route had the shortest distance but took longest time to complete a trip. It was concluded that the optimization of the routes for collection and transportation of solid waste is a crucial factor of an environmentally friendly and cost effective solid waste management system. The routes and suitable sites obtained through GIS and spatial modeling techniques optimize waste collection and transportation and may provide significant economic and environmental savings through the reduction of travel time, distance, fuel consumption and pollutants emissions.The project recommended that to be able to achieve sustainable solid waste management in fast developing urban areas, GIS and MCDA methods should be applied.

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ACRONYMS

AHP	-	Analytical Hierarchical Process
ASL	-	Above Sea Level
CI	-	Consistency Index
CIDP	-	County Integrated Development Plan
CR	-	Consistency Ratio
EEE	-	Electrical and Electronic Equipment
ESIA	-	Environmental and Social Impact Assessment
GIS	-	Geographic Information System
ICT	-	Information and Communications Technology
IEBC	-	Independent Elections and Boundaries commission
KARLO	-	Kenya Agricultural Research and Livestock Organization
KFS	-	Kenya Forest Service
KNBS	-	Kenya National Bureau of Statistics
KRB	-	Kenya Roads Board
MCDA	-	Multi-Criteria Decision Analysis
NAMATA	-	Nairobi Metropolitan Authority
NEMA	-	National Environment Management Authority
POPs	-	Persistent Organic Pollutants
QGIS	-	Quantum GIS
SoK	-	Survey of Kenya
SWM	-	Solid Waste Management
UNEP	-	United Nations Environment Programme
USEPA	-	United States Environmental Protection Agency
WC&T	-	Waste Collection and Transport
WRMA	-	Water Resources Management Authority

CHAPTER 1: INTRODUCTION

1.1 Background

Solid waste is defined as the useless, unwanted and discarded material resulting from day-to-day activities in the community. Solid waste management on the other hand is a discipline associated with the control of generation, storage, collection, transfer, processing and disposal of solid waste which helps to enhance aesthetics as well as safeguard environmental and human health. In addition, production processes that are Inefficient, unsustainable production and consumption patterns, low durability of goods lead to excess waste generation. Despite having been efforts to encourage recycling, reusing, and recovering waste, amounts of solid waste generated appears to remain high and on the increase. There are other types of wastes that require special attention which includes: medical wastes from various health facilities and also electronic waste. To be able achieve sustainable economic development, protecting the environment should not be an alternative but a pre-condition. The rates of waste generated is directly related to the degree of industrialization, rate of socioeconomic development and climate change; This means that the greater the economic growth and higher the rate of industrialization, the greater amounts of solid waste generated and the higher the effects of climate change (Shoba and Rasappan, 2013).

Municipal or local authorities charged with the responsibility of providing solid waste management services have found it difficult to play this role. The difficulty has been aggravated by lack of effective legislation, inadequate funds and services, and inability of municipal authorities to provide the services cost-efficiently (Kumar *et al*., 2013). The consequence is that a growing percentage of urban dwellers particularly the urban poor in developing countries, will not be able to access solid waste management services and therefore will subsequently suffer from environmental and health problems related pollution (UNEP, 2005).

In Kenya, the public sector is unable to deliver services effectively, regulation of the private sector is limited and illegal dumping of domestic and industrial waste is a common practice. Solid waste dumping and management in the surroundings remains a main challenge for Murang’a County in which the area of study is located. Kenol Municipality is among the urban areas in Murang'a County that are in dire need of facilities for solid waste management. The other areas include Makuyu, Kangema, Kangari, Maragwa, as well as Kahatia, Kiria-ini, Kigumo, and Kandara Markets (Murang'a County, 2014).

1.2 Problem Statement

The challenges in solid waste management in Kenol Town are embedded in every stage of the waste management cycle. These range from reduction of waste generation, separation, habits change, assembly and transportation, recycling and waste disposal. Kenol Town is among towns in Muranga that are in a serious need of solid waste management services and facilities due to high urban population growth, urban sprawl and high rate of development in the town. The Open uncontrolled dumping sites available in the study area is not sustainable and not optimally located; these sites should be located in places with the minimum destructive effects and the lowest environmental impacts. In addition, it the existing site was not chosen by applying multi criteria analysis which is critical to get an optimal site. Kenol town fails to have optimal collection points referred as Transfer stations or chambers that are located in most suitable areas to enhance service delivery and save on resources. To address transportation challenges that exist. The town also has challenges to do with inadequate resources allocated and inadequate service coverage, high costs of waste transportation.

This study will therefore show how GIS technology can be used in solid waste management in Kenol Town and this will be achieved through selecting suitable site for disposing solid waste, selecting suitable sites for chambers/transfer stations and designing appropriate routes for disposing the waste.

1.3 Objectives

1.3.1 General objective

The overall objective is to show how GIS can be used in solid waste management in Kenol Municipality.

1.3.2 Specific Objectives

i. To select suitable site for disposing solid waste.
ii. To select suitable sites for waste collection centres.
iii. To design the most appropriate route for disposing the waste.

1.4 Justification for the study

The County Government of Murang'a plans to embark on GIS mapping of all its resources to deal with the data inadequacy challenges which the county faces. According to 2018-2022

Murang’a CIDP, solid waste dumping and management remains Murang’a county major challenge; urban centres and markets are in dire need of facilities for sustainable solid waste management. At present, the county and in turn Kenol municipality lacks a robust solid waste management facilities. However, a sanitary landfill facility has been proposed at Mitubiri which is co-funded by Nairobi Metropolitan Authority (NAMATA) and the Murang’a County Government. As in almost every field of life, GIS can help in achieving excellence in Solid waste management. It significantly aids in planning, monitoring and managing of the complex systems involved in solid waste management. GIS helps in determining capacity enhancements, improving operations, and identifying the most strategic investments for keeping the solid waste system in any area running optimally.

1.5 Scope of work

The study will focus on the use of Geographical Information System in carrying out suitability and network analysis for management of solid waste in Kenol Municipality, Murang’a County. The study area is a fast growing urban centre with very many challenges in terms of public service provision. Therefore, the study will show usability of GIS in the selection of suitable sites for waste disposal and collection centres and in addition, design an appropriate route for disposing the waste emanating from the area.

1.6 Report organization

The report is organized into five chapters that are outlined below:

Chapter One: Contains the background, problem statement, justification, scope and organization of the report.

Chapter Two: Contains literature review of the waste management theories, methods of solid waste management applied in Kenya and Murang'a County, and application of GIS in solid waste management.

Chapter Three: Gives detailed information on area of study, data used in the study and their sources plus all the methods that have been applied to achieve the results.

Chapter Four: This gives the results obtained and a discussion of the results.

Chapter Five: This gives conclusions and recommendations based on the findings obtained.

These are followed by References.

CHAPTER 2: LITERATURE REVIEW

2.1 Solid Waste Management

Solid waste management is one of the major problems faced by today's world. Municipal authorities in the developing countries face critical environmental problems one of the most critical considered to be solid waste management. A higher generation of several types of waste has been caused by rapid urbanization together with increasing commercial, economic and industrial development (Shoba and Rasappan, 2013).

Solid Waste Categories

Waste can be classified as industrial, domestic and hazardous wastes but there are other categories of waste that are emerging and they include; waste tyres and e-waste which are as a consequence of growth of ICT and mechanization. It should however be noted that the composition of general waste vary considerably based on the source either from industries businesses and residential households. The following are the categories of waste in Kenya (NEMA, 2015):

a) **Domestic Waste**

   This includes waste generated from the households and comprises mainly of biodegradable waste like kitchen waste and non-biodegradable like cans, plastics among others.

b) **Waste Tyres**

   This includes damaged or worn out tyres which cannot be reused or recycled. In most developing countries the tyres are burnt to recover the steel in it and this leads to the emission of harmful gases which cause air pollution and contamination of the soil.

c) **Commercial Refuse**

   This is waste emanating from the offices, restaurants, warehouses among others. Examples include packaging material, office supplies, and food wastes.

d) **Institutional Refuse**

   This is waste emanating from institutions such as churches, hospitals, schools among others. The waste can be the same as that of the household if the institutions have residents. In developing countries, waste from the hospitals is managed privately while the municipalities manage the rest of the institution's waste.

e) Construction and Demolition Waste

Reconstruction, demolition or new constructions lead to the generation of waste that includes steel, tiles and ceramics among others. Another example is asbestos which is hazardous and if not properly disposed can lead to health risks.

f) E-waste

This is waste from Electrical and Electronic Equipments (EEEs) and includes heavy metal components and materials used in the manufacture of electronic goods. Examples include mercury, brominates flame retardants, and cadmium which are considered hazardous if not well handled during dismantling or recycling can become harmful to human health and the environment.

Batteries:

Batteries can either be alkaline (dry cells) or acid based which support domestic and industrial applications. The acid based (rechargeable and silver oxide) batteries contain heavy metals such as mercury and cadmium which are classified as hazardous substances. This hazardous material if not properly handled and disposed presents a risk to the human health and the environment.

g) Fluorescent Lamps

In modern days, the fluorescent lamps are mainly used for illumination and they are known to contain mercury though in a small amount of. The mercury is a neurotoxin and it can be dangerous even in small amounts. These lamps can be recycled successfully and effectively and the mercury in them recovered. However, the mercury in these lamps can be released at any stage if there is poor management and handling which is hazardous .

h) Pesticide waste

i) This category includes the contaminated and expired pesticides as well as the already used containers. The pesticides are toxic hence lead to pollution and threaten human health. For this reason, they should be handled with care during their transportation, treatment and disposal.

j) Biomedical waste

This category is also called the medical waste and is usually generated from health facilities and research institutions among others. The waste is classified into the following; infectious, pharmaceutical, pathological and chemical. This category poses health risks to human hence should be treated before disposal.

k) Used Oil and Sludge

This type of waste is as a result of usage of petroleum products and has a slow rate of decomposition and hence any spillage can cause soil and water pollution.

l) Sewage Sludge

This is a sediment material formed in sewage treatment plants and ponds that accumulates over time. Improper disposal of this waste leads to the contamination of water and soil hence posing a problem to human and animal health especially if the waste contains heavy metals.

m) Industrial waste

Industries produce both hazardous and non-hazardous waste which includes chemical solvents, paints and radio-active waste among others. The waste poses health risks to human especially the ones handling it as well as damaging the environment.

2.2 Solid Waste Management in Kenya

Urbanization in Kenya has led to increased waste generation and complexity of the waste streams. There are several laws and policies that govern waste management in the country but that fact that they are not well implemented or practiced, waste is poorly managed hence pollution to the environment which affected the health of both human and animals.

Kenya's Vision 2030 calls for efficient and sustainable systems for managing waste in the country and this has led to the identification of five cities and towns which are to be used as one of the flagship projects in sustainable solid waste management. They include Eldoret, Kisumu, Nakuru, Mombasa and Thika. It is the mandate of National Environment Management Authority (NEMA) to implement the project and the same strategy will be eventually applied across the country (NEMA, 2015).

Minimum Requirements for Solid Waste Management by NEMA

It is the County Government's duty to ensure proper waste management systems and NEMA has developed some basic minimum requirements which the County Governments should comply to. The minimum requires are as shown in Table 1 below;

Table 2.1: Waste Management Cycle

Waste Management Stage	**Requirement**
Waste collection	a) Zone out the waste collection areas;
	b) All solid waste should be collected on a regular basis through door to door collection or from centralized collection points;
	c) Waste collection facilities should be regularly emptied and should not become eye-sores;
Waste transportation	d) Use NEMA licensed vehicles t transport the collected waste and dispose at the designated disposal sites;
Waste disposal site	e) Designated waste disposal sites are available;
	f) Waste disposal site should be fenced and guarded by a county government official;
	g) Weigh or estimate all the waste received in tonnes.
	h) Motorable roads should be developed and maintained for easy access of the disposal site during waste disposal;
	i) Waste should be spread, covered and compacted at regular intervals;
	j) Appropriate control measures should be put in place for the management of dumpsite fires;
	k) Security and control of the disposal sites should be enhanced in order to contain any illegal activities;
Requirement for licensing	l) Vehicles used for waste transportation should have NEMA license;
	m) Licenses should be obtained for operating waste disposal

	sites.

The Kenyan constitution 2010 grants every citizens a right to have an effective and efficient solid management systems and consequently the county governments strives to make sure that there is a continuous improvement in the solid waste management system.

Table 2.2: Summary of Waste Generation, Collection and Recovery status in Major Towns

Name of town	**Estimated Waste generated(tons/day)**	**% Waste collected**	**% waste Recovery**	**Uncollected waste**
Nairobi	2400	80%	45%	20%
Nakuru	250	45 %	18%	37%
Kisumu	400	20%	Unknown	Unknown
Thika	140	60%	30%	40%
Mombasa	2200	65%	40%	35%
Eldoret	600	55%	15%	45%

(Source: NEMA, 2015)

2.3 Solid Waste Management in Murang'a County

Murang'a County, just like any other County, generates different types of waste and the management of this waste still remains a challenge. There are several factors which contribute to this challenge and they include;

2.3.1 Solid Waste Management Process in Murang'a County

a) *Waste Generation* - Utmost waste is generated at household level, cities and towns, market places, institutions, and also in the industries.

b) *Waste Collection* - The waste is then collected and transported to the dumpsites using open trucks and carts. The County Government is the main solid waste management service providers but may in future be gradually taken up by the private sector.

c) *Waste segregation* - Waste is not usually separated at the source and this leads to hampering of material recovery, reuse and recycling. Sorting of the waste is mostly done by the ones that pick the waste as well as the street boys.

d) *Waste Transportation* - Waste transportation in the municipality and also in the county is largely rudimentary using open trucks and carts.

e) *Disposal sites* - Waste is disposed off to open dumpsites found across the county and as much as it is not a recommended practice, it is the most common. Incinerators and kilns are used for the disposal of biomedical as well as expired goods.

2.3.2 Challenges in Waste Management in Murang'a County

a) *Lack of awareness and knowledge:* A clean and healthy environment is very important but this is not known to all hence the poor management of waste by the public. This has in the long run led to the environmental pollution being experienced in Murang'a County.

b) *Disposal sites Availability, siting and management:* Poor Management of the available disposal sites have led to issues from the neighboring community being in disagreement with the disposal sites being in their backyard.

c) *Funding:* Inadequate funds for waste management are another challenge faced in Murang'a County. This calls for the need to strategize how the available funds can be efficiently and effectively utilized in the entire process of waste management

d) *Lack of segregation:* Failure to sort solid waste at the source is another challenge faced in the County and this interferes with the process of recovery of useful materials from the waste which can be reused or recycled.

e) *Slow adoption of modern technological options:* There is limited technical capacity for managing solid waste in the County. This affects the management process in that the facilities and equipment used are not well managed and end up not attaining their full capacity. There are modern technologies that can be used for better management of waste in the County but inadequate funds as well as resistance to change and lack awareness have hindered the adoption of these technologies.

2.4 Solid Waste Management in Kenol Municipality

Kenol Municipality is in Murang'a County and is in urgent need of solid waste management facilities. The challenges in solid waste management in Kenol Municipality range from reducing generation of waste, separation, change of habits, collection, transport, treatment, re-use and disposal of the waste. Kenol municipality does not have a site designated as a disposal site and also no collection centres. The waste generated from different areas is normally transported using donkeys and it's disposed anyhow near the roads and the municipal council takes the responsibility of collecting the waste and dumps it on an open ground set aside for cemetery which is at Kimorori-Nevi. The process of waste management is not well defined and therefore it's curbed by very many challenges.

Plate 2.1: Dumping of waste at Kenol
(Source: Fieldwork January 2020)

2.5 Contribution of GIS in Solid Waste Management

GIS is a system of computer hardware and software, designed to allow users to collect, manage, analyze and retrieve large volumes of spatially referenced data and associated attribute data collected from a variety of sources. In an extensive variety of applications, GIS has been used successful. These diverse applications include natural resource management, transportation planning, disaster management, environmental monitoring, health and Forestry applications among others. Solid waste management and particularly selection of suitable facilities and optimization of waste collection and transportation (Chalkias and Lasaridi, 2011).

Among these applications, the study of complex waste management systems have been a preferential field of GIS applications from the early onset of the technology. Nowadays, integrated GIS technology has been recognized as one of the most promising approaches to automate the process of waste planning and management (Chalkias and Lasaridi, 2011).

2.5.1 GIS-based Modelling for Landfill Selection

According to the recommendation by the Food and Agriculture Organization of the United Nations (FAO), land evaluation can be categorized into steps including the choice of the evaluation factors, evaluation of every element, determining the weight of each criterion, and finding the value of evaluation (Yang *et al*., 2011).

A typical GIS Model used in selection of a suitable land fill is shown in Figure 2.1.

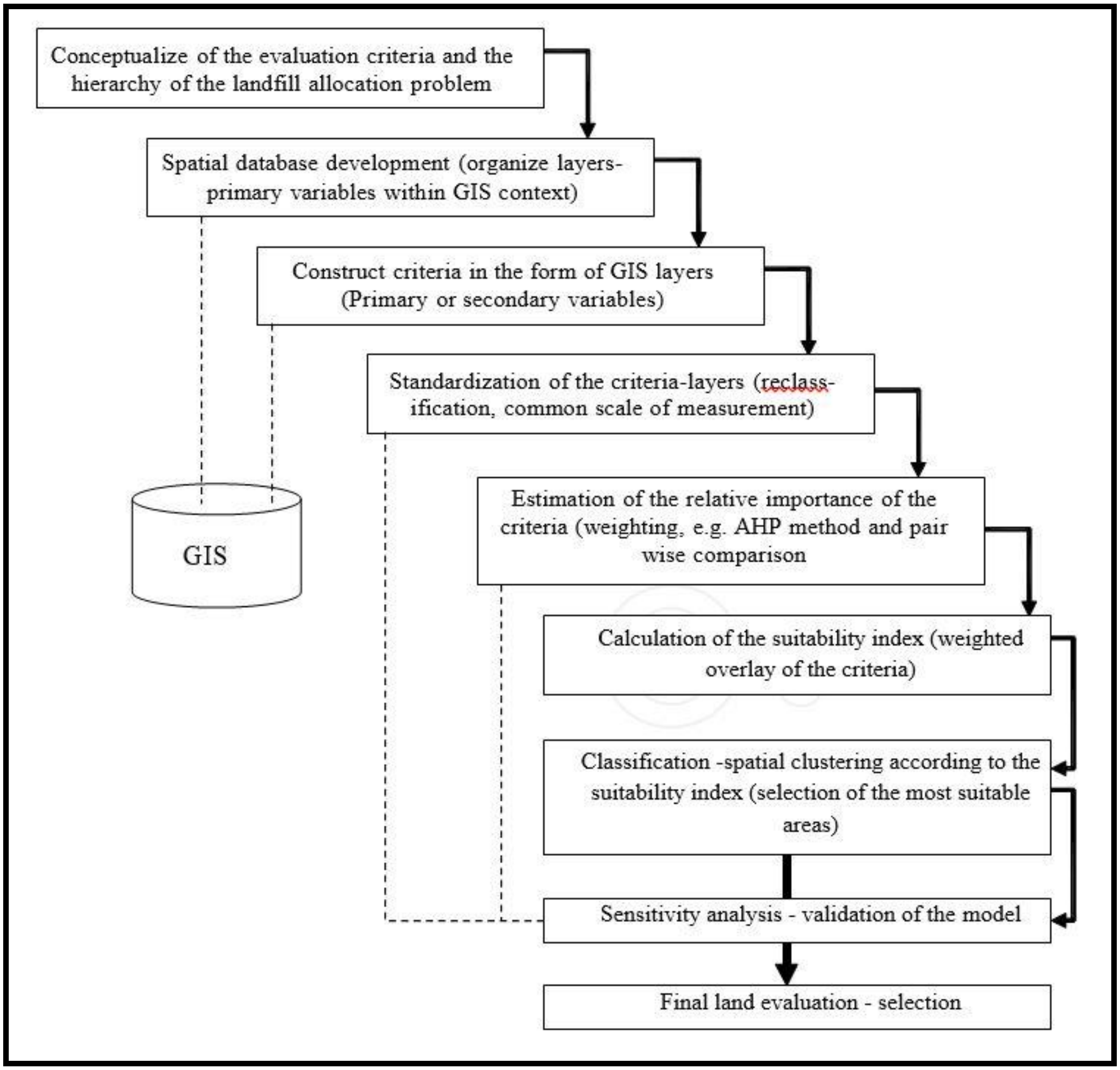

Figure 2.1: A GIS Approach for Landfill Site selection.

2.5.2 GIS Modelling for the Optimization of Waste Collection and Transport (WC&T)

One of the crucial factors of an environmentally friendly and cost effective solid waste management system is the optimization of the routing system that's used for collection and transportation of solid waste. Creation of these routing scenarios is a very complex task. It has however been made possible by making use of the GIS which provides significant economic and environmental savings through the reduction of distance, travel time, pollutants emissions and fuel consumption (Das and Bhattacharyya, 2015). Geographic information system methodology permits processing of extra considerations for instance the environmental pollution consideration, street network modeling, the vehicle routing problem solver incorporating all network constraints, and impact of land use changes on routing. According to Siddam *et al.* (2012), GIS has the capability to determine the minimum cost or distance for efficient collection and transportation of solid waste to the disposal sites. GIS applies both spatial and aspatial data for the optimization process such as road network, population density, storage bins, collection vehicles, and waste generation capacity

GIS has been applied in solving vehicle routing problems which allows for integration of extra considerations for instance restrictions, turns, and impedances to carry out street network model. Dijkstra algorithm has been used in GIS network analyst extension and it mainly analyzes the shortest route between two points. GIS optimization methods utilize algorithms developed using mathematical models and display outputs that incorporate spatial components. GIS application to solve vehicle routing problems improves collection of waste and ensures efficient and effective system for managing waste. Inaddition, GIS also generates routes which are cost effective and shorter. GIS is a tool that has been proven to provide alternative options of operational costs minimization (Sulemana *et al*., 2018).

2.6 Previous Studies

Gakungu *et al.* (2012) studied solid waste management in Kenya a case study of Public Technical Training Institutions. The study assessed how waste is generated, collected and disposed in these institutions. His results showed lack of involvement of the local authorities by the institutions in the management of waste which hence led to environmental pollution in the institutions. He therefore recommended use of landfills instead of open dumping of solid waste since landfills are a relatively inexpensive method of solid waste disposal and that they also minimize the impact the waste has on the environment.

Islam *et al.* (2016) studied using GIS for municipal solid waste management in Mirpur area of Dhaka city in Bangladesh. Their study increased waste collection efficiency as well as aided in the selection of waste collecting routes. The study showed that GIS is a low cost tool, efficient and can be used to select a suitable dumping site which facilitates the process of decision making The results obtained proposed an efficient scenario with relocating the existing waste collection centres and another scenario was proposed 73 collection centres attaining 93.68% waste collection efficiency. These also included optimization and selection of waste collection routes for the study area.

CHAPTER 3: MATERIALS AND METHODS

3.1 Area of Study

The study area, Kenol Municipality, is located in Murang'a County which is one of the counties created under the Kenya Constitution 2010. Murang'a is one of the five counties in the Central region of the Republic of Kenya and occupies an approximate area of 2,558.8Km^2. Murang'a county borders Nyeri to the North by, Kiambu to the South, Nyandarua to the West, and Kirinyaga, Embu and Machakos counties to the East. It lies between Longitudes 36^o East and 37^o 27' East and latitudes 0^o 34' South and 1^o 7' South. The county lies between 914m to 3353m above sea level (CIDP 2018-2022).

The 2019 Population and Housing Census documented a population 1,056,640 persons for Murang'a County comprising of males 523,940 and females 532,669 (Kenya National Bureau of Statistics, 2019). The county is largely supported by agricultural activities; Main cash crops grown in the area include tea, coffee, macadamia, and avocado horticultural crops. Crops are also largely grown And they include French beans, tomatoes, Sukuma wiki/kales, cabbages among others. In addition, food crops are also grown including various types of beans, maize, sweet potatoes, cassava and bananas.

Kenol Municipality is expanding at a very high rate and it occupies approximately 190 square Kilometers, it lies between 0^o 52' 22.8'' and 1^o 02' 56.4''south and 36^o 59' 09.6'' and 37^{o}14' 49.2'' East. It lies at the intersection of three sub counties: Kandara, Gatanga and Maragua.

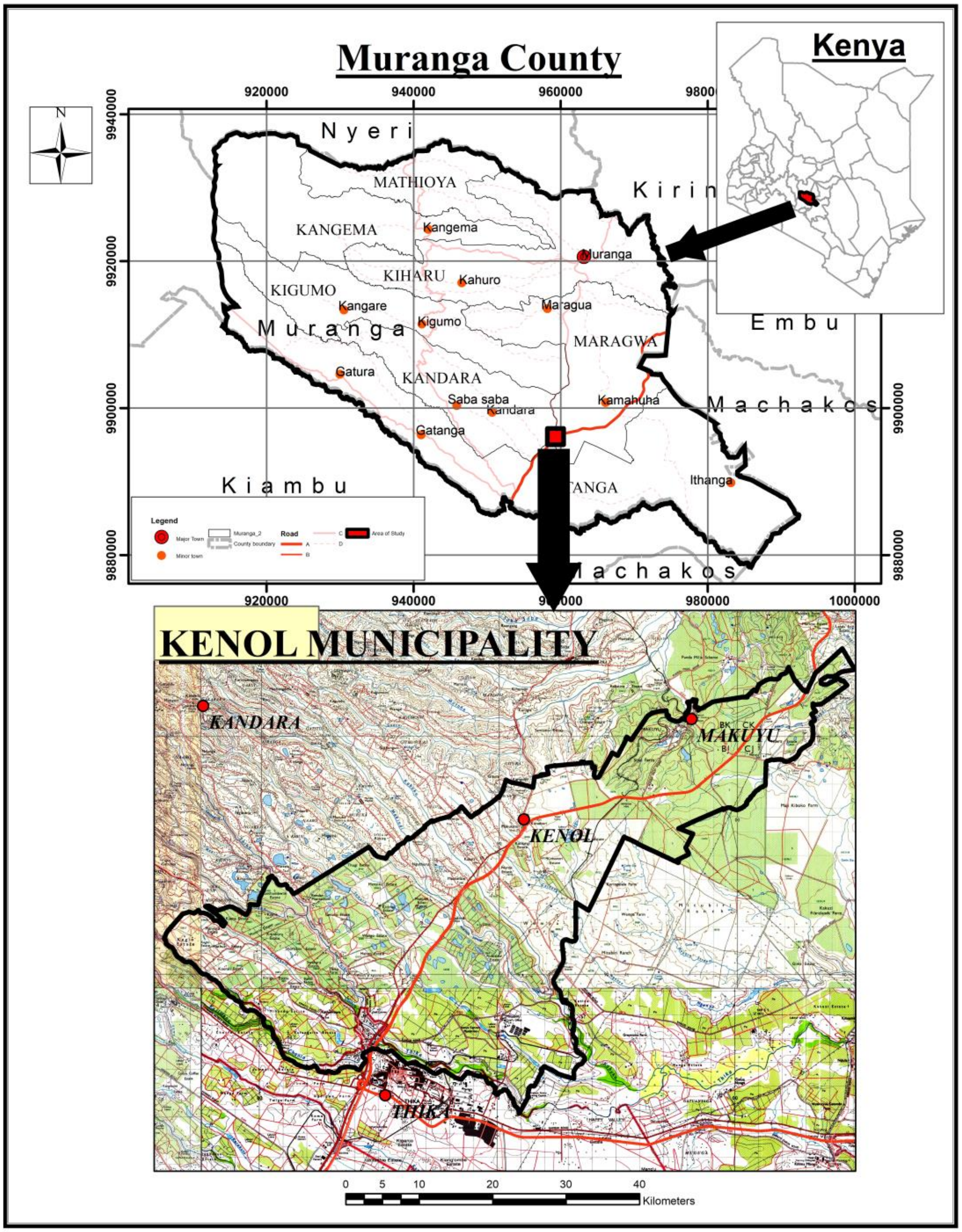

Figure 3.1: Map showing the study area

3.2 Datasets and Sources

Much available data which was in both hard and soft forms were utilized for this study. The datasets were obtained from different sectors in the country. Datasets used were founded on its suitability and availability to meet the objectives of the study. These datasets type together with their sources are as shown in Table 3.1.

Table 3.1: Datasets and sources

Objective	**DATA**	**SOURCE**
1. To select suitable site for disposing solid waste.	Contours	Dept. of Lands, Murang'a county
	Soils	KARLO
	Land use/Land cover	FAO, 2014
	Buildings	Planning Department, Murang'a
	Parcel size	Dept. of Lands, Murang'a county
	Educational facilities	Ministry of Education
	Rivers	SoK
	Protected areas	KFS
	Major electricity transmission or other	Planning Department, Murang'a
	Boreholes	
	Wetlands	WRMA
2. To select suitable sites for Collection centres.	Utilities Landuse Zones Buildings Water points Soils- Drainage	Planning Department, Murang'a county WRMA KALRO
3. To design appropriate routes for disposing waste.	Suitable Disposal site Suitable Collection centres	Obtained from objective 1 and 2
Basemap	Auxiliary data: – Administrative boundaries – Transportation network – Topographical map 1:50,000 – Towns	IEBC KRB Survey of Kenya (SoK)

3.3 Methodology

In order to achieve the objective of this study, the methodology shown in Figure 3.2 was followed.

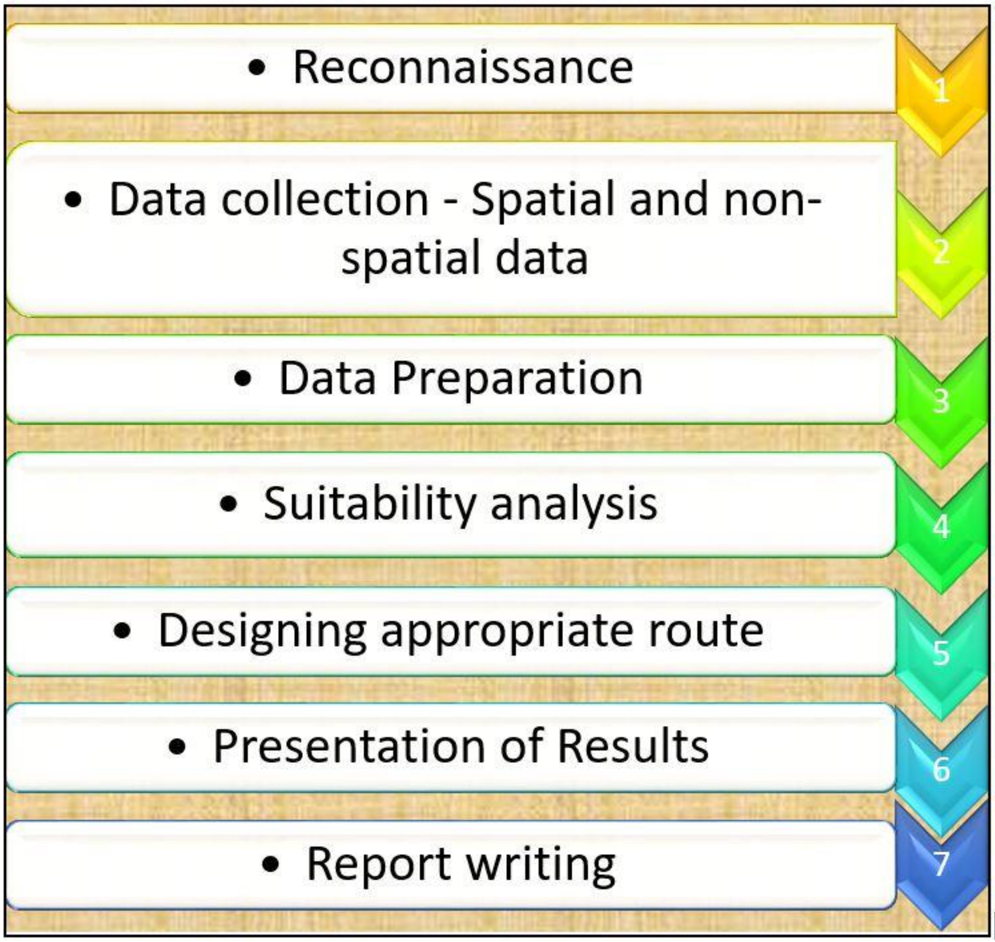

Figure 3.2: Overview of methodology

3.3.1 Identification of a Disposal Site

In many studies involving a combination of GIS and Multi Criteria Decision Making (MCDM), Analytical Hierarchical Process (AHP) is widely used as one of the methods of MCDM. Briefly, GIS-MCDA is a technique that explicitly evaluates multiple conflicting criteria in decision making. These technique aims at informed decision making and it involves the integration of georeferenced spatial data in a problem solving environment. The GIS-based MCDA basic principles is a choice between alternatives; It provides a rich collection of techniques and procedures for structuring decision problems, designing, evaluating & prioritizing alternative decisions (Estoque and Murayama, 2011).

Criteria are a set of requirements or guidelines or used as basis for a decision making. The criteria were carefully selected after a lengthy consultation with experts and an exhaustive review of available literature. In addition, Criteria selection was also based on the datasets availability. These literature included among others the Mitubiri Sanitary Landfill ESIA report and NEMA guidelines for establishment of a disposal site. In any site selection project, criteria selection is crucial because the reliability of the site majorly depends on it. The selected criteria were reclassified into different suitability classes by adopting four suitability categories, namely: (1) Not Suitable, (2) Moderately Suitable, (3) Suitable and (4) Highly Suitable.

Two types of criteria used were factors and constraints.

a) Factor

A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. The Factors that were used are shown in Table 3.2.

Table 3.2: Factors for identifying a suitable disposal site and their reclassification details

Factor	(1) Not Suitable	(2) Moderately Suitable	(3) Suitable	(4) Highly Suitable
Slope (percent)	>40	30-40	<20	20-30
Elevation (M a.s.l.)	>1800	1600-1800	1400-1600	<1400
Roads (Meters)	>2000	1500-2000	1000-1500	<1000
Soils (Texture)	Very Fine	Fine	Coarse	Medium
Land use/Land cover (Type)	• Built-up / Artificial Surfaces • Water bodies and flooded areas • Forest • Prime agricultural land	Agricultural land	Open Woodland vegetation	• Rangeland • Bare ground • Shrub savanna/ Shrub land

b) Constraints

A constraint serves to limit or restrict the alternatives under consideration; these is area that is not preferred in any way or area that is considered unsuitable for example water body or protected area among others. These are usually represented by a Boolean mask. The constraints used identification of a suitable disposal site were obtained mainly from Mitubiri Sanitary Landfill ESIA report, NEMA guidelines and Kirimi and Waithaka, 2014. These constraints are shown in Table 3.3.

Table 3.3: Constraints in identifying a suitable disposal site

Constraints	
Buildings	500m away
Educational facilities	500m away
Rivers	300m away
Protected areas	750m away
Power line and Sewer line	750 m away
Boreholes	500m away
Wetlands	Not suitable
Parcel size	>10Ha

Weighting using AHP

The study utilized Analytical Hierarchical process by Saaty (1980) for calculating the weights. The weights are derived by normalizing the eigenvector of the square reciprocal matrix of pairwise comparison between criteria (eqn. 1- 3). The weight consistency is also assessed (eqn. 4-7). In doing this, Saaty (1980) established a consistency ratio (CR) which is the measure that gives a consistency departure, and suggests that a matrix re-evaluation should be done if the CR is greater than 0.1. Following the calculation of weights using the Analytical Hierarchical Process, CR was estimated and found to be 0.087 for disposal site which is less than the 0.1 proposed by Saaty (1980) and therefore found to be acceptable.

The pairwise comparison matrix and obtained weight are shown in Table 3.4.

Table 3.4: Pairwise comparison matrix and weights for identification of Disposal Site

A	B					
	SLOPE	ELEVATION	ROADS	LULC	SOILS	Weight
SLOPE	1	1/3	1/3	1/7	1/7	4.06
ELEVATION	3	1	1/3	1/7	1/7	6.70
ROADS	3	3	1	1/3	1/5	12.50
LULC	7	7	3	1	3	44.22
SOILS	7	7	5	1/3	1	32.52
Sum	**21**	**18.33**	**9.66**	**1.94**	**4.48**	100.00

The AHP Method applied to get the weights is achieved by the following process:

1. Obtain the a pairwise Comparison matrix for the criterias

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix}$$

2. Carryout value summation of the pairwise matrix

$$C_{ij} = \sum_{i=1}^{n} C_{ij} \qquad \text{...eqn. (1)}$$

3. Generate a normalized pairwise matrix by dividing each element in the matrix by its column total

$$X_{IJ} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}} \begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} \qquad \text{...eqn. (2)}$$

4. Generate a weighted matrix by dividing the sum of the normalized column of matrix by the number of criteria used (n)

$$W_{IJ} = \sum_{j=1}^{n} X_{ij} \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix} \qquad \text{...eqn. (3)}$$

5. Carryout Consistency measure calculation:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} = \begin{bmatrix} Cv_{11} \\ Cv_{21} \\ Cv_{31} \end{bmatrix}$$ ………..……..…………….……………………..eqn. (4)

$$\lambda = \sum_{i=1}^{n} Cv_{ij}$$ …………………...……………………….……………………..eqn. (5)

$$\text{CI} = \frac{\lambda\_max - n}{n - 1}$$ …………………...………………..….………………….eqn. (6)

$$\text{CR} = \frac{CI}{RI}$$ …………………...………………..….………………….eqn. (7)

Where

CR = *Consistency Ratio,*

CI = *Consistency Index,*

RI =*Random Index*

Consultation of Expatriates and decision makers was done to assign weights and fill up the comparison matrix, five and six criteria that are not of equal importance were used in determining the location of disposal site and collection centres respectively. The scale of relative importance used in pairwise comparison is shown in Table 3.5.

Table 3.5: Pairwise comparison scale of Relative Importance.

Intensity of Relative Importance	**Definition-Degree of importance**
1	Equally important
3	Equal to moderately important
5	Moderately important
7	Moderately to strongly important
9	Strongly important

3.3.2 Identification of collection centres

a) ***Factor***

The Factors and constraints used in identification of a suitable collection centre sites were mainly obtained from USEPA (2004).The factors are shown in Table 3.6.

Table 3.6: Factors for identifying a suitable Collection centres site

Factor	**Suitable**	**Moderately suitable**
Utilities	Within 500m	
Water points	Within 500m	
Transportation network	Within 500m	
Soils- Texture	Medium	
Land use Zones	– Industrial – Commercial – Open spaces	– Agricultural
Buildings	Within 500m	

b) Constraints:

The constraints for establishment of suitable collection centres are shown in Table 3.7.

Table 3.7: Constraints in identifying suitable Collection centre sites

Constraint	
Residential	Not suitable and site must be within 500m from a residential area
Wetlands/Water bodies	Not suitable
Land parcels	Undeveloped
Educational facilities	500m away
Public Purpose land	Not suitable
Rivers	300 – 500m away
Prime agricultural land	Not suitable
Conservation/Protected areas	Not suitable
Recreational area	Not suitable

Weighting

Following the Saaty's weights calculation method, CR was computed and a CR of 0.081 was obtained for collection centres which is less than the 0.1 proposed and therefore it was also found to be acceptable. The comparison matrix used and weights obtained are shown in Table 3.8.

Table 3.8: Comparison matrix and weight for identification of Collection Centres (CR =0.081< 0.1).

A	B						
	Utilities	Water points	Soils	Landuse Zones	Roads	Buildings	Weight
Utilities	1	1	0.33	0.2	0.2	0.2	4.49
Water points	1	1	0.2	0.14	0.2	0.2	3.89
Soils	3	5	1	0.33	0.33	0.2	11.19
Landuse Zones	5	7	3	1	3	3	36.63
Roads	5	5	3	0.33	1	3	23.86
Buildings	5	5	5	0.33	0.33	1	19.93
Sum	**20**	**24**	**12.53**	**2.33**	**5.06**	**7.6**	100.00

After the Criteria were set and weights obtained for identifying both the disposal site and collection centres, a model was created in Arc GIS model builder. It contained the data and set of spatial modelling tools to automate the process. Figure 3.3 shows the disposal site suitability model being executed.

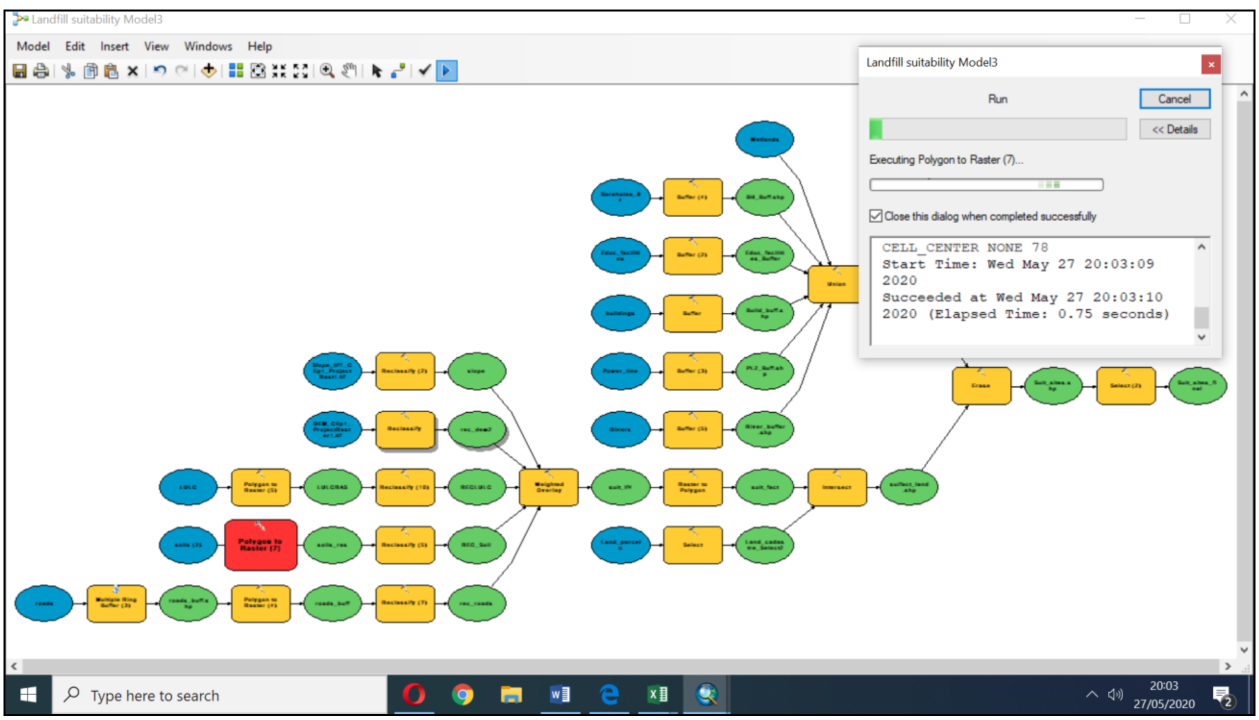

Figure 3.3: Running the model in the ArcGIS environment

3.3.3 Designing appropriate routes for disposal

Designing an appropriate route analysis meant determining the quickest or shortest way to travel between locations. Shortest path (Layer to point) tool in QGIS software was utilized to generate driving directions to visit multiple stops (Collection centres). The tool is capable of finding routes for one or more vehicles each time it runs.

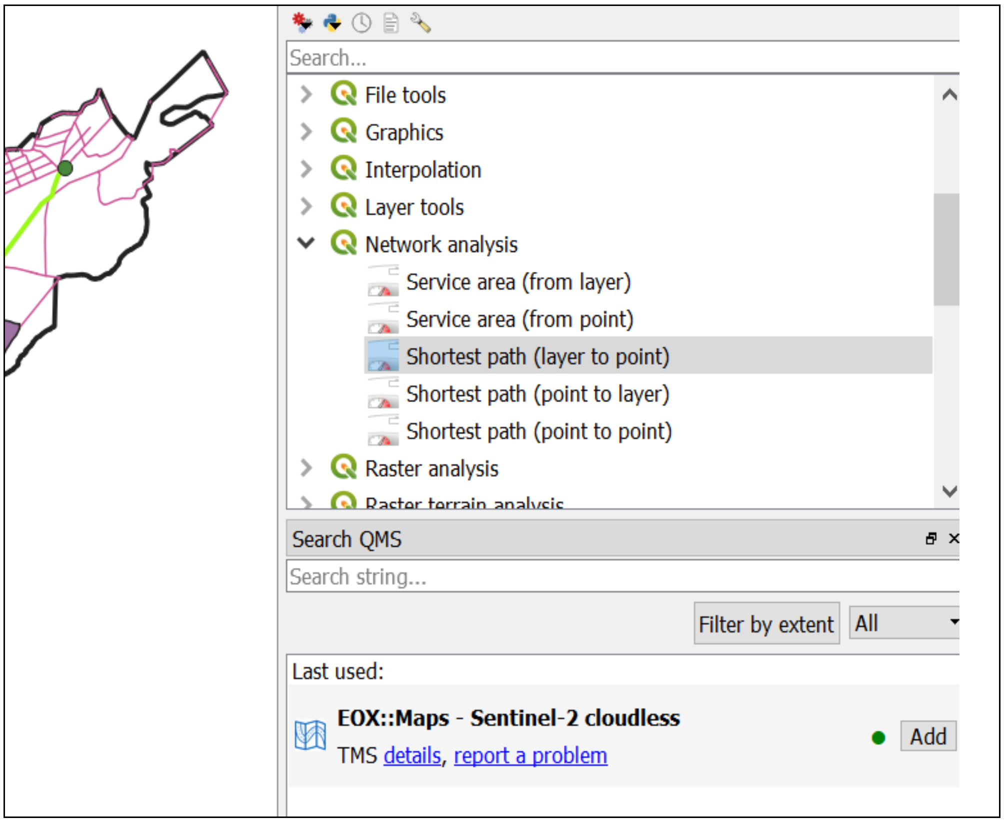

Figure 3.4: Shortest path tool in QGIS environment

Shortest path (layer to point) tool was used, establishing routes that can be used if you are coming from the layer (collection centres) and to an end point which is the disposal site. Shortest and fastest routes were generated individually which had optimization of distance and time respectively. Processing windows are shown in Figure 3.5.

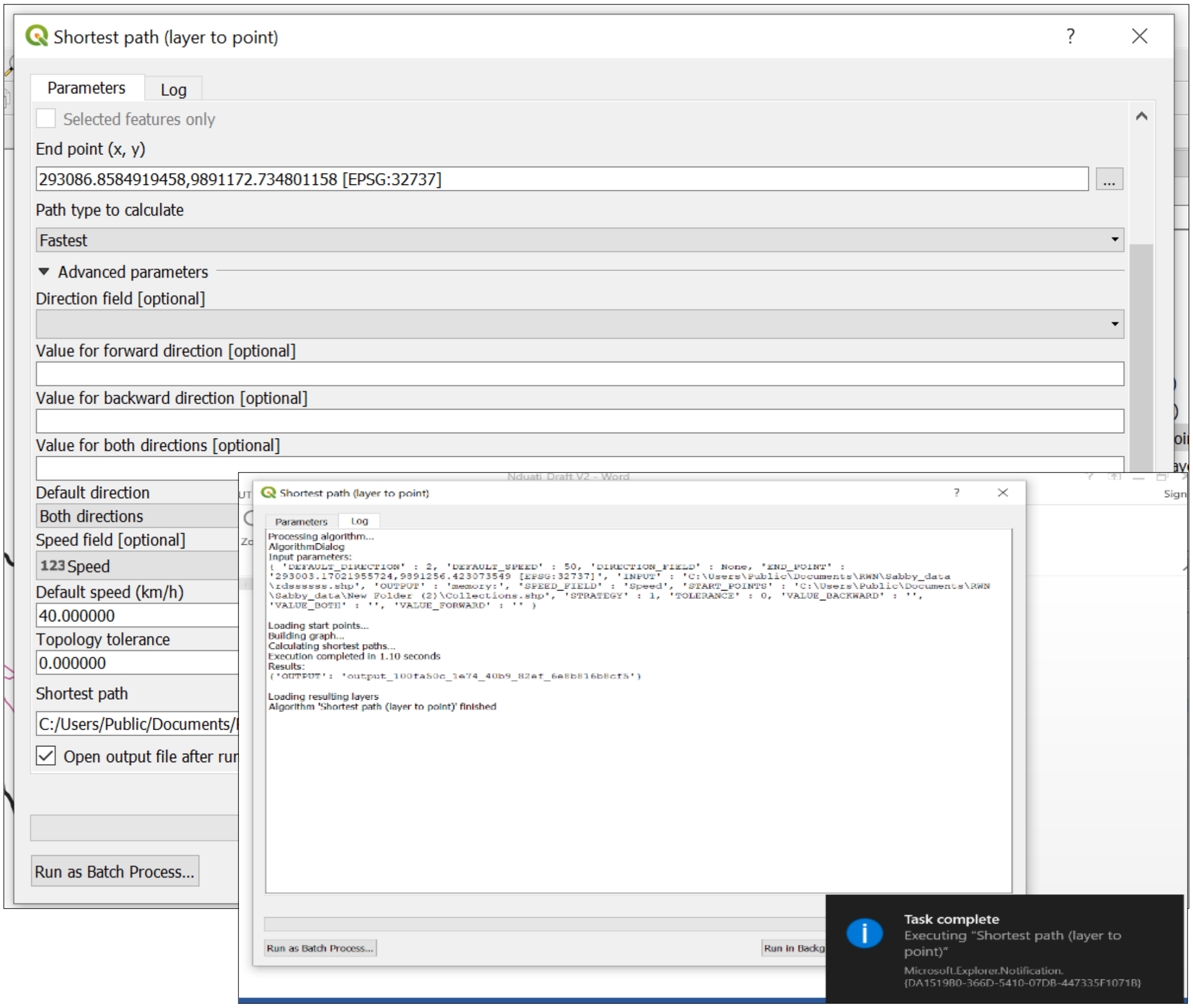

Figure 3.5: Processing routes in the QGIS environment

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Results

In line with the objectives, the following results were obtained:

4.1.1 Suitability derived criteria maps for disposal site

The Landfill suitability analysis considered five factors namely Slope, elevation, Roads, Land use land cover and Soils. Suitability criteria maps for disposal site are shown in Figure 4.1.

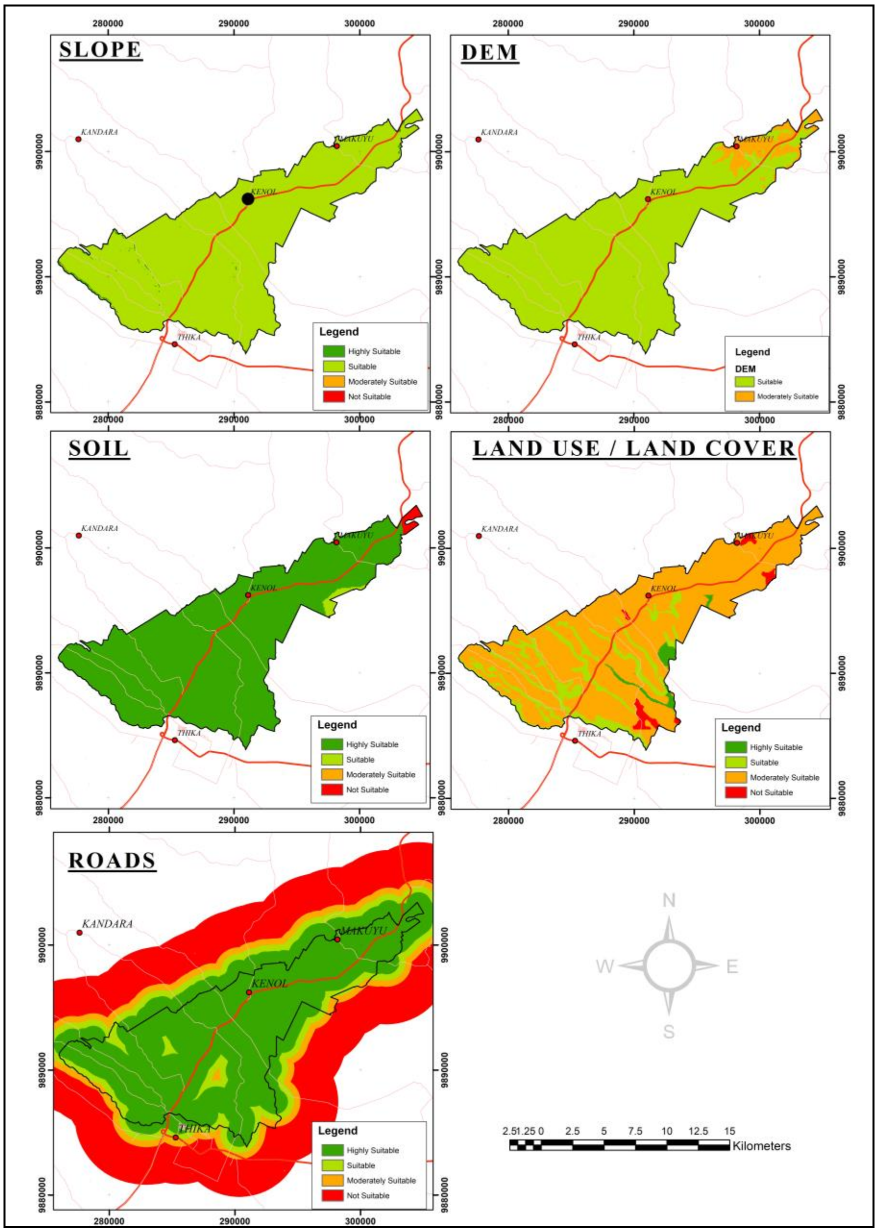

Figure 4.1: Suitability criteria maps for identifying Disposal site

4.1.2 Suitability model for Disposal site

A workflow model that combines all the criteria developed in ArcGIS software is shown in Figure 4.2.

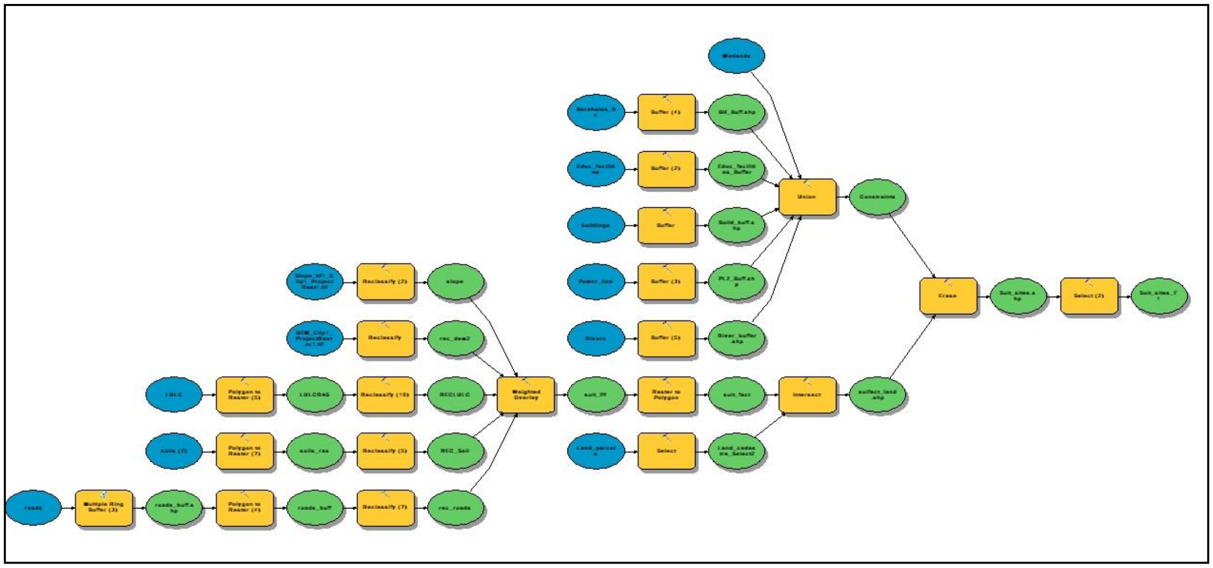

Figure 4.2: Suitability model for Disposal site

4.1.3 Suitability map for Disposal sites

Using Multi-Criteria Evaluation Analysis, 36 sites were obtained: 32 in the moderately suitable and 4 in the suitable categories, as shown in Figure 4.3.

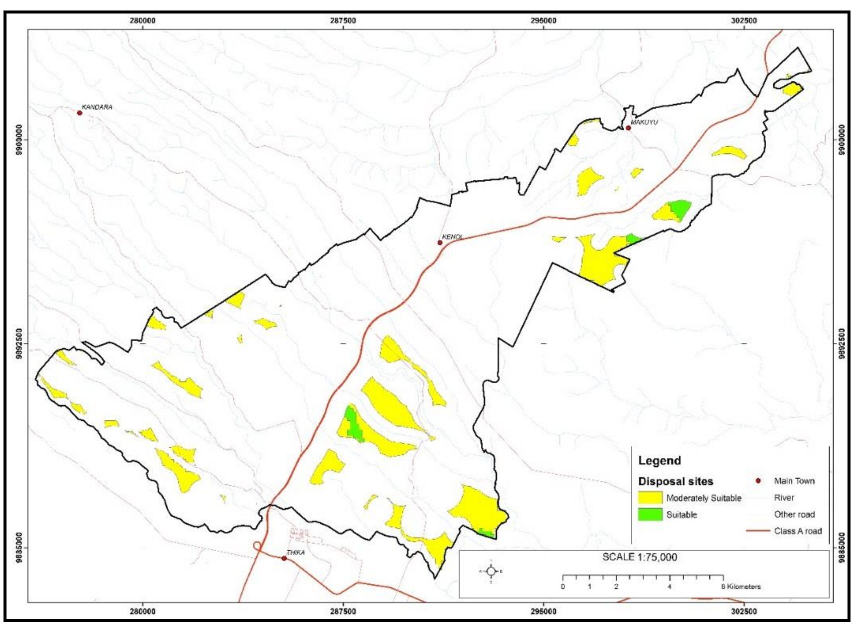

Figure 4.3: Suitability map for Disposal site

4.1.4 Suitable site for a disposal site

The four sites in the Suitable category are shown in Figure 4.4

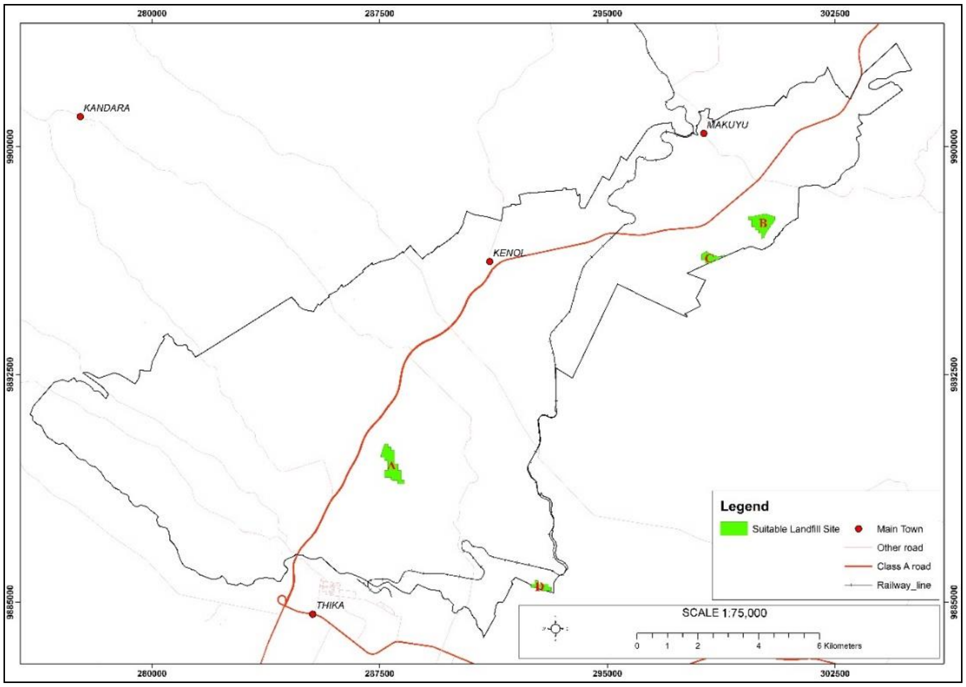

Figure 4.4: Suitability model for disposal site

The Four sites in the Suitable category shown in Table 4.1were further analyzed: The optimal site was selected as site **A** since it was the biggest in terms of acreage and also was easily accessible.

Table 4.1: Four Suitable Sites for a disposal site

Analysis of the 4 sites			
Site	**Size(Ha)**	**Distance (m) to main road**	**Rank**
A	44.9	685	1
B	37.7	697	2
C	13.7	846	3
D	10.9	**1936**	**4**

The optimal site for waste disposal is shown in Figure 4.5.

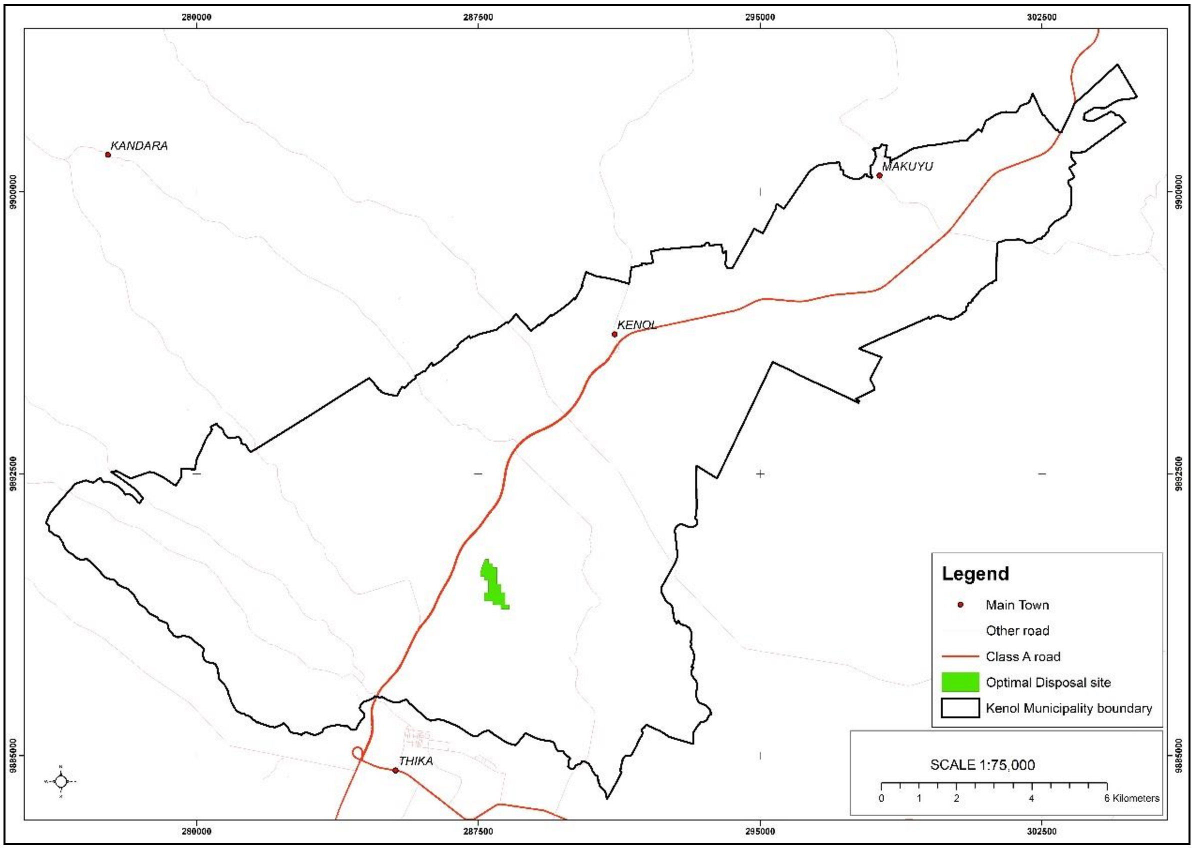

Figure 4.5: Suitability map for Disposal site

4.1.5 Suitability derived criteria maps for collection centres

Suitability derived criteria maps for collection centres are shown in Figure 4.6.

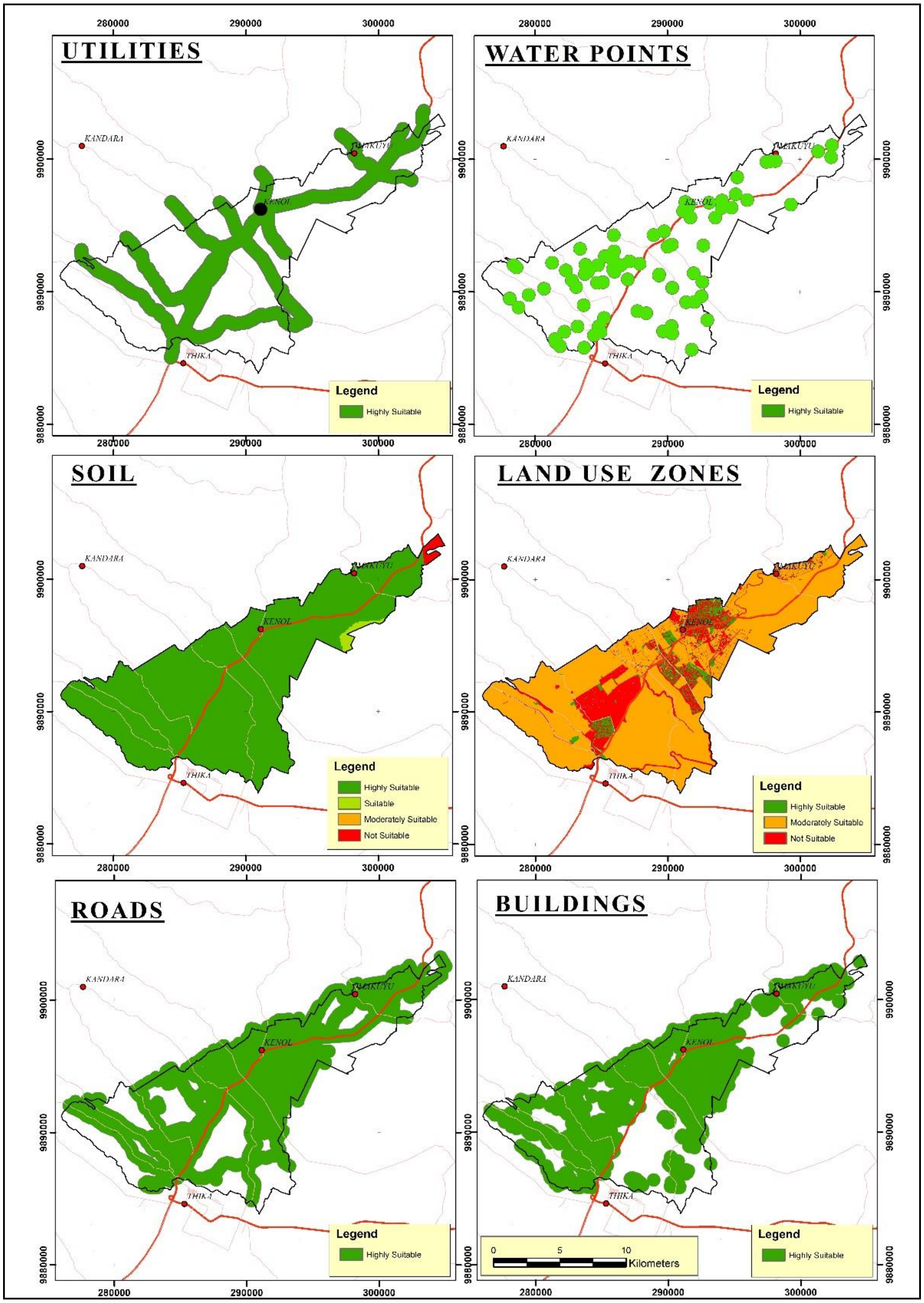

Figure 4.6: Suitability criteria maps for identifying Collection Centres

4.1.6 Suitability model for Collection centres

The Collection Centres Suitability model is shown in Figure 4.7

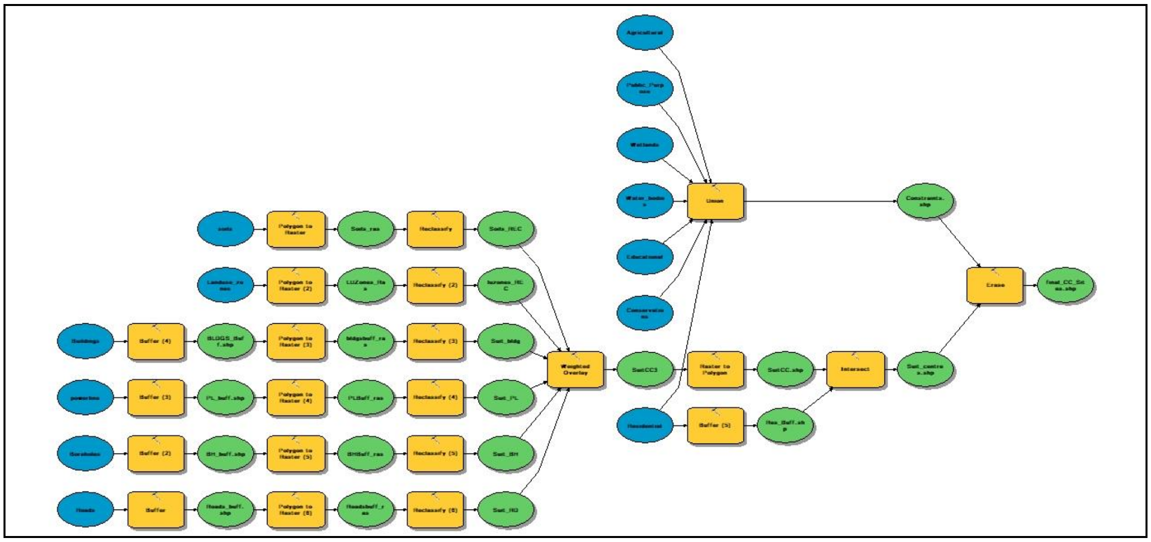

Figure 4.7: Suitability model for collection centres

4.1.7 Suitability map for collection centres

Various sites in Kenol Municipality were found to be suitable for establishing waste collection centres. The suitability map for collection centres shown in Figure 4.8 was derived from the model in Figure 4.8.

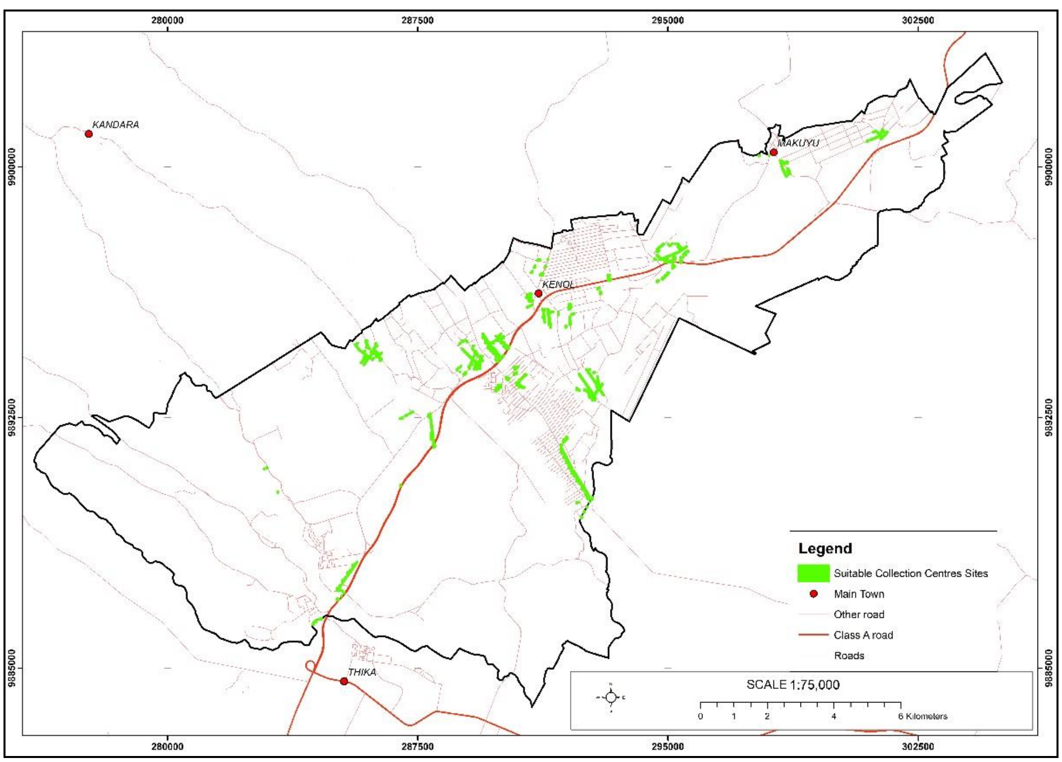

Figure 4.8: A map showing suitable collection centre sites

4.1.8 Suitable sites for collection centres as points

The points were obtained using group analysis in ArcGIS. Suitable sites for collection centres as points are shown in Figure 4.9.

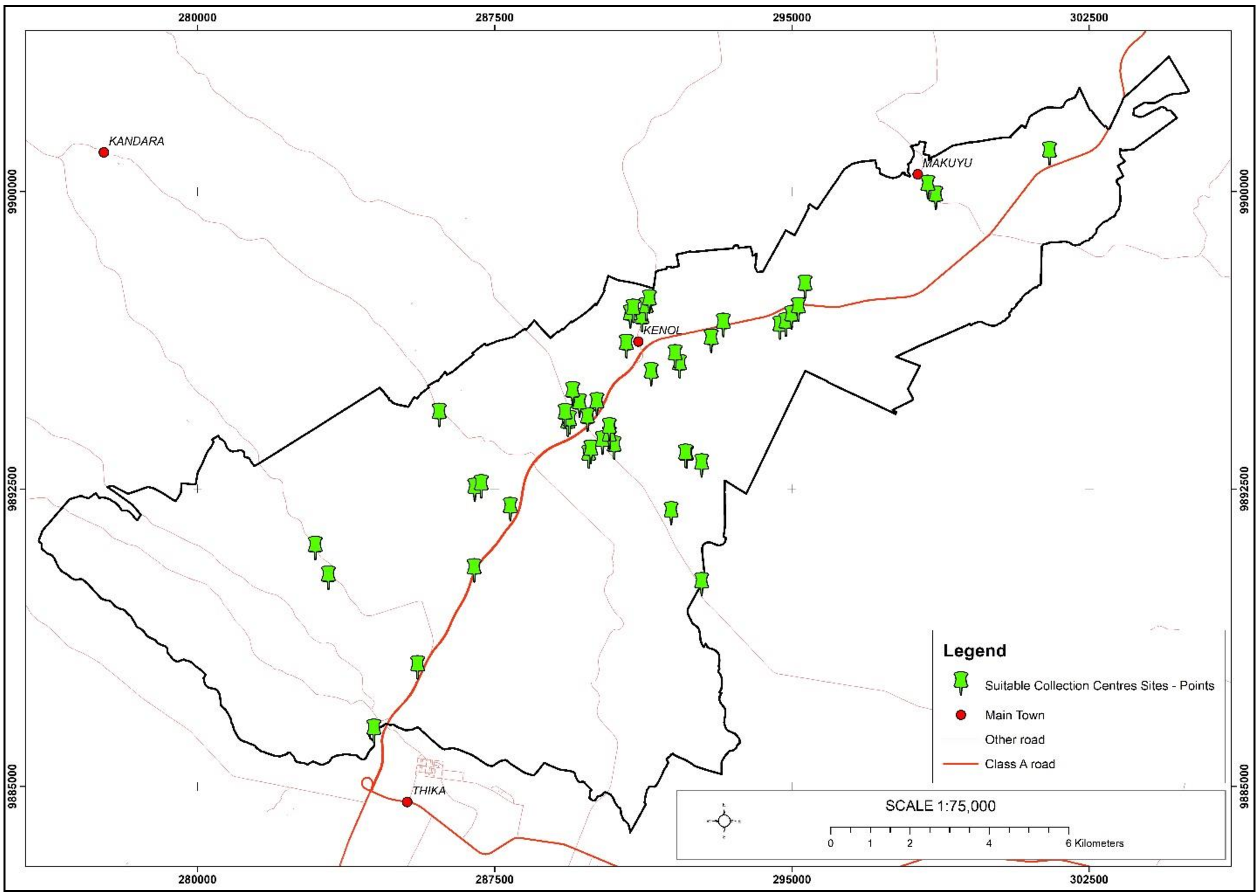

Figure 4.9: Suitable sites for collection centres as points

4.1.9 Optimal routes for waste disposal in Kenol Municipality

The appropriate routes for waste disposal in Kenol municipality were designed using the network analysis tools in Qgis (Figure 3.4).In this study, two routes were obtained after running the network analysis. The shortest route which considered distances and the fastest route which considered time. The routes assumed that all collection centre sites were to be visited. The optimal route was considered to be the one taking the shortest time. The optimal and alternative routes are shown in Figure 4.10.

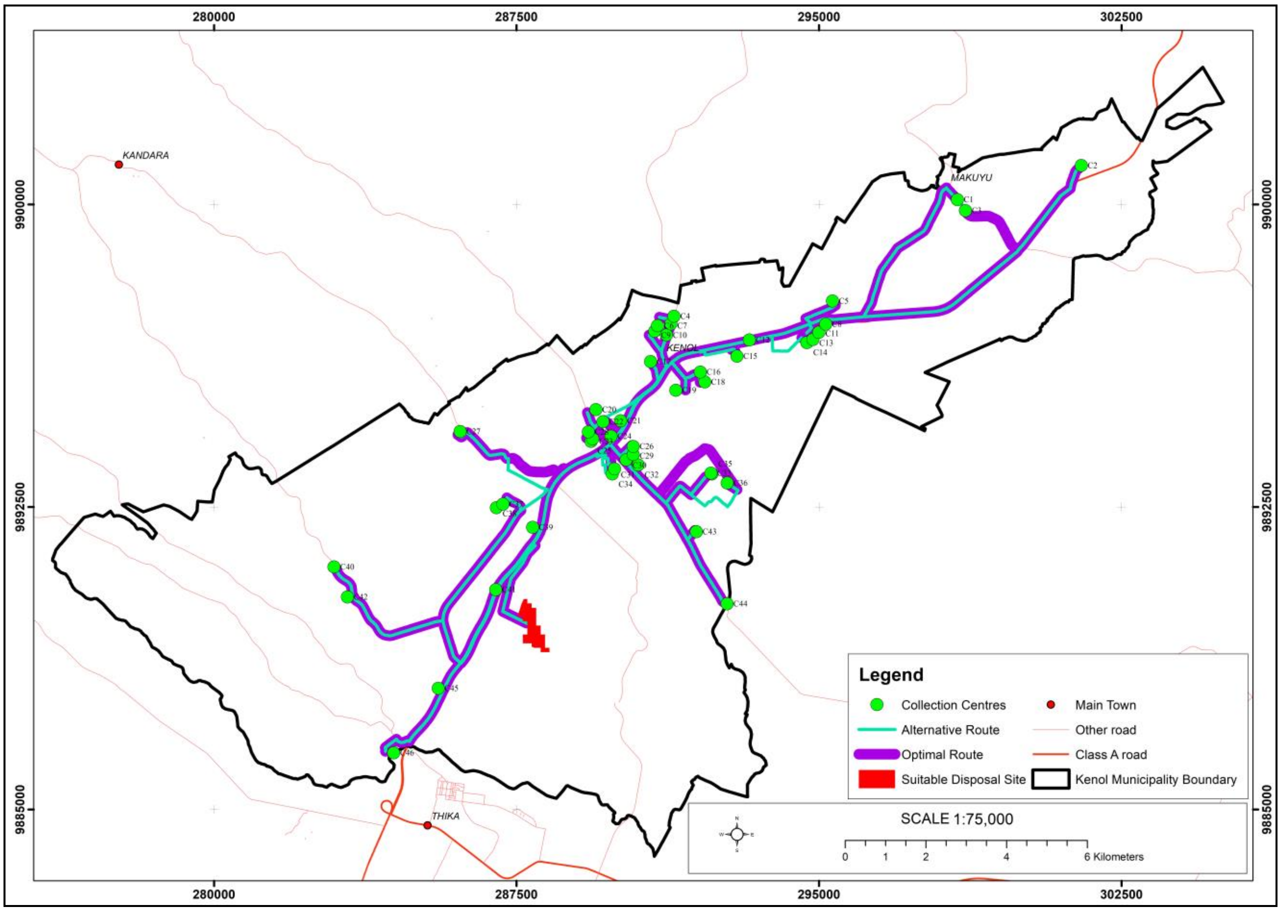

Figure 4.10: Optimal and alternative routes map for waste disposal

At an average speed of 40 km/hr and traveling from each individual collection centre to the disposal Site, a total of 2.03 hours is required to travel a total distance of 81.37 km. Table 4.2 shows a summary of breakdown of the optimal route.

Table 4.2 : summary of breakdown of the optimal route.

FROM	TO	DISTANCE(Km)	TIME(Minutes)
C1	C3	0.338	0.51
C2	C3	4.378	6.57
C3	C8	7.099	10.65
C4	C6	0.636	0.95
C4	C7	0.213	0.32
C5	C12	2.542	3.81
C6	C7	0.762	1.14
C7	C10	0.292	0.44
C8	C12	2.096	3.14
C8	C11	0.265	0.40
C9	C10	1.121	1.68
C10	C17	1.655	2.48
C11	C13	0.231	0.35
C12	C15	0.87	1.31
C12	C16	2.945	4.42
C13	C14	0.167	0.25
C15	C16	2.83	4.25
C16	C18	0.346	0.52
C17	C21	1.985	2.98
C18	C19	1.285	1.93
C20	C28	0.817	1.23
C22	C24	0.781	1.17
C23	C24	1.227	1.84
C23	C25	0.078	0.12
C24	C31	1.222	1.83
C25	C28	0.327	0.49
C31	C34	0.125	0.19
C27	C39	5.293	7.94
C29	C30	0.219	0.33
C30	C32	0.5	0.75
C30	C36	4.468	6.70
C30	C33	3.122	4.68
C30	C35	0.029	0.04
C30	C43	2.81	4.22
C37	C41	7.227	10.84
C37	C38	0.184	0.28
C39	C41	2.05	3.08
C40	C42	1.019	1.53
C41	C45	2.967	4.45
C42	C45	4.983	7.47
C45	C46	2.408	3.61
C43	C44	2.163	3.24
C39	C41	2.042	3.06
C39	DS	3.248	4.87

4.1.10 Composite map for all spatial results:

The composite map showing a combination of suitable disposal sites, suitable collection centre sites and appropriate routes at Kenol is shown in Figure 4.11.

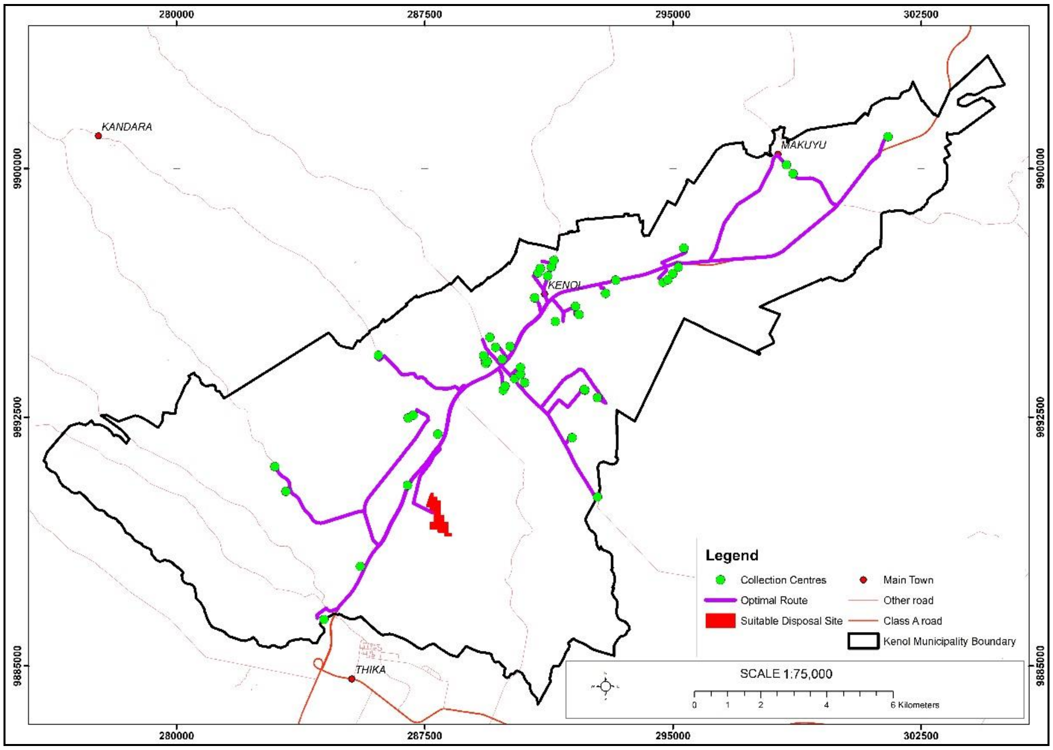

Figure 4.11: Composite map for potential Kenol waste disposal facilities

4.2 Discussions

The overlay of the various weighted suitability criteria maps and masking the constraints through GIS Multi Criteria Evaluation analysis resulted in a suitability index map from which optimal sites were obtained. After carrying out suitability analysis, 36 sites were obtained: 32 Sites which were Moderately Suitable occupied a total are of 1499.6 Ha and four sites in the Suitable category occupied a total of 107.2 Ha. The sites that were moderately suitable were more; this can be interpreted to mean that most of the areas in Kenol municipality cannot be used as disposal sites due to the immense negative impacts they will cause. This means that such kind of study is key in decision making in Kenol municipality and similar areas.

The Thika – Nyeri highway divides Kenol municipality into two, the upper part which is on the left side of the road as one heads to Nyeri and the lower side which is to the right. The results obtained reveal that there is no identified suitable site on the upper side of the road. This can be attributed to the fact that most of these areas are mostly low and high density residential areas hence could not accommodate a disposal site.

Out of the four suitable disposal sites identified, further analysis was done using size of the site and its accessibility. Site A was found to be the optimal site since it is easily accessible and nearest to an existing road which means that there will be no need to establish a new access road. Also Site A has a total acreage of 44.9 Ha which means that Site A can significantly provide some space for future expansion and a buffer for tree planting to serve as barrier for noise, dust and odor screening.

A total of 46 collection centres were identified all in the Suitable category. The collection centres identified seemed to be clustered in populated areas which in reality means that these are the waste generation sites. The result also showed that low density areas required fewer collection centers while the opposite was true for high density areas.

After designing the appropriate routes, two routes were obtained that can transfer waste from the collection centres to the disposal site. The optimal route was found to be the one taking the shortest time to complete a trip while the alternative route had the shortest distance but took longest time to complete a trip. These means, you could find a long route in terms of distance but shorter when considered the travel time taken.

The weights obtained for the identification of a disposal site and collection centres indicate that Landuse / landcover and landuse zones, soils and roads are the very important factors that carry the highest weights in identification of the sites. An evaluation of the weights was done through use of a pairwise comparison matrix obtained with the assistance of experts. The matrix had a consistency ratio of 0.087 for disposal site and 0.081 for collection centres which is less than the threshold of 0.1. This means that the weights assigned were consistent and acceptable.

In comparison with the current situation, Kenol municipality does not have a defined solid waste management system; there are designated sites for either waste disposal or collection. Normally, the generation centres dispose waste near the roads and the municipal council takes the responsibility of collecting the waste and dumps it on open ground set aside for cemetery which is at Kimorori-Nevi. These makes management of waste very challenging. With the proposed sites for disposal and collection, the municipality can be able to assign trucks and drivers at specific day and time and be able to monitor performance.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The Objectives of this study were:

1. To select suitable site for disposing solid waste.
2. To select suitable sites for collection centres.
3. To design appropriate routes for disposing waste.

These have been carried out and it can be concluded that:

- Selection of suitable disposal and collection centres sites was achieved.
- Appropriate routes for transporting waste from potential collection centres to a potential disposal site have been designed
- With availability of Spatial Data, it is possible to make informed decisions that helps avoids great negative environmental impacts.
- This study has well demonstrated the use of the MCDA and GIS for site selection, therefore GIS can be used to identify optimal sites with minimal impacts
- Multi-Criteria Decision Analysis is able to consider and incorporate various conflicting objectives and decision maker preferences into spatial decision models
- The routes and suitable sites obtained through GIS and spatial modeling techniques Optimizes waste collection and transportation and may provide significant economic and environmental savings through the reduction of travel time, distance, fuel consumption and pollutants emissions.

5.2 Recommendations

From the study it is recommended that;

- GIS and MCDA methods be applied for Solid waste management in similar situations
- In order to achieve Sustainable development, the results of the study can be used by planners plus other policy makers in setting policies for solid waste management
- To achieve sustainable solid waste management mainly in fast developing urban areas, , spatial data development and resource mapping should be upheld by relevant authorities since it is key in obtaining good and precise results that are used in informed decision making

- A comprehensive Environmental Impact Assessment to be conducted, to establish the suitability of the identified sites in Kenol municipality. Traffic studies to be carried out in order to incorporate traffic data in establishment of cost optimal routes.

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