Municipal solid-waste collection and disposal management using geospatial techniques in Maseru City, Lesotho

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Abstract

The use of geospatial techniques plays a crucial role in solid waste management. Collection and transportation of solid waste must be done in an efficient manner to avoid negative environmental impacts. At the time of study, there are no collection and routing system in Maseru City, leading to haphazard collection and disposal of Municipal Solid Waste (MSW). The aims of the study are: (i) To get an understanding and address the challenges faced by relevant stakeholders in solid waste management for Maseru City, (ii) To minimize adverse environmental impacts due to unscientific location of a disposal site and (iii) To minimize transportation costs and time during collection. The objectives of this study are summarized in the following: assess the current solid waste management, model suitable disposal/dump sites, determine MSW collection points and develop an optimal route for MSW collection and disposal in Maseru City.

To assess the current solid waste management, 130 households, 73 community waste pickers, 15 Maseru City Council (MCC) management staff and 3 drivers were interviewed, and relevant data collected. Both primary and secondary data collection methods were used. Primary data collection methods included interviews, questionnaires and observations and creating feature classes in a geo database. Secondary data collection was done from relevant government repositories, digitization, and internet web sites. Simple random, area, cluster, and convenience sampling techniques were applied. Geographical Information Systems (GIS) and Remote sensing techniques were used to carry out suitability and network analysis, and location of MSW collection points.

The study found out that the dump site (Ts'osane) was used by MCC and was not suitably located, hence more suitable alternative dump sites have been proposed. However, Ts'osane dump site was adopted in the analysis as it is the one used by MCC at the time of study. The researcher also found out that there were no designated MSW collection points and optimal routes, and that solid waste collection was done by both MCC and CBOs. In this regard, 334 collection points have been determined based on population and generated solid waste per Constituency and were randomly located in the study area. However, due to the policy that within 25m from the road no development could take place, only collection points which fell

within 25m from the road were selected and used in the routing analysis. One truck was used in the analysis, although more trucks could be used as it was at the time of study.

For future research, there is a need to research on policy so that criteria for locating solid waste disposal and location of collection points is explicitly specified in the law to be able to conduct scientific analyses. A multi modal network analysis that would include all the vehicles used by MCC and the CBOs to develop a comprehensive network analysis that would also include necessary attributes such as road names, type, class, and length is needed.

Acknowledgements

I would like to give my sincere thanks to all stakeholders that participated in data collection with all their hearts. This research would not have been a success without Maseru City Council staff including drivers, households, and community waste pickers. I also thank the Chiefs and Community based personnel for making this study a success. I also want to give my sincere gratitude to government of Lesotho for giving me an opportunity to further my studies, thus granting me study leave and financing my studies and also providing necessary data that was needed in this research through relevant ministries. I would not forget the support from my colleagues and fellow students for the amazing support. Thank you, University of Cape Town, for making a hustler out of me, making a hard worker and making someone who cares for others. My wonderful parents! Ntate Monethi and ‘M’e ‘Malitlhare, you are amazing and thank you for always pushing me to get master’s degree. My entire family, thank you for your amazing support. To my wonderful supervisor A/Prof Patroba Odera, thank you for guiding me all the way through, without despair. You have been with me even in difficult times. Finally, I would like to thank the Almighty God for guidance, protection and strength to make it.

Dedication

I dedicate this research to my only two daughters Ntebo and Thato, who have been supportive all the way through. I want them to know that I love you and with this research you will remember that mummy left you for some months for school. Thank you for such support and always giving encouraging words all the time.

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List of Abbreviations

CBOs: Community Based Organizations

CRP : Capacitated Routing Problem

GIS : Geographic Information Systems

HH: House Hold

MCC : Maseru Community Council

SWM : Solid Waste Management

MSW : Municipal Solid Waste

MSWC: Municipal Solid Waste Collection

MSWM: Municipal solid Waste Management

RCP : Risk Constrain problem

SVRP : Stochastic Vehicle Routing Problem

TSM : Travelling Salesman

VRP : Vehicle Routing Problem

VRPTW: Vehicle Routing Problem Time Windows

VRP : Capacitated Routing Problem

UTM : Universal Transverse Mercator

WLC : Weighted Linear Combination

CHAPTER ONE: INTRODUCTION

1.1 Background

Solid waste management has been considered as the concerning issue over the world. The ever-increasing world population, increasing consumption of resources and rapid urbanization have led to increase in the generation of solid waste (Kaza et al., 2018). As cities grow and expand, the amount of municipal solid waste grows even faster than urbanization (Hoornweg & Bhada-Tata, 2012). Municipal Solid Waste (MSW) is defined to include refuse from households, non-hazardous solid waste from industrial, commercial and institutional establishments (including hospitals), market waste, yard waste and street sweepings (Gavrilita, 2006). It is estimated that in 2012, world cities generated about 1.3 billion tons of solid waste per year, and this volume is expected to increase by 2.2 billion tons by the year 2025 (Hoornweg & Bhada-Tata, 2012). Waste and solid waste studies have projected that by 2050, global waste is expected to grow by 3.40 billion tons per year; making collection of all waste and procuring of land more and more difficult, globally, waste generation per capita averages to 0.74 and nationally from 0.11 to 4.54 kg (Kaza et al., 2018). In low income countries, such as in Sub-Saharan Africa, collection of waste is haphazard, insufficient and limited to areas with more wealth and willing to pay for the services and it ranges as low as 41% while in high income countries such as in Europe, Central Asia and North America it is about 98 % (Hoornweg & Bhada-Tata, 2012).

Financing Municipal Solid Waste Management is a critical challenge facing municipalities and low-income countries spend about 20% of their budget in waste management (Kaza et al., 2018). Solid Waste Management can be defined as the discipline that deals with various aspects such as control of solid waste generation, storage, collection and transport, processing and disposal of solid waste in a manner that is environmentally and economically sustainable (Kaza et al., 2018). With these constraints, and statistics, transportation and disposal of solid waste from point of generation to disposal site must be high, which would translate to higher costs and time and consequently most solid waste will go unpicked. Generated solid waste should be transported and disposed timeously and efficiently. Failing to do so, waste could be illegally and haphazardly disposed. With these insights there is need to manage solid waste effectively, as the impacts of uncollected waste are severe. Considering the waste management problems, the waste hierarchy is used globally to remind those who generate and manage waste that reducing, reusing and recycling (3Rs) waste is the best possible ways although efficient use of raw material is the best option. The 3Rs (Reduce, Reuse and Recycle) strategy happens to be Ontario's Pollution Probe in the early 1970s and recently a fourth R (recovery) is frequently added (Hoornweg & Bhada-Tata, 2012). The Ontario's Pollution Probe was a Canadian movement which was against environmental pollution in the city of Ontario (O'Connor, 2010). Figure 1 shows strategies to solid waste management and how they are approached differently globally. As shown in figure 1, in the advocated desirability, the reduction of waste is at the top of the hierarchy, re use of materials is advocated to avoid more waste. Recycling of materials and recovering could also reduce waste. Land filling and controlled dumping is encouraged. However, globally the advocacy is done vice versa. Figure 1 below shows waste management hierarchy.

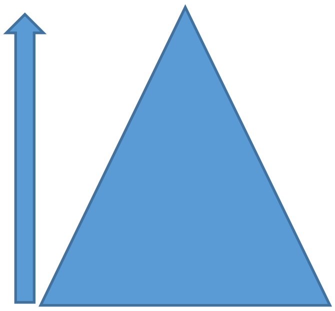
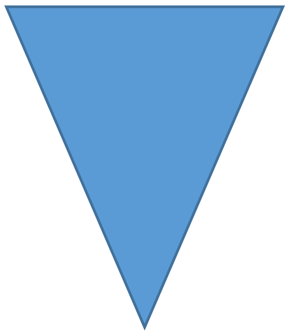
Strategies to solid waste management	Advocated desirability	Global trend
Reduce	Most preferred	Least practiced
Reuse		
Recycling		
Recovery (digestion and compositing)		
Landfilling		
Controlled dump	Least preferred	Most practiced

Fig. 1: Waste management hierarchy (Source: (Hoornweg & Bhada-Tata, 2012)

1.2 Description of the Study Area

Lesotho is a country with a coverage of 30355 square kilometer located between latitudes 28° to 31° S and longitudes 27° to 30° E (Ambrose, Pomela & Talukdar, 2000). Lesotho is entirely enclosed by Republic of South Africa. It is divided into ten districts of which Maseru district has the capital city 'Maseru' (Ambrose, Pomela & Talukdar, 2000). Maseru city has a population of about 297225 (Lesotho. Bureau of Statistics, 2016). The population for constituencies was derived from Village list (Lesotho. Bureau of Statistics, 2016). Maseru is divided into ten electoral Constituencies. The constituency is composed of several villages and small electoral wards according to the size of the constituency. Figure 2 shows location of constituencies in Maseru City.

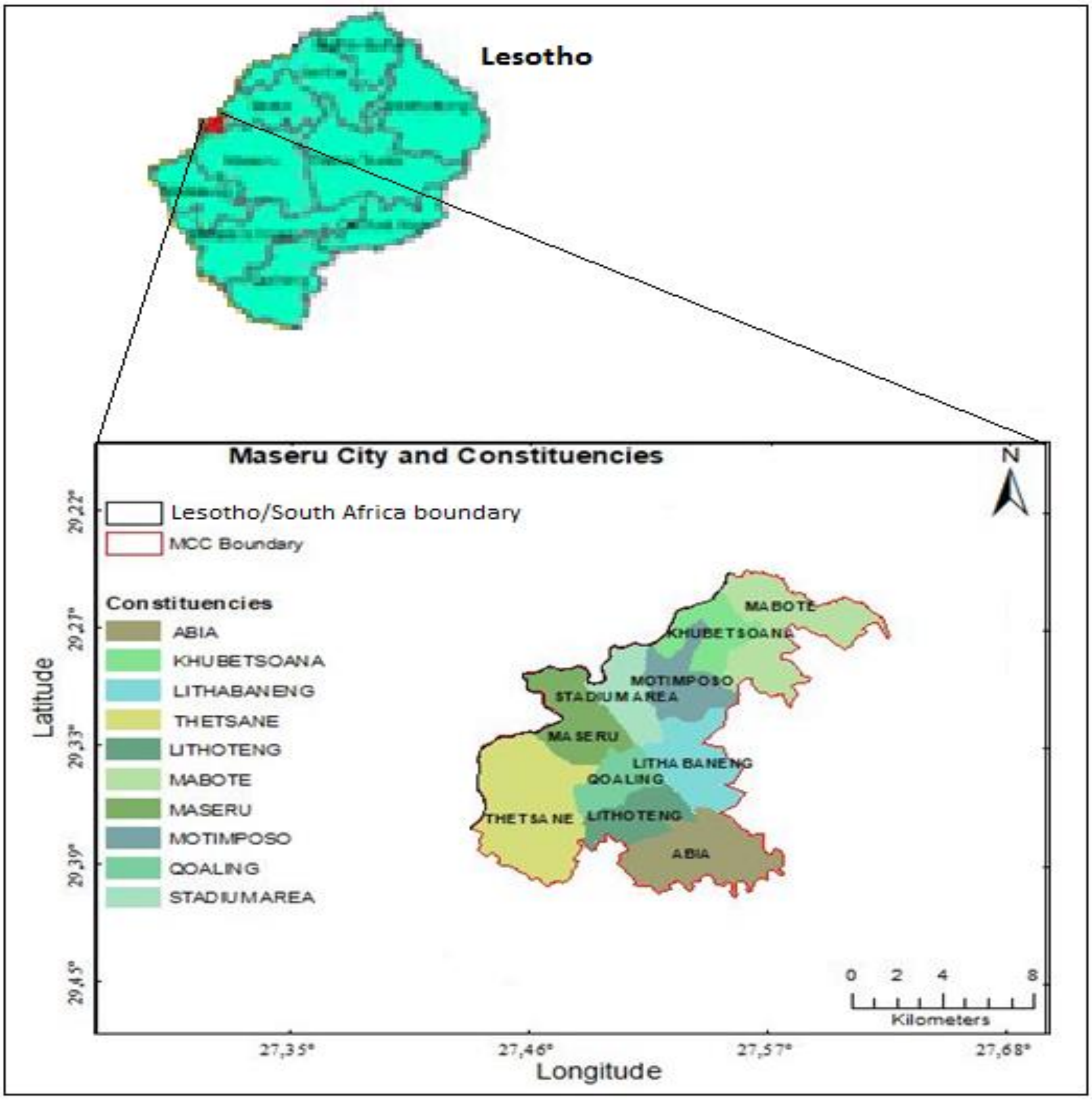


Fig 2: Study Area

Lesotho, like other developing countries, solid waste management is one of the main problems which poses threats on the environment and social life, starting from collection to disposal due to unplanned facilities, increased waste generation and population growth. Although open dumping is criticized of its contribution of methane gas in the atmosphere which increases global warming (Hoornweg & Bhada-Tata, 2012), it is still occurring in Maseru city. Open dumping and haphazardly disposed waste were an ongoing problem and these habits cause environmental degradation and poses threats on public health. An effective solid waste management is needed to curb environmental problems. Maseru is one district among the ten districts in Lesotho.

MCC oversees management and administration of the municipality including promotion of public health and good sanitation. MCC is the body mandated to manage municipal solid waste in Maseru City, Lesotho. The Municipal Solid Waste (MSW) is managed in categories. MCC only deals with solid waste in households and in the business sector. The collection of solid waste from households is managed differently to that of the business sector. In the households, solid waste is collected by different groups. The two groups are MCC and Community Based Organizations (CBOs). However, not all communities have CBOs, some villages only have informal waste pickers and some residents manage their own waste. Currently, the system applied by MCC was unscientific and inefficient as there are no designated collection points and routes, solid waste collection was done haphazardly. The CBOs were introduced because MCC lacked adequate provisions such as finance, poor road infrastructure, planning, equipment and staff to deal effectively with ever growing solid waste. To solve the problem, there was an introduction of CBOs. The CBOs are formal Community structures to manage waste in different communities whose aim is to manage waste in communities. The structure constitutes the chairperson, the treasure and other four members. In some areas in the communities, roads are very narrow and not well maintained for MCC trucks to collect waste. Households and business sector. MCC collects waste in planned areas with accessibility, whereas those with no proper roads suffer.

There is no practice of segregating solid waste at source. People were not aware of the drawbacks of illegally or haphazardly disposing of solid waste or littering. The collection by CBOs and informal waste pickers was both house to house and road curbside. Road curbside collection is whereby residents put their waste on the curb before time of collection and the collector collects waste at the curb. Door to door or house to house collection is whereby the collector enters the premises or yards and collects waste. Collection by MCC was done at the curbside. All waste collected from communities by CBOs was firstly collected in one chosen open space for the private truck /van to take it to the dumping site situated at the village called Ha Tso'sane just within MCC jurisdiction. However, some residents who were not able to pay for collection fees managed their own waste by either burning their waste, and some take their waste to the dumping site. The collections centers were temporary and illegal, mostly in open areas within villages or at the road junctions, or near people's houses. Waste heaps were often seen uncollected and scattered all over places which was unsightly and unhygienic.

MCC used three types of vehicles: Rear Loader Compactor trucks with 330-liter capacity or 4-ton, 60 liter or 1 ton half truck and a tractor and a trailer for collection of solid waste. The compactor truck was advantageous in that they could carry a lot of waste when full and it was covered such that waste cannot spill over during hauling. The half truck and a tractor are open and are much smaller and due to their sizes, they took a lot of trips to collect and to dispose solid waste to the dumpsite. As a result of to and from travelling, fuel and time is wasted. However, due to circumstances, collection could be done from morning to evening. Waste was collected from Monday to Saturday. Residents used private storage such as plastic bags, metallic bins, and plastic containers to store their waste. This process of collecting from street to street, from house to house was tedious and costly in terms of time, distance and fuel. The truck became on an idle mode until it goes to the dumping site regardless of time it took at the collection site. There were four to five crew members who collected waste and loaded solid waste manually into the truck. Community solid waste pickers used their own equipment to collect waste such as wheelbarrows. The collection schedule for MCC included both households and other institutions. The drivers used the daily schedule to collect solid waste from different communities. Solid waste in each community was picked once a week. However, drivers did not normally abide by the times stipulated in the schedule.

Current collection schedule for collection of solid waste at MCC

Table 1 shows the general schedule for collection of solid waste for Maseru City including commercial areas and institutions. Maseru Central included both villages and commercial area. The time for collection of municipal waste is indicated in hrs.

Table 1: Current collection schedule for MCC.

Days	**Collection Time 06h00-07h00**	**Collection Time 08h00-13h00**	**Collection Time 13h00-17h00**
Monday	Bus stop	Maseru West	Khubetsoana
Tuesday	Bus stop	Lower Thetsane and Hills view	MaseruEast, Mabote Police
Wednesday	Bus stop, Thetsane	New Europa	Sea Point and Moshoeshoe 2
Thursday	Maseru Central and Chritie House	Mohalalitoe and Fokothi	Upper and Lower Thamae, Matala, Makoanyane
Friday	Complex, Banks	Banks	Cathedral
Saturday	Maseru Central and Bus Stop	Maseru Central & bus stop	Maseru Central & bus stop

Source: MCC

The vehicles used by MCC are shown in Figures 3 and 4.

Compactor Truck

Half Truck

Fig. 3: 330 litre Compactor truck Fig. 4: 1 ton Half truck

Solid waste disposal is done in one dumping site at the village called Ha Ts'osane within the city boundary. It is about 5km from the city center. The dumping site was located at the proximity of settlements and leachate from the dumping site run towards peoples' houses and yards polluting the nearby environment and creating a bad smell to residents. Figure 5 Shows Ts'osane dumping site image acquired from Google Earth. Figure 6 shows solid waste illegally disposed on open areas. Figure 7 shows solid waste disposed illegally at the backyards of households.

Fig. 5: Ts'osane dumping site.

Fig. 6: Solid waste dumped in open spaces

Fig. 7: Solid waste dumped at back yards

In this study, the total estimated solid waste for Maseru city was found to be 107877kg. Rate of solid waste generation was 0.36 per constituency per week. After the trucks dumped the waste, it was spread over and covered by soil. Solid waste was partly segregated by village people searching for things of value to them. The household solid waste included toilet paper, plastic, bottles, cans, paper, etc.

1.3 Statement of the problem

Solid Waste management has been the greatest concern around the globe of which municipalities have difficulty in managing due to several reasons such as financial constraints and poor routing systems (Kaza et al., 2018). In Maseru City, illegally and haphazardly disposed solid waste was recognized along streets, open spaces, and near road junctions. Inappropriate disposal of waste result to polluted environment. In some other cases, children living near the dump site become at risk of contaminating poisonous substances from discarded solid waste. In Maseru City, solid waste is disposed at the dump site that is in proximity of houses. In some instances, the dump site catches fire and puts the surrounding residents at greater risk. Furthermore, the bad odor coming from the dump site was unbearable as the site was not properly managed. The trucks of MCC hauls in some parts of the city collecting solid waste from gate to gate from morning to evening. Although, drivers have schedules on which areas to serve on which days, there were no designated routes and collection points. The driver randomly decided which route to take. The system was costly and time consuming as the trucks became on idle mode throughout until it drove to the dump site consuming a lot of fuel. It is important to conduct the study to create awareness to relevant stakeholders to see the importance of optimal route planning as a tool for saving costs, time and using optimal methods to locate a disposal site to save the environment and human life. To do this, a suitability and network analyses were developed together with determining collection points for Maseru City. The suitability analysis was done to scientifically assess the suitability of the current dump site and to locate the new suitable site(s). Location-allocation problem was run to optimally locate collection points. The network analysis was done to plan an optimal routing system that could save costs.

This study used ArcGIS to tackle multiple problems by developing an optimal routing system through developing a network analysis where designated collection routes and collection centers were planned in such a manner that could save distance travelled and time. ArcGIS was also used to develop a suitability analysis using the criteria stipulated by MCC coupled with literature. The models were designed to propose a routing system that could allow trucks not to go gate by gate collecting but could collect solid waste on designated collection points and dispose solid waste in a newly selected best site. GIS was employed because it has capabilities of collecting, storing, analyzing and modelling spatially referenced data.

Several authors have conducted studies to solve routing and disposal problems using GIS in different parts of the world (Ntarangwi & Odera, 2017; Emmanuel, Musa & Nanpon, 2017; Khan & Samadder, 2016; Duru et al., 2014). Bulane (2009) conducted a study in Maseru City to locate suitable areas for transfer stations. In the study, Bulane (2009) described a transfer station as an intermediate transitory between collection points and disposal facilities to avoid collection vehicles having to haul waste over long distances to disposal and proposed transfer stations in Maseru city and used modern technologies and environmentally cautious approaches. However, Bulane's study did not indicate on how MSW should be managed from collection to disposal and did not include estimation of solid waste generation. Transportation and cost issues have not been addressed in Bulane's study. This study has addressed routing problems and by solving location- allocation problem and conducted suitability analysis to select best sites for solid waste collection. The knowledge from the study will contribute to scholarly literature by unravelling the problems of solid waste management in Maseru city and providing optimal solutions. Also, this study would provide an insight of the role space is playing in unlocking the overall development planning thought and it could be of great interest to relevant planning authorities and to emerging researchers. The findings may act as a baseline for future research and planning for solid waste management. Understanding and exploring collection and disposal methods could help to reveal the related problems and gaps and could help stakeholders to come up with mitigation strategies. The knowledge generated could also serve as an input to decision making.

1.4 Research question

How can MCC improve solid waste management using geospatial techniques?

1.5 Research aims

The aims of the study were stipulated as below:

1.5.1 To get an understanding and address the challenges faced by relevant stakeholders in solid waste management for Maseru City.

1.5.2 To minimize adverse environmental impacts due to unscientific location of a disposal site.

1.5.3 To minimize transportation costs and time during collection.

1.6 Objectives of the study

1.6.1 To assess the current solid waste management in Maseru City.

1.6.2 To carry out suitability analysis for the dumpsite using geospatial techniques.

1.6.3 To determine suitable solid waste collection points

1.6.4 To develop an optimal route network for MSW collection and disposal in Maseru City using geospatial techniques.

1.7 Limitations

This study is limited to Maseru city. Also, the study focuses only on generation, collection, and disposal of municipal solid waste: it does not consider solid waste treatment. Waste from institutions, hospitals, agriculture, construction, demolition, and municipal sewage is not part of the study.

1.8 Research structure

The structure of this research follows six chapters as illustrated below.

Chapter one introduced background of the study, research problem, statement of the problem, research questions, and objectives. The scope of the study was also addressed and limitations.

Chapter two reviews previous literature on solid waste collection and disposal systems. The methods of locating an optimal disposal site, and criteria used were explored. Also, the methods used to develop routing system and location allocation problem were also explored. Methods of research approach and data collection methods were also explored.

Chapter three presented methodologies, tools and techniques employed in the study. The analysis methods for this study were also outlined.

Chapter four presented the results obtained from the study through use of geo spatial techniques for solid waste management in Maseru city.

Chapter five presented the Discussions on the findings

Chapter Six represented the conclusions and recommendations of the study.

CHAPTER TWO: SOLID WASTE COLLECTION AND DISPOSAL MANAGEMENT

The purpose of this chapter is to review the existing literature on solid waste management strategies and the infrastructure and to also identify gaps in such literature to propose a strategy that could work for the Maseru city. Past studies have been reviewed related to waste management and methods such as general methods of MSW collection and disposal, and methods on determining optimal disposal site, determining solid waste collection points, solving location-allocation problem, and determining optimal routing system. First, general methods for collection and disposal of MSW were explored.

2.1 General Methods for MSW collection and disposal

Several methods for collection of solid were discussed. There are several methods to collect MSW: House to house, curbside and self-delivered (Gukhool, 2015). A house-to-house method is whereby waste collectors visit each individual house to collect garbage. There is a certain fee that a user generally pays for such a service. A curbside method is whereby waste generators leave their garbage directly outside their homes and wait for collection as per schedule by a collector. Self-delivered method occurs where households dispose and transport waste themselves (Gukhool, 2015). Some cities use dual mode of collection from door to door to a centralized point and aggregation is normally done at that point. In Jakarta, the waste collectors are generally volunteers who are not paid, only security guards and cleansing workers are paid. (Pasang, Moore & Sitorus, 2007). Waste is then transported to temporary transfer points prior to collection by relevant authority (Pasang, Moore & Sitorus, 2007). Collection in Jakarta is done in two ways: (i) door to door by each household by truck, (ii) the truck announces collection time by music, then residents bring waste by themselves (iii) private collection is done by privately contracted companies which directly collects waste from residential or commercial areas. The door-to-door method in Jarkata, uses bins which are about $10m^3$ or open concrete about $6m^3$ which is placed close to communities so that households can dump their waste in there before collection. The method of door to door is also practiced in

African countries such as, Mozambique, Lesotho and Nigeria (Ferrão, 2006; Lesotho government, 2006; Agunwamba, 1998; Parrot, Sotamenou & Dia, 1989). Although Bins are mostly used to store MSW like in India (Khan & Samadder, 2016) whereby bins are located at some points near neighborhoods to wait for collection, they are not properly designed and not optimally located or maintained resulting in poor collection.

Transportation of waste is seen as the most important activity in the solid waste management. The type of vehicles plays an important role throughout the process. Vehicles are categorized as 'simple emptying' vehicles and Container Vehicles. In Africa, collection and transportation of waste is done by non –mechanical methods such as human-drawn or animal-drawn carts, and wheelbarrows. Also, mechanical vehicles are still in use (Gukhool, 2015). Rear loading vehicles are rigged with compactors which allows the bigger quantity of waste to be loaded into the container either, manually or mechanically (Gukhool, 2015). Topper bins are used in some areas where waste is loaded from the top and compacted as much as possible. The front loaders are equipped with the front -lifter which it raises to tip bins into their container. The multi chambers have vertical and horizontal sections or chambers to load different kinds of waste. Container vehicles are used for exchanging of containers to load and unload containers or boxes of waste and the sizes ranges from 120 to 1100 litres in most countries. The collecting vehicle consists of a driver, and from two to eight crew members who collect waste containers and load them into the vehicle (Gukhool, 2015).

Proper disposal of waste is also a critical issue in most developing countries. Method of disposal could either be open dumping, controlled dumping to sanitary land filling (Hoornweg & Bhada-Tata, 2012). Globally, waste disposed in landfills is approximated at 40% while 33% of waste is disposed in open dumpsites (Kaza et al., 2018). In low-income countries, where landfills are not yet available or well managed, open dumping is most prevalent with about 93% of waste burnt, dumped in roads, open spaces or water ways (Kaza et al., 2018). Solid waste disposal around the world is mainly done on land and almost 40 percent is disposed in open areas or dumpsites in low-income countries (Kaza et al., 2018). Low-income African countries such as Lesotho, Mozambique, Nigeria, and Ghana use dump sites for solid waste disposal. While open dumping and burning of waste cause health and environmental problems, the widely used disposal method is to develop an optimal disposal method which will be environmentally safe, (Hoornweg & Bhada-Tata, 2012).

According to a study conducted by Lesotho government (2006) in some areas, a community had to collect waste by itself and transport it to the nearest collection point because MCC could not afford to collect waste around the city and there were no collection points. Each resident had to pay around $0.4 per month to buy their own storage for solid waste. The challenges of solid waste transportation according to the study was that the servicing of vehicles was done once a week to once a month which put pressure on collection. As a result of the unreliability of the MCC trucks, private companies were hired to take over while waiting for the truck to be road worthy. The Ts'osane dumping site was used for dumping of municipal solid waste in Maseru City (Mvuma, 2010; Bulane, 2009; Lesotho government, 2006; Seholoholo, 1998). However, the disposal site according to Bulane and Lesotho government studies found out that Ts'osane dumping site was not well situated because it was at the proximity of houses. Table 2 shows past studies which estimated solid waste generation of municipal solid waste in Maseru City.

Table 2: Past trends on solid waste generation in Maseru City

Reference	**Solid waste (tons)**
(Bulane, 2009)	32900
(Lesotho government, 2006)	84060
(Mvuma, 2002)	23632

2.2 Methods for siting an optimal disposal site

Locating a disposal site such as a landfill requires various factors to be considered and incorporated into geographic approaches that will take care of environment through considering multi alternatives (Chabuk et al., 2017). Methods explored for siting a disposal site were Weighted Linear Combination and Nonlinear Combination methods. Nonlinear combination methods included Gestalt Method, Binary and Fuzzy Overlay.

2.2.1 Weighted Linear Combination (WLC)

Lane and McDonald (1983) introduced the Weighted Linear Combination method in the decision rules. Weighted Linear Combination method is also defined as Simple Addictive

Weighting (Chabuk et al., 2017). This method uses overlay technique to apply a common scale to differing alternatives to create an integrated analysis (ESRI, 2020). Cells are transformed to a common scale between 1-10. Raster are transformed, weighted and then combined using weighted overlay. The importance of the criterion is dependent on the weights assigned to each factor. However, the importance of factors can vary from one study area to another based on the local circumstances, therefore relative importance should be based on local conditions (Al-Hanbali, Alsaaideh & Kondoh, 2011). Weights are based on a relative percentage not exceeding 100 percent and are determined by experts, stakeholders, decision makers and determine the relative importance of one criterion to one another. The weight is described as the degree of importance of one criterion in relation to another. The underlying assumptions in this method are that there is no integration or effect between the layers and in an attribute and any additional unit remains constant at any level of that attribute (Malczewski, 2000).

2.2.2 Nonlinear Combination methods

The nonlinear combination method was described by Hopkins (1977). In this method, unlike Linear combination method, the results are analytically obtained for all factors put together. The only difference from WLC is that the relationship of factors is nonlinear instead of addition. Lane and McDonald (1983). Relationships required to deal with the full range of costs and impacts are not known.

Nonlinear methods include Gestalt method where decisions are made based on partitioning the entire study area into homogeneous parts directly through field observations (Hopkins, 1977). Factors can be drawn from aerial photographs, or topographic maps. Land cover types are determined by implicit judgments rather than explicit rules. Another model is Binary Model Esri (2020), which uses logical expressions to select spatial features from multiple rasters. The output format of the binary model is in binary format where raster cells are transformed to a binary scale of 0 or1, where 0 represents raster values which are not suitable, 1 represents cell values that meet the selection criteria. Transformed raster values are multiplied to get a raster layer representing all criteria. Fuzzy Overlay model is another nonlinear model (ESRI, 2020). In the fuzzy model, the logic behind fuzzy is based on the 'set' where raster cells are combined on a scale of 0-1, cells with a value of 1 have more membership to a cell while cells with a value of 0 have low membership to a set. Transformed raster are combined using one or more overlay steps. The overlay is used and assigns the minimum values from all the input raster to the suitability surface.

2.3 Criteria for locating suitable disposal site

Locating a disposal site requires various factors to be considered and incorporated into geographic approaches that will take care of environment through considering multi alternatives (Chabuk et al., 2017). This is to state how various factors affects location of a disposal site hence care be taken. The factors explored were slope, ground water depth, soil classifications, geology, land cover, distance to roads and distance to streams.

Slope: Slope is defined as the measure of rate of change of elevation at a surface location and normally expressed as percent or degrees slope (Chang, 2019). Land slope is an important factor in selecting a land fill location as areas with steep slopes have a possibility of increasing drainage of pollutants such as leachate to flow from the landfill site to the surrounding environment (Lin & Kao, 1998). Higher slopes increase excavation costs (Wang et al., 2009) and stability issues during the construction phase and such areas are considered not suitable for construction of a disposal site (Demesouka, Vavatsikos & Anagnostopoulos, 2013). There is a higher risk of landslides due to landfills placed on hill sides and valleys as this can cause serious accidents and health problems (Colomer-Mendoza, 2013). In degrees, a slope between 8-10 is considered highly suitable for construction of a disposal site (Kamdar et al., 2019; Chabuk et al., 2017; Effat & Hegazy, 2012). In percent rise, a slope between 10-20 was considered highly suitable (Alanbari et al., 2014; Al-Hanbali, Alsaaideh & Kondoh, 2011).

Ground water depth: Depth to water table is explained as depth from the ground surface to the water table (Al-Hanbali, Alsaaideh & Kondoh, 2011). Ground water is considered as one of the most crucial phenomena to consider when selecting a disposal site as contamination of ground water through percolation of leachate from the land fill results in adverse impacts (Kamdar et al., 2019). A disposal site must not be sited near ground water sources such as springs, or wells (Effat & Hegazy, 2012) as ground water is the source of water. Shallow ground water depth is considered not suitable for locating a disposal site to safeguard water pollution (Kontos, Komilis & Halvadakis, 2005). According to several researchers, a disposal site should be located where the ground water depth is low (Kamdar et al., 2019; Kahraman et al., 2018; Chabuk et al., 2017). To derive ground water depth, Interpolation method is used.

Inverse Distance weighting (IDW), has been used by several researchers, (Chabuk et al., 2017; Arkoc, 2014; Al-Hanbali, Alsaaideh & Kondoh, 2011)

Soils and geology

Soils and Geological strata were important to consider when selecting a solid waste disposal site. Carrol and Bascom (1967) described the type of rocks: Elliot, Molterno, Clarens and Tarkstad. Elliot type of rock is also known as '*red beds'* because of their reddish/yellowish color. It is mainly dominated by reddish mud stones and silt stones and yellowish sandy shales. Molteno beds are type of sandstone rocks which are composed of calcium and weather to form a rich stiff clay sandstone. Clarens rocks are also called '*cave sandstone'*. It contains fine grained sandstone and weathers to a clay rich material. Tarkstad rocks are shale with sandstone and are also called Upper beaufort beds. Upper Beaufort rocks are mainly composed of shandy shales with sand stones and reddish mudstones. Siting a disposal site also requires a cautious determination of soil stratums which are permeable and risky of leaching (Demesouka, Vavatsikos & Anagnostopoulos, 2013) hence areas with high permeability such as sandy and loose stones are given low suitability weighting. Vertisols soils consist of clay particles with low permeability while Fersiallitic consists of medium to high coarse sand (Carrol & Bascom, 1967). The texture of Fersiallitic soils was relatively finer that sandy soils, that is they are low clay and formed from a sandy parent rock. Lithosols are those soils that developed from sedimentary rocks or ferromagnesium rocks and are caused by slow weathering of dolomite which may result of steep slope (Carrol & Bascom, 1967), these rocks are mainly mixed soils. Claypan soils are composed of rich clay. Soils that are rich in clay are good for siting a disposal site since clayey soils are not porous. Porous soils such as gravel, and sands are unsuitable, because of their high porosity and high-water permeability, quality of underground water could be affected. The best are silty clays and silty sand (Arkoc, 2014) since these soils are composed of fine particles which can decrease permeability and are good for compaction (Arkoc, 2014; Demesouka, Vavatsikos & Anagnostopoulos, 2013).

Land use/cover: Land cover is described as the natural characteristics or physical material of the earth surface, which included trees, bare land, water, bare rocks, built up land, vegetation and soil (Kahraman et al., 2018), while land use describes how people use land (Arkoc, 2014). The land cover is important as it reflects the existing cover and its spatial distribution (Tavares et al., 2009).

Land use/cover have been used by researchers as one factor to consider when locating waste disposal site. Chabuk et al. (2017) considered orchards and unused land as suitable for land fill siting, while Kontos et al.(2003) made classifications of agricultural lands and pasture lands. However, Bulane (2009) also considered agricultural land, unused land, crop lands as land use which has potential of siting a transfer station.

Simsek et al. (2014) included forest, agriculture, residential, industrial, and military and archaeology and settlements as land use types for waste disposal site. Arkoc (2014) used land cover classes to come up with suitability for siting a landfill. Areas such as agriculture, forests were unsuitable while abandoned land or dry fields were suitable for placing a land fill (Arkoc, 2014).

Roads: Distance from roads is considered important for the location of waste as waste is transported daily from the place of generation to the disposal sites. Distances near roads decreases transportation cost (Al-Hanbali, Alsaaideh & Kondoh, 2011; Kontos, Komilis & Halvadakis, 2005). Roads need to be as direct as possible to avoid spillage of waste along roads (Kahraman et al., 2018; Ekmekçioğlu, Kaya & Kahraman, 2010). A buffer of 250m was considered highly suitable (Kamdar et al., 2019; Alanbari et al., 2014). However, Bulane (2009) used a buffer of 500m from the roads.

Surface water: Landfills should not be placed near any surface waters such as lakes, and rivers (Kahraman et al., 2018; Al-Hanbali, Alsaaideh & Kondoh, 2011; Kontos, Komilis & Halvadakis, 2005) as landfills produce leachate and poisonous gases. A buffer of 300m around surface water was considered highly suitable (Kamdar et al., 2019) while 250m buffer was considered (Alanbari et al., 2014).

There are different opinions on the scoring/ranking on the suitability of factors found in literature. Tables 3,4, 5, 6, 7, 8 present the differences in ranging, scoring/ranking and scaling for different criteria. Table 3 presents slope range and ratings.

Table 3: Scoring/rating of slope

References	**Ranges**	**Score/Ratings**	**Suitability**	**Scale**
(Yal & Akgün, 2013) (%)	0-10	5	Highest	5
	10-20	4	High	
	20-30	3	Medium	
	30-40	2	Low	
	40-50	1	Lowest	
(Wang et al., 2009) (%)	0-10	5	Highest	5
	10-20	4	High	
	20-30	3	Medium	
	30-40	2	Low	
	40-50	1	Lowest	
(Uyan, 2014) (%)	0-10	1	High	3
	10-20	2	medium	
	>20	3	Low	
(Arkoc, 2014) (degrees)	<10	5	Ver high	5
	10-20	4	High	
	20-40	3	Medium	
	40-60	2	Low	
	>60	1	Very low	

According to literature, different ranges and ratings are used to rate and score distance to roads. Table 4 presents the ranges and rating to distance to streets.

Table 4: Distance to roads/streets

References	**Ranges**	**Score/rating**	**Suitability**	**Scale**
(Uyan, 2014)	<250	1	Unsuitable	5
	250-500	2	Low Suitable	
	500-750	3	Medium	
	750-1000	4	Highly suitable	
	>1000	5	Very highly suitable	
(Kamdar et al., 2019)	>1000	3	Moderate important	4

	100-750 750-250 <250	2 1 0	Weak or slight Equal importance Unsuitable	
(Pandey, Sharma & Nathawat, 2011a)	<500 500-1000 100-1,500 >1,500	1 2 3 4	Highly suitable Medium Low suitable Restricted	4
(Alanbari et al., 2014)	0-500 500-1000 1000-2000 >2000	0 3 2 1	Not important Moderate Equal to moderate Equal	4

Distance to streams is one of the criteria used to locate a suitable disposal site. Table 5 below shows ranges, ratings to distance to streams.

Table 5: Distance to streams

Reference	**Ranges**	**Score/rating**	**Suitability**	**Scale**
(Yal & Akgün, 2013	0-100 100-400 400-1500 1500-5000 >5000	1 2 3 4 5	Unsuitable Low suitable Medium Highly suitable Very highly suitable	5
(Wang et al., 2009)	500 1km 1.5km 2km >2km	1 2 3 4 5	Highly suitable Low suitable Medium Very low suitable Restricted	5
(Uyan, 2014)	<500 500-1000 1000-1500 1500-2000	1 2 3 4	Low suitable Suitable Medium Highly suitable	5

	>2000	5	Ver highly suitable	
(Kamdar et al., 2019; Pandey, Sharma & Nathawat, 2011)	>900 900-600 600-300 <300	3 2 1 0	Moderate important Weak or slight Equal importance Unsuitable	4

Land use has been used as one of the criteria for locating a disposal site. Different land use/cover classes have been classified according to suitability. Table 6 below shows suitability on land use/cover.

Table 6: Land use/cover

Land use/cover classes	**References**	**Suitability**
Agriculture	(Asefa Bedasa, & Mindahun Wondwossen, 2019; Kamdar et al., 2019; Mugo & Odera, 2019; Arkoc, 2014; Pandey, Sharma & Nathawat, 2011a) (Wang et al., 2009)	Unsuitable Highly suitable
Bare rocks	(Alanbari et al., 2014)	Unsuitable
Trees	(Asefa Bedasa, & Mindahun Wondwossen, 2019; Mugo & Odera, 2019; Arkoc, 2014))	Unsuitable
Built up	(Asefa Bedasa, & Mindahun Wondwossen, 2019; Kamdar et al., 2019; Mugo & Odera, 2019; Alanbari et al., 2014)	Unsuitable

Bare areas	(Mugo & Odera, 2019; Chabuk et al., 2017; Alanbari et al., 2014; Demesouka, Vavatsikos & Anagnostopoulos, 2013)	Highly suitable
Surface water	(Asefa Bedasa, & Mindahun Wondwossen, 2019; Alanbari et al., 2014)	Unsuitable

Ground water depth is seen as one of the crucial elements in determining a disposal site. Shallow ground water is regarded unsuitable while deep ground water is considered highly suitable. Table 7 below shows range and rating to ground water depth.

Table 7: Ground water depth

References	**Range**	**Score/rating**	**Suitability**	**Scale**
(Arkoc, 2014)	<5.0	1	Ver low	5
	5.0-20.0	2	Low	
	20.0-50.0	3	Medium	
	50.0-70.0	4	High	
	>70.0	5	Ver high	

Soils and geology have been considered important factors for locating a disposal site. Soils and geology present same classes. Table 8 below shows suitability for soils and geology.

Table 8: Soils types and geology

Soil types	**Suitability**	**References**
Silty clay	Highly suitable	(Kamdar et al., 2019; Arkoc, 2014; Demesouka, Vavatsikos & Anagnostopoulos, 2013; Pandey, Sharma & Nathawat, 2011a)
Clay	Moderate importance	
Mixed soil	Weak or slight	
Sandy gravel	Equal importance	
Silt to very fine silty clay	Highly suitable	
Sandy	Restricted	

Using a Weighted Linear Combination method requires weights to be assigned to factors (ESRI, 2020). Table 9 presents weights assigned to factors found in the literature.

Table 9: Weights from literature

Criteria	**Weights**	**References**
Slope	0.784	(Kamdar et al., 2019)
	0.0459	(Kontos, Komilis & Halvadakis, 2005)
	0.3	(Effat & Hegazy, 2012)
	0.067	(Chabuk et al., 2017)
	0.044	(Alanbari et al., 2014)
	0.1	(Al-Hanbali, Alsaaideh & Kondoh, 2011)
Ground water	0.111	(Chabuk et al., 2017)
	0.1427	(Kamdar et al., 2019)
	0.0471	(Effat & Hegazy, 2012)
	0.2074	(Kontos, Komilis & Halvadakis, 2005)
	0.05	(Al-Hanbali, Alsaaideh & Kondoh, 2011)
Soils	0.078	(Chabuk et al., 2017)
	0.0727	(Kamdar et al., 2019)
	0.097	(Alanbari et al., 2014)
Geology	0.1033	(Kamdar et al., 2019)
	0.04714	(Effat & Hegazy, 2012)
Land use	0.056	(Chabuk et al., 2017)
	0.0628	(Kamdar et al., 2019)
	0.0731	(Kontos, Komilis & Halvadakis, 2005)
	0.071	(Alanbari et al., 2014)
	0.15	(Al-Hanbali, Alsaaideh & Kondoh, 2011)
Roads	0.22	(Chabuk et al., 2017)
	0.0422	(Kamdar et al., 2019)
	0.0825	(Effat & Hegazy, 2012)
	0.25	(Pandey, Sharma & Nathawat, 2011b)
	0.0266	(Alanbari et al., 2014)
	0.1	(Al-Hanbali, Alsaaideh & Kondoh, 2011)
Surface water	0.1373	(Kamdar et al., 2019)
	0.1266	(Pandey, Sharma & Nathawat, 2011)
	0.155	(Alanbari et al., 2014)

	0.1	(Al-Hanbali, Alsaaideh & Kondoh, 2011)

2.4 Determination of the number of collection points

Several researchers have solved location-allocation problem to locate and allocate solid waste collection points and bins. The different methods used by different studies were explored.

When calculating waste collection bins for waste, Adelakun et al. (2019) used population per ward, rate of solid waste generation per person per day and capability of each collection bin as main parameters. The following equation was use by Adelakun et al. (2019). The number of bins required is calculated as follows:

$$\boldsymbol{B = \frac{W}{C}} \tag{1}$$

Where $\boldsymbol{B}$ is the total number of bins required per ward per day, $\boldsymbol{W}$ is the total waste generated per day per ward and $\boldsymbol{C}$ is the capacity of the collection bin. The capacity of a bin was equal to the capacity of the vehicle which was 4000 m^3. Cubic meters were converted to kg.

Khan and Samadder (2016) used two equations to calculate number of waste bins required for collection of solid waste. For the first method, the main parameters were area covered by a settlement within a ward and desirable service area for a solid waste bin. The first equation was as follows:

$$\boldsymbol{A = \frac{B}{C}} \tag{2}$$

Where $\boldsymbol{A}$ is the number of solid waste collection bins, $\boldsymbol{B}$ is the area covered by a settlement within a ward and $\boldsymbol{C}$ is the desirable service area for a solid waste bin. A radial distance of 100m as the service area for the first equation was used. After collecting data and doing analysis, Khan and Samadder (2016) used the distance inhabitants' willingness to have bins as close as possible to their homes, the following second equation was used:

$$\boldsymbol{D = \frac{W}{d\,S\,E\,C}} \tag{3}$$

Where ***D*** is the number of solid waste bins, ***W*** is the amount of solid waste generated per day in kg, ***d*** is the average density of organic waste in Kg cubic meters, ***S*** is the size of the solid waste bin m^3, ***E*** is the average collection efficiency of a solid waste collection bin and ***C*** is the collection frequency. The loading capacity of the vehicle was $15m^3$ and this was taken as the capacity of the waste bin. The bins were located at the intersections and Euclidean distance was run to see which points fell inside the radial distance. The radial distance was 100 m, which was the distance people were willing to travel to the bin.

Ntarangwi and Odera (2017) determine the number of collection points using the following equation.

$$\boldsymbol{NPS = \frac{RWG \times PS}{Cp}} \quad (4)$$

Where ***NPS*** is the number of collection points required for a sub location, ***RWG*** is the rate of solid waste generation per person, ***PS*** is the population for a sub location and ***Cp*** is the capacity of each collection point which was equal to the capacity of the front-End loader (400 kg in their study). Collection points were located randomly in the study area. A cut off distance of 200 m was used. A buffer of 200 m applied around roads. Points which fell outside the buffer were ruled out of the analysis.

2.4.1 Location-Allocation Problem

Location-allocation problem is considered as one of the most important problems in operational research. Cooper (1963) explained that location-allocation problem is used to increase operation efficiencies through optimizing various networks such as transportation and communication. A set of destinations that have a known location need to be served and supplied in an optimum manner. Things that need to be determined are number, location and size/capacity of the sources that will most supply a given service or destination in an economic manner.

Boskovic & Jovicic (2015) solved a location-allocation problem in waste collection using GIS. In their methodology, the situation was assessed, then after, they defined optimal locations for collection points as per chosen distance and defining number of bins depending on the estimated waste generation for each location. Reduction in fuel consumption, time and distance was achieved. Ntarangwi & Odera (2017) solved location-allocation problem for Thika

Municipality and found that there is a possibility of improvement of 34% in terms of service delivery from the previous service of solid waste management to proposed service delivery. Khan & Samadder (2016) presented a method for solid waste bin collection at appropriate places using ArcGIS with a uniform distance and locations which were easily accessible for the collection routes to be minimal for the city of Dhandad India. Rathore, et al., (2019) solved the problem of bin allocation for waste collection system. In their model, determination of number of different bins for varying kinds of waste was developed, then best potential points for allocation of bins were selected. Rathore, et al., (2019) integrated GIS with Mixed Integer Linear Programming methods. This resulted in a reduction in the number of collected points by 15% and reduction in idling costs. Ghose, et al., (2006) used parameters such as population density, width of roads, availability of space and minimum travel distance from a house to propose distribution of different types of collection bins.

A minimum distance constrained was used for location- allocation problem by several researchers (Erfani et al., 2017; Ntarangwi & Odera, 2017; Vijay et al., 2005). Zamorano (2009) proposed an algorithm for allocation of different types of bins to optimize waste collection service in Churriana de la Vega and used GIS technology to collect city routes, population density and space availability to allocate bins. Zhao & Ke (2017) developed an optimizing model to minimize total costs and risk to decide where to locate collection centers, how to manage inventory level for each center, how many vehicles needed, how to route explosives from generation to collection centers and from collection centers to recycling facility and results showed a significant improvement in both system costs and environment. A heuristic solution for optimal waste collection and transportation was developed by Das & Bhattacharyya (2014). The optimization was done from source and collection centers, then from collection centers to transfer stations, from transfer stations to processing plants and finally to the landfill. In their study, Das & Bhattacharyya (2014) found out that waste collection path length was reduced by 30 percent and costs saved. Erfani et al., (2017) used an integrated model by solving location-allocation problem and used GIS to solve vehicle routing problem. In their model, Erfani et al., (2017) found that the current collection system was not efficient and not compatible with the existing urban structure and population distribution. The model improved storage and collection system and walking distances were optimally solved by finding optimal bin locations and potential location for bin allocation were identified using population distribution, per capita solid waste generation and road network constraints. Lella et al. (2017) also used GIS techniques through network analysis to present possible collection methods for solid waste management in India. Lella et al. (2017) optimized route system for collection and transportation efficiency following the various dustbin locations in the city. Network analysis was used to propose an optimal route for transportation of waste from the transfer station to the disposal site. Possible transfer stations were proposed based on various design factors. A uniform solid waste collection bin size was used. (Vijay et al., 2005) used Triangular Irregular Networks (TINS) to allocate solid waste collection bins and the travelling distance of the loaded vehicle with the ascending slope direction, the results showed a decrease in travel distance and fuel consumption.

2.5 Developing an optimal routing system

The material discussed here provides full understanding of the Vehicle Routing Problem (VRP) from the literature. The issue of VRP has been existent since 1950s and has been researched widely by many researchers. The brief history of the VRP was discussed. The VRP has been formulated with additional constraints such as distance, time, capacity and risk. These variations of the VRP were also discussed.

2.5.1 A brief history of Vehicle Routing Problem (VRP)

The VRP phenomenon was first established by Dantzig & Ramser (1959), where linear approach was followed to come up with the VRP. The VRP is one of the popular and most well-known optimization models that is aimed at designing the optimal set of routes for serving customers, such that it is compatible with the existing constraints. It is used to solve problems in many areas such as supply chains, air cargo, logistics, and many management deliveries. The popularity of VRP rests in its flexibility since various supplementary constraints can be added to the problem. Supplementary constraints may be added to suit specific service, nature of goods, and vehicle used in the problem (Dantzig & Ramser, 1959). Supplementary constraints may include distance limitation in some routes, load capacities, time frames where a service or vehicle needs to adhere to certain time windows, vehicle types based on the type roads and precedence where there should be a specific organization between a customer being serviced and the supplier (Dantzig & Ramser, 1959). It involves the delivery of commodities to customers in a transportation network (Laporte, 2010)

The Vehicle Routing Problem (VRP) consists of designing optimal delivery or collection routes from a central deport to a set of geographically scattered customers, subject to various constraints (Dantzig & Ramser, 1959). In the VRP, a concern is to determine the optimal routes used by fleet of vehicles based in a certain deport to serve customers, then return to the deports after finishing serving the demand (Toth & Vigo, 2002). A customer may be serviced by one vehicle and one vehicle may service many customers. Supplementary constraints may be implemented based on the service provided or nature of goods transferred. VRP is the generalization of the Traveling -Salesman (TSM) Problem.

Traveling-Salesman Problem is concerned with the determination of the shortest route which passes through a certain number of points once (Dantzig & Ramser, 1959). The assumptions are that there is a link joining the given points and that the total number of different routes through such given points is half of the points. In the TSM, problem there is only one salesman which must find the shortest routes to service all the cities in the network. The objective of the TSM is to minimize the overall costs of travelling between the cities. The salesman must start and ends the travel in their hometown. The routes connecting to the cities in the network are called edges and the cities are represented by nodes, thus edges should connect to nodes. The TSM has been generalized by introduction of additional conditions such that the TSM may be required to return to the terminal point whenever he has finished serving the demands.

2.5.2 Variations on Vehicle Routing Problem

There are various types of routing problems. Precedence constrained, Distance Constrained Routing problem, Capacitated routing, Risk constrains, and time windows constrained. In Precedence Routing Problem (PRP), the objective is to minimize the distance travelled. The PRP is set to state the order in which customers are to be served e.g., customer (i) be served before customer (j) (Dantzig & Ramser, 1959). Although in the Distance Constrained Problem the restriction is also time, the vehicle cannot exceed the amount of distance specified as it is characterized by service systems (Li, Simchi-Levi & Desrochers, 1992). The Risk Constrained Problem deals with safety of goods during transportation (Talarico et al., 2015) while in Capacitated Routing Problem, the objective is to minimize distance, however, vehicles are restricted according to capacities (Li, Simchi-Levi & Desrochers, 1992). In the Vehicle Routing Problem with Time Windows, the restriction is time (Dantzig & Ramser, 1959). Real life constraints are not incorporated in this model and, the customer may not be served before the time and at the same time it is not allowed to arrive after time.

2.5.3 Methods for developing routing problem

GIS and its extensions have been extensively used by many researchers to improve waste collection and transport by optimal routing (Ghose, Dikshit & Sharma, 2006 ; Ntarangwi and Odera 2017). GIS can provide effective handling, display and manipulation of such geographical and spatial information (Ghose, Dikshit & Sharma, 2006). GIS tools generate efficient vehicle routes for solid waste collection over a road network (Kinobe, 2015). Vijay et al., (2005) also used Triangulated Irregular Network (TIN) to locate waste collection points. Apaydin and Gonullu, (2013) used The Route Pro™ Software as an optimization tool. ArcGIS NA Tool was used to calculate routes according to distance and time criteria (Kallel, Serbaji & Zairi, 2016). ArcGIS NA Tool provides easy and direct the most efficient route solution. Farahbakhsh and Forghani (2019) defined locations for the construction of waste collecting and sorting centers optimally by using GIS with social attribute "waste sorting culture". The sorting centers were also optimized by routing to minimize cost and distance travelled.

2.6 Research Approach

Creswell (2014) describes research approaches as plans, procedures that outline the steps from broad assumptions to detailed methods of data collection, interpretation, and analysis. A research approach involves philosophical assumptions that are brought to the study and design related to the view and distinct methods and procedures. Three approaches were explored: qualitative, quantitative and Mixed methods. The world views that were explored were, positivism, Constructionist, Transformative and Pragmatic.

There are three methods used to inquire a phenomenon; Quantitative and Qualitative (Neuman, 2014), and Mixed Methods Research (MMR) (Creswell, 2014). Quantitative method is based on numerals using techniques that include simply describing the problem or looking for significant differences between or among variables (Tashakkori & Treddie, 1998). It tests objective theories deductively as to protect bias and being able to generalize and replicate findings (Creswell, 2014). Qualitative approach explores and understand the meaning people or groups ascribe to social problem (Creswell, 2014). The techniques of data gathering, analysis, interpretation and presentation are inductive and narrative (Tashakkori & Treddie, 1998). Mixed methods approach involves collecting both qualitative and quantitative data and integrating the forms of data (Creswell, 2014). Although Mixed method design is seen as an alternative to qualitative and quantitative designs as it advocates for use of whatever methodological tools required to answer research questions under study (Tashakkori & Treddie, 1998) and bringing corroboration and convergence (Johnson, Onwuegbuzie & Turner, 2007), the wedding between qualitative and quantitative is epistemologically incoherent, thus lacking a link between paradigms and research methods, which is called 'incompatibility thesis' (Howe, 2016). Since social phenomena is complex, researchers are encouraged to employ pragmatism, thus using numerous ways of collecting and interpreting data (Greene, 2006; Tashakkori & Treddie, 1998). However, pragmatism is rejected of practically lacking logic to solve philosophical issues (Johnson & Onwuegbuzie, 2004) and faces problems of integration (Onwuegbuzie & Johnson, 2006) and that findings are not stand-alone (Bryman, 2007).

To define Mixed methods research (MMR), Johnson, Onwuegbuzie & Turner (2007) presented 19 alternative definitions of MMR from different authors. The general definition of MMR was given as follows:

'*Mixed methods research is the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration'*.

Creswell (2014) describes types of mixed methods research which includes three categories: Convergent Parallel, Exploratory Sequential and Explanatory Sequential. Convergent mixes both qualitative and quantitative data collection and analysis, then compared or related, then interpreted. Exploratory is more into qualitative design then builds into quantitative, then interpretation. Explanatory is more in quantitative then follows up qualitative.

2.6.1 Research paradigms/world views, and logic of reasoning

While there are several research paradigms, only those employed in the study were discussed. *Positivism/post positivism:* This world view is sometimes called scientific method or doing science research (Creswell, 2014). The principle behind positivism is that reality exist whether we are aware of it or not (Bell, Bryman & Harley, 2018). Positivism believes in 'absolute' truth and holds that because phenomena exist externally and objectively, the appropriate way to conduct a research is to observe the phenomena directly or to measure such phenomena through surveys or other instruments to explain human behavior and to draw general conclusions on the findings (Bell, Bryman & Harley, 2018). Hermeneutics: Hermeneutics asserts that there are other possibilities which a phenomenon can be studied (Packer & Addison, 1989). In the post positivism, there is protocol to be followed when conducting a research and laws that govern the world. Although positivism is of the view that a researcher investigates a reality that is independent of actors (Bell, Bryman & Harley, 2018). Packer & Addison (1989) assert that the traditional scientific ways of investigating a phenomenon are misleading as people interpret reality differently.

Constructionist world view: Creswell (2014) describes Constructionist world view in that it is underpinned by qualitative research. It is of the notion that since human beings try to find meanings of the world they live subjectively; researchers need to rely on participants' views of the situation under inquiry.

Pragmatic view: In the pragmatic view, researchers use all approaches or techniques to inquire about the social problem (Creswell, 2014). It arises out actions, situations and consequences rather than antecedent as in post positivism (Creswell, 2014). It is a world view that underpins mixed method research and truth is what works at the time and it debunks concepts such as 'truth' and 'reality' as in post positivism (Tashakkori & Treddie, 1998).

2.7 Types of Study Designs

Kumar (1999) identifies three types of study designs based on the number of contacts: Cross-sectional, Before-and-after and longitudinal. Cross sectional designs are used to obtain the overall picture of the phenomena and done as once off project Before- and after usually measure impact of change. Longitudinal studies determine pattern of change. Cross sectional is easy and simple but cannot measure change.

2.8 Data collection methods

Data collection methods are Primary and Secondary. Primary sources of data collection are where a researcher collects data themselves or by someone else for the specific purpose in mind (Kumar, 1999). Secondary data collection is when data has already been collected by someone else and only information in the data source is needed for the purpose of study although validity and reliability is compromised (Kumar, 1999). While survey designs have other advantages of getting administered to many, people and be completed anonymously, researchers cannot make inferences to a level of cause and effect and are unable to rule out rival hypothesis as in the experimental designs (Coldwell & Herbst, 2004).

2.8.1 Primary Data collection methods

Questionnaires

Questionnaires are another method for collecting data. Some of the questionnaires are self-administered, some are used for collecting data through interviews. Closed and open-ended question are used in questionnaires. Although open ended questions are criticized of lacking flexibility and difficult to analyze (Kumar, 1999), they provide a potential for richness of responses from the respondent, some of which the researcher was not anticipating (Coldwell & Herbst, 2004). While closed questions are easy to analyze especially for aggregation, researchers face challenges of fitting their responses in the interviewer's categories which might be irrelevant to participants or impersonal (Kumar, 1999).

Ethnography

Ethnography is a unique case study where a researcher participates in a group of interest to understand inner workings of the inquiry (Denzin & Lincoln, 2018; Thomas, 2003). The intent of conducting ethnography is to obtain insight experiences of everyday activities (Kumar, 1999) . Although collecting data through ethnography has a disadvantage that people being observed could change their behavior (Kumar, 1999), a possibility of distorting 'objective truth' (Denzin & Lincoln, 2018) and being obtrusive (Creswell, 2014), ethnography has an advantage that a researcher is able to gather information about how a programme operates and observe processes inherent (Coldwell & Herbst, 2004) and also a researcher can record information as it occurs (Creswell, 2014).

Interviews

Interviews are used to find out about the phenomena of interest through someone else' mind (Kumar, 1999). Some of the advantages of interviews are that a researcher can fully understand one's expressions and experiences of the phenomenon and gain face to face encounter (Coldwell & Herbst, 2004), however, reliability is compromised as data quality depends on the honesty and cooperation or respondents and data is often subjective to observer effects (Kumar, 1999).

2.8.2 Secondary data collection methods

Documentation

In this type of collection method, a researcher gets hold of the existing documents as part of data collection method (Kumar, 1999) to get the impression on how the programme operates without interrupting the programme (Coldwell & Herbst, 2004). Although, secondary sources have a possibility of lacking validity, reliability and having personal bias (Kumar, 1999), the advantage is that information already exists and the researcher gets comprehensive and historical information (Coldwell & Herbst, 2004).

Digitization

Heads-up Digitizing is a process whereby vectors are created from raster on screen using a mouse (Hull, Slingsby & Wells, 2017). Maps such as photographs are used for digitization. Digitizing is widely used to capture objects such as land parcels, streets and buildings, rivers etc.

2.8.3 Sampling Designs

Sampling methods discussed include Simple random sampling, Cluster sampling, Convenience sampling and Geographical/Area sampling. However, there are other methods such as systematic sampling, stratified, purposive, Quota and Snowball which exist but have not been employed in the study and will not be discussed.

Probability sampling methods

Nonprobability sampling methods include Simple and Cluster sampling. Simple random sampling is conducted in such a way that each element in the sample has an equal chance of being selected and it is free from bias (Coldwell & Herbst, 2004). One of the advantages of simple random sampling is that inferences drawn from such a sample can be generalized to the total population (Kumar, 1999). However, there are drawbacks in simple random sampling such as difficulty in accessing lists of the full population. Costs, time and that bias can still occur under certain circumstances (Coldwell & Herbst, 2004).

Cluster sampling: In this type of sampling, the population of interest is grouped into small homogeneous groups called clusters and a sample can be drawn by randomly selecting elements in each cluster (Coldwell & Herbst, 2004) and it is ideal when it is impossible to compile a list of the elements in the population (Creswell, 2014).

Non-probability sampling methods

Nonprobability sampling methods include Convenience and Geographical sampling. Convenience or volunteer sampling is whereby the population is selected purely based on their convenience or availability (Coldwell & Herbst, 2004). However, Convenience sampling lacks representation of the population (Thomas, 2003). Geographical or Area Sampling is used to a population that can be defined geographically (Fowler, 2009). However, geographical sampling has a disadvantage of having a possibility of leading to poor representation of the overall parent population especially if the area is large (Fowler, 2009).

2.8.4 Selecting a sample size and related considerations

Several methods of selecting a sample, types of case studies, validity and reliability, scales of measurement and ethical considerations are important designs in the research and are discussed below. Firstly, methods of selecting a sample size are explored.

There are several methods for selecting a sample such as selecting a fraction of the population such as percentage, selecting by size, (Creswell, 2014) and margin of error and willingness of tolerance by a researcher

A case study research normally comprises of a single or multiple case studies. A single case study focuses on one case while multiple case studies focus around two or more case studies Yin (2018). However, case studies have a tendency of generalizing findings of a specific case to another at a considerable error (Thomas, 2003) and multiple case studies require more time and resources far beyond the means of a single case study, as a result, external validity become compromised (Yin, 2009). (Yin, 2018) states that a case study investigates a phenomenon in a real-world context and must be focused and bounded, if the case is not bounded it is not a case study (Bryman & Bell, 2014).

Validity of the study refers to whether the measurement measures what is supposed to measure (Kumar, 1999). Reliability of study refers to whether the study can be repeated and give the same results (Creswell, 2014). To establish content validity, there should be a link between questions and objectives (Kumar, 1999). Yin (2018) states that collecting data with multiples sources and using ‘how’, ‘what’ questions increases validity of the study.

Kumar (1999) distinguishes between four types of measurement scales: Nominal, ordinal, interval and ratio scales. In the nominal scale, there is commonality among subgroups in characteristics or property. Ordinal scale has all characteristics of nominal scale and that subgroups have relationship to one another. Subgroups are arranged in ascending or descending order. Interval scale has all the characteristics in both nominal and ordinal scales plus it has a unit of measurement, of which there is an arbitrary starting or terminating points. Ratio scales has all the characteristics of the interval scale plus it has a fixed starting point.

Conducting a study requires a research to abide to certain rules and conducts (Kumar, 1999). Ethics is made up of norms or standards principles, values, that guide professionals to accommodate culture of stakeholders (Creswell, 2014) and moral choices of about peoples’ behavior and relationship with others (Coldwell & Herbst, 2004). Some of the principles include, seeking institutional approval, gaining local permission to access participants, stakeholders’ consent for information (Bryman & Bell, 2014) confidentiality, anonymity and not distorting the findings of the study (Creswell, 2014).

CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY

3.1 General Methodology

The general methodology outlines processes/procedures followed in assessing the current solid waste management, carrying out suitability analysis for the dumpsite, determining suitable solid waste collection points and developing an optimal route network for solid waste collection and disposal in Maseru City. Figure 8 below shows the general methodology for the study.

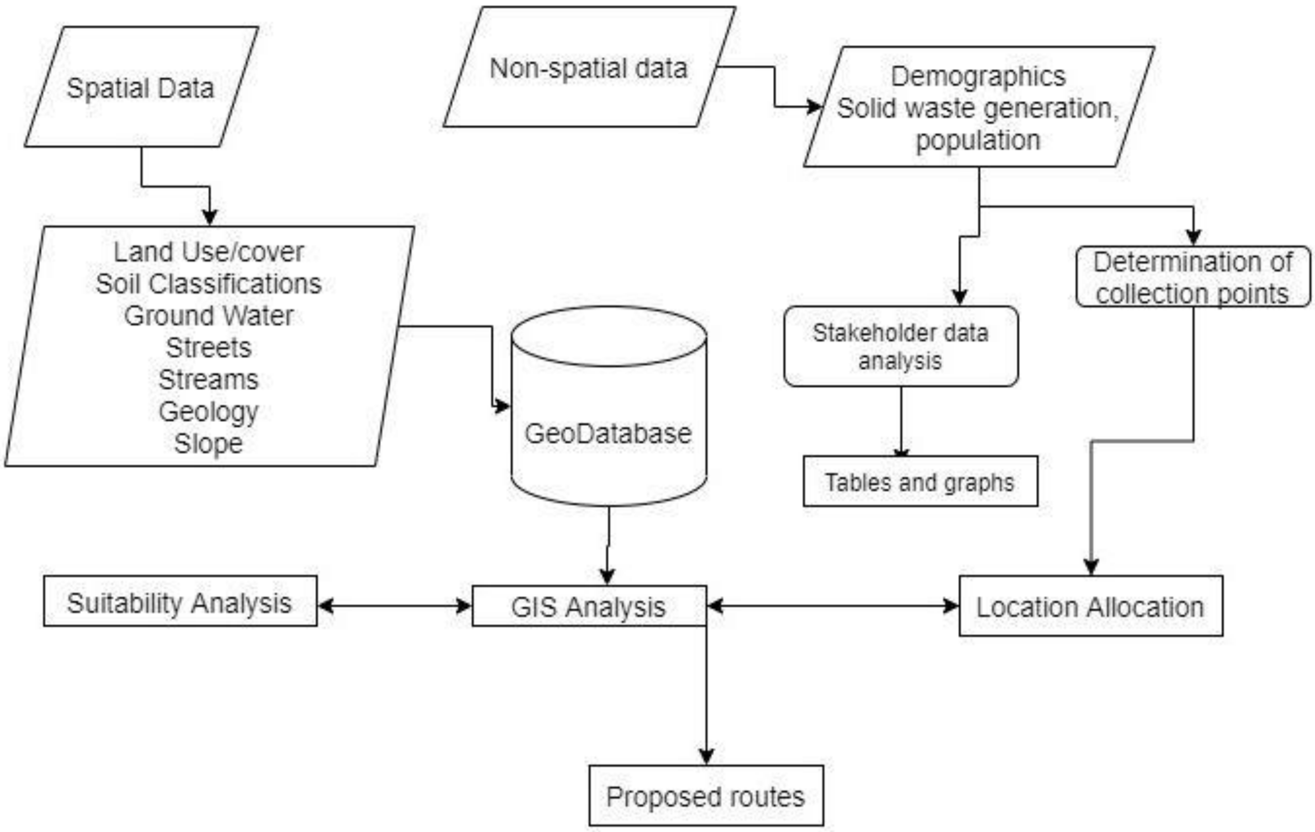


Fig 8: General Methodology

In the general methodology, both spatial and non- spatial data were collected to address the objectives of the study. Spatial data such as land use/cover, soil classifications, geology, ground water table, streets and streams were used for conducting suitability analysis. Road's data was used for conducting network analysis. Non-spatial data such as population and solid waste were used to determine collection points and to run location-allocation problem. All data was stored in the geodatabase in Arc GIS and analyzed. The study was a single case study, cross sectional and used Mixed methods research whereby both qualitative and quantitative research were used. It was also Constructionist and pragmatic as several methods of data collection was conducted (Questionnaires, interviews and observations). Both primary and secondary data were used in this study. The primary data collection was done for all solid waste management stakeholders (MCC, drivers, community waste pickers and households) through questionnaires, interviews and observations. Secondary data collection was done from government repositories and digitization. The sampling methods used in this study were Simple random sampling, cluster and geographical.

3.2 Assessing the current solid waste management in Maseru City

In order to assess the current solid waste management in Maseru City, Primary data collection was done for stakeholders. Questionnaires, face to face interviews and observations methods were used. Although simple random sampling, cluster sampling, convenience, and geographical/area sampling were employed in this study. The methods employed relate and fit to the specified objective. The procedures were discussed. Figure 9 shows data collection methods and analysis for stakeholders.

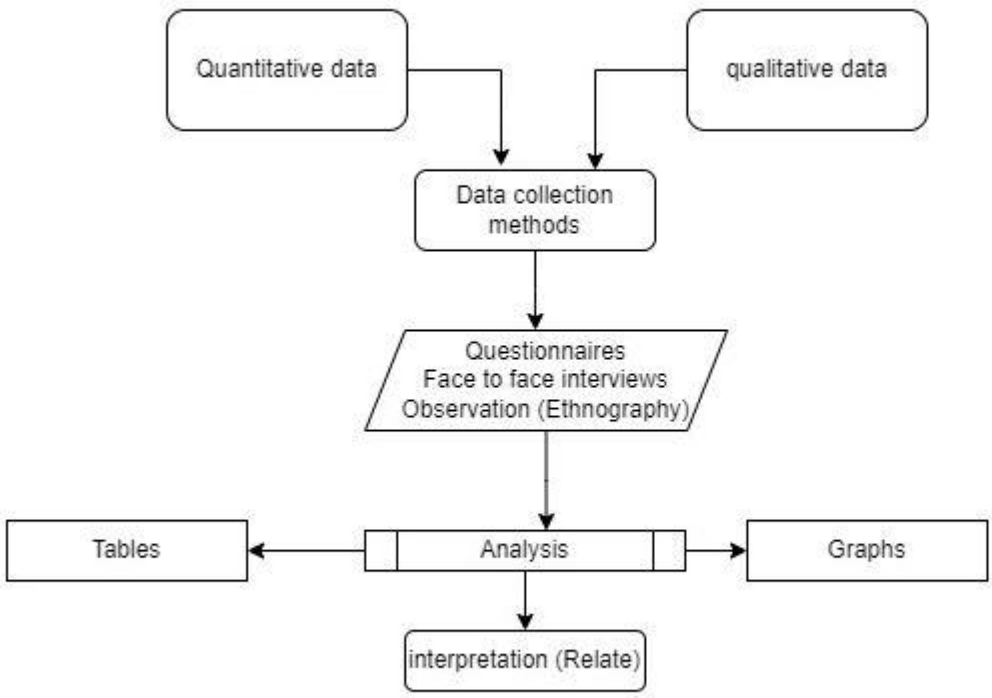


Fig. 9: Methodology for stakeholders' data collection and analysis

The methodology for conducting data collection and analysis for stakeholders requires collection of both quantitative and qualitative data. The scale used was Likert scale. Data collection methods included questionnaires, face to face interviews and observations. In the interpretation, the relation was done for both qualitative and quantitative data.

3.2.1 Data collection for Households

Data collection for households started with preparing a high-resolution aerial image to view the households clearly on the ground. To make things simpler, the researcher printed images as per constituencies. It was impossible to get a list of households and occupants as there was no such data. A multistage approach was conducted. First, cluster sampling was conducted, that means an electoral ward was taken as a cluster as it has defined boundary. A Constituency constitutes several villages under jurisdiction of a particular Chief. A cluster of villages under the Constituency were used to sample households per village. Secondly, area sampling was used whereby within the villages, households were geographically selected randomly. This means that on the aerial map, households were picked randomly. The researcher used tolerant sample size of 130 households in Maseru City and for the entire study as the researcher had limitations of time and funds. 13 households were selected randomly from each Constituency. Simple random sampling has an advantage that each element has equal probability of being selected and random samples are most likely to yield a sample that truly represents the population (Neuman, 2014). However, the researcher had difficulty to select the households randomly and geographically as the study area was large. Maseru city is about 156,289,615m^2. The ward depends on the villages in it.

However, to make sure that each geographical area was visited, if a chosen household was not accessible for a period of data collection, a convenience sampling was conducted such that a nearby household was selected. Household heads were the target of the sample regardless of gender and economic status. Sample size was chosen based on the affordability of the researcher to collect data around the city. To access the respondents, first the village or ward Chief was consulted for approval to enter their jurisdiction and to be given permission to interview people. There are Chiefs responsible for certain group of villages. The ward is composed of several villages in constituency. There could be two chiefs in constituency or more. The researcher introduced themselves clearly to the Chief and presented all the research ethics. The ethics letter was acquired from the Department of Architecture, Planning and Geomatics (APG), Geomatics division. The approval letter from the chief had to be offered to the researcher in order to enter the communities and interview them. However, the approval differed from one place to another or from one Chief to another. In some places a Chief made an approval letter to present to the households, while in some, a delegate accompanied the researcher to the households then the Chief/delegate introduced the researcher and the purpose of the researcher and told the respondents that data was confidential and used for the research purpose only. A consent letter was also presented to the respondent to sign.

A face-to-face interview was conducted, and questionnaire was administered. As respondents were asked the same questions, responses were written down on the questionnaire. The researcher had already sequenced the questions during questionnaire design process and issues related to the inquiry were outlined in advance to allow for systematic and comprehensive data collection. The researcher inquired of the Chief residence and asked to meet with the selected household. The researcher visited the selected household with the permission of the relevant Chief. For each household that was randomly and geographically chosen in the sample, an agreement was made with the researcher to keep the waste for a week in order to weigh. The total waste for a week was weighed and recorded. The total solid waste for all thirteen respondents for a Constituency was calculated.

3.2.2 Data collection for MCC Management

MCC respondents involved top and middle management and the drivers responsible for solid waste collection and disposal. To access all respondents from MCC, the town clerk of MCC was informed in writing and sought for permission to interview the staff. The respective directors were then informed. Each of the Directors, directed the researcher who should be interviewed, this means that a purposive sampling was also conducted. All necessary documents were submitted to the office of the Town Clerk including ethics approval. The most relevant departments were Planning and Health departments. In the Planning division, there were 8 respondents. In the Health division there were 7 respondents. All planning staff preferred to fill questionnaires themselves. In the Health division, three respondents were interviewed while four filled the questionnaires themselves. For those who filled the questionnaires themselves, questionnaires were collected whenever they were complete, and the researcher's details were included for clarifications. The respondents were issued the ethical clearance and the consent form. In each section two people were used to test the validity of the questionnaire and the responses were included in the analysis.

3.2.3 Data collection for MCC Drivers

There were only three drivers responsible for solid waste collection and disposal at MCC. To access the drivers, since the directors were all involved and informed, the researcher was directed to the drivers' manager to get accessibility to the drivers. The researcher made an introduction to the manager and the drivers were then introduced to the researcher. The ethical procedures such as introduction and purpose of the research and assurance of anonymity and confidentiality were done. The consent form was issued to them. A face-to-face interview was conducted for all three drivers from MCC using the local language. No sampling was done in this category all drivers were interviewed.

Direct observation was also done through ethnography. The researcher went to the field with the drivers and observe how activities were done. However, the researcher was a mere observer not a participant. In the field, drivers were asked open ended questions to give more details, and this was done as a discussion. Responses were jotted down as critical issues emerged during the discussion. The overall approach to this study was mixed methods research whereby both quantitative and qualitative methods were used. Survey methods such as using questionnaires, face to face interviews and ethnography were used.

3.2.4 Data collection for Community waste pickers

Solid waste collection in some communities was handled by Community Based Organizations (CBOs), in some, by volunteers who do the same job as CBOs. Data collection methods for Community waste pickers was a very challenging one for the researcher since it was difficult to get hold of the solid waste pickers since the so called 'structures' were not functioning as they should and there was no specific way to get hold of them. The researcher had to ask the Chief where waste was collected in the specific community to get hold of the pickers as they go drop the solid waste. The community Chief was either noticed verbally or issued the permission letter for consent. It was very challenging as MCC did not collect the whole city but in some parts of the city such as Maseru Urban and other parts of Thetsane, Stadium area, Mabote, Lithabaneng. The rest of the constituencies were CBOs and volunteers. It was difficult to know the number of community waste pickers. A total of 64 waste pickers who do house to house were interviewed. Convenience sampling in this category was conducted due to constraints mentioned. Also, the issue of COVID 19 played a major role in inhibiting the movement, time and accessibility of respondents and the study as whole. Community waste pickers included those truck/van owners who collect solid waste from illegal collection points in communities to Ts'osane dumping site. There are no legal collection points in Maseru City. Only 9 truck/van owners were interviewed. Also, solid waste truck pickers were sampled using convenient sampling because it was difficult for the researcher to get hold of them as sometimes, they did not come to collect waste. A face-to-face interview was conducted in this category. The ethical issues were clearly stated to the respondents.

3.3 Selecting a suitable solid waste dump site for Maseru City

The methodology for selecting a suitable dump site required secondary data collection from relevant government ministries in a digital format. However, some data such as streets were digitized from screen. The main criteria were adopted from Kamdar et al., (2019). The main factors were Morphological, environment and Socio economic. Under Morphological the sub factors were soil texture and slope. Environmental composed of ground water depth, surface water and geology. Socio-economic composed of streets and land use/cover. Data was entered into the geodatabase. Weights were assigned and transformed to a common scale and criteria maps were produced. The model builder was used to weigh factors to get a suitable raster. The factors did not have the same weights for the determination of solid waste disposal site. The suitability of waste disposal depended on the availability of data based on the local conditions of the study area. Different weights were determined for different factors. To access data from different ministries, a letter was written to relevant division and ethics approval was attached. As the approval response was granted, either by phone or email, the researcher had to be directed to the relevant personnel to get required data. Some data was downloaded from United States Geological Survey (USGS). Figure 10 below shows methodology for developing a suitable dump site for Maseru City.

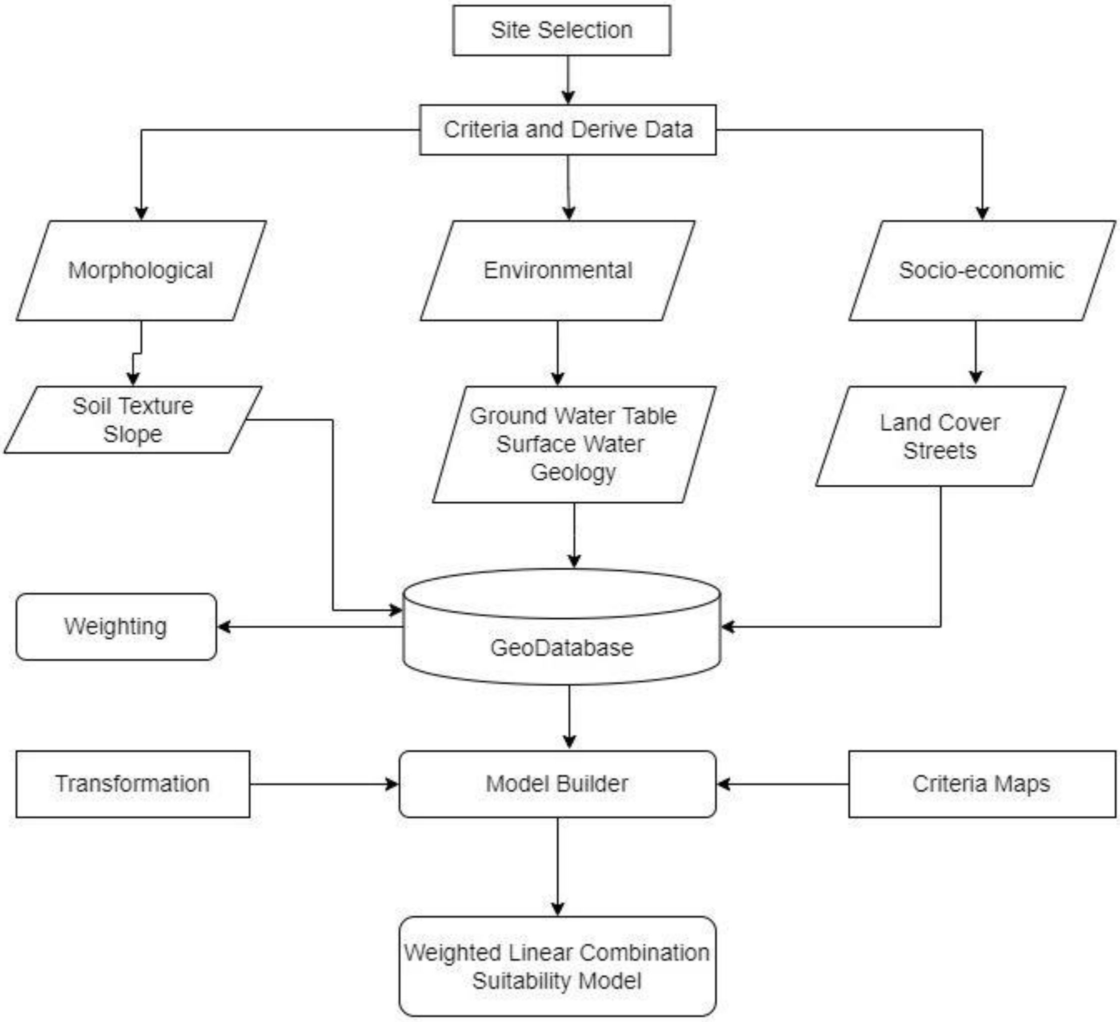


Fig. 10: Methodology diagram for location of a solid waste dump site.

According to Esri, (2020). Developing a suitability model requires the following steps:

- Defining a problem
- Criteria to be used in the analysis be determined and developed for each factor
- Gathering and formatting of data to be used in the analysis
- Data Preparation and Processing
- Reclassification of data
- Final suitability model: Combination or overlay of factor maps to produce final suitability map. The final composite map shows the overall suitability of the phenomena under study. The final suitability was shown in the Results Section.

The problem was to locate a suitable disposal site for Maseru City.

3.3.1 Criteria used in the study and Reclassifications of data

The factors used in this study were" slope, ground water depth, distance to streets, distance to roads, soil classifications, geology and land use/cover. However, in Lesotho there are no guidelines nor policies for siting a suitable disposal site. The researcher adopted the factors from literature and adopted the suitability rankings and ranges. From all the adopted literature, Analytical Hierarchy Process (AHP) was used to derive weights and rankings whereby a pairwise method was used at a scale of 1-9 and used Weighted Linear Combination (WLC) method for overlaying of factors. The weights and rankings used in this research were adopted from existing literature cited in the subsequent sections. Since in the literature, no one has all the factors used in the study, different factors were adopted from different literature. The criteria weights were adopted from Kamdar et al. (2019), see table 11. The suitability ranking for slope, ground water depth, soils and geology was adopted from Arkoc (2014), while the suitability ranking for streets and streams were adopted from Uyan (2014). Land cover suitability was adopted from other researchers (Mugo & Odera, 2019; Chabuk et al., 2017; Alanbari et al., 2014; Demesouka, Vavatsikos & Anagnostopoulos, 2013). The scaling is such that the higher the value the more suitable it is. 5 (Very Highly suitable, 4 (Highly Suitable), 3 (Medium), 2 (Low suitable) and 1 (Unsuitable). Table 10 below shows the factors and ranges adopted and used in the study.

Table 10: Factors and Ranges

Factors	**Ranges**	**Suitability ranking**	**Adopted from**
Slope	0-10 10-20 20-40 40-60 >60	5 4 3 2 1	(Arkoc, 2014)

Ground water table (m)	<0.5 0.5-20.0 20.0-50.0 50.0-70.0 >70.0	1 2 3 4 5	(Arkoc, 2014)
Distance from Streets (m)	<250 250-500 500-750 750-1000 >1000	1 2 3 4 5	(Uyan, 2014)
Distance from Streams (m)	<350 350-700 700-1050 1050-1400 >1400	1 2 3 4 5	(Uyan, 2014)
Soil texture	Sand and gravel Silty sand, clayey and silty gravel Silty sand and clayey sand Clay	2 3 4 5	(Arkoc, 2014)
Geology	Sandstone Silt and sandstone Sandstone with clay Sandstone with shale	2 4 3 1	(Arkoc, 2014)
Land use/cover	Agriculture	1	(Asefa Bedasa, & Mindahun Wondwossen, 2019)
	Trees	1	(Asefa Bedasa, & Mindahun Wondwossen, 2019)
	Built-up (Residential)	1	(Mugo & Odera, 2019)

	Built-up (Commercial)	1	(Mugo & Odera, 2019)
	Surface water	1	(Asefa Bedasa, & Mindahun Wondwossen, 2019)
	Bare areas	5	(Mugo & Odera, 2019)
	Bare rocks	1	(Alanbari et al., 2014)

Analyzing a suitable dump site requires assigning weights to factors. Weights were adopted and used in the study. Table 11 below shows the adopted weights for different factors.

Table 11: Criteria and weights.

Main Criteria	Sub criteria	Sub weights/scores
Morphology	Slope Soil texture	0.12 0.11
Environmental	Ground water table geology streams	0.18 0.14 0.17
Socio-economic	Land use Roads	0.15 0.13
Total		**1**

To conduct, suitability analysis, data was needed. Table 12 below shows data sets that were used to conduct suitability analysis, source and the intended mapping output.

Table 12: Data sets, Source and intended out put

Data set	**Source**	**Mapping output**
Land use/cover	Ministry of Local Government and Chieftainship, Department of Lands, Surveys and Physical Planning	Suitability Analysis
Digital Elevation Model (DEM)	Shuttle Radar Topography Mission (SRTM) from USGS	Slope and determining ground water depth and suitability analysis
Street data	Digitized from screen by the researcher using the aerial photo to extract street layer	Suitability and routing analyses
Soil texture	Ministry of Forestry, Range and Soil Conservation	Suitability analysis
Geology/lithology	Ministry of Mining	Suitability analysis
Streams	Ministry of water	Suitability analysis
Boreholes	Ministry of water	Suitability analysis/ground water depth

3.3.2 Data sets and processing

Digital Elevation Model (DEM): DEM was acquired from Shuttle Radar Topography mission (SRTM) downloaded from USGS with the resolution of 30m, extending over the area between latitudes 29° 14′ - 29° 56° S and longitudes 27° 17′ - 28° 16′ E. The data was downloaded in Geo Tiff format in geographic coordinates and based on World Geodetic System of 1984 (WGS84) for horizontal datum with vertical datum as EGM96.

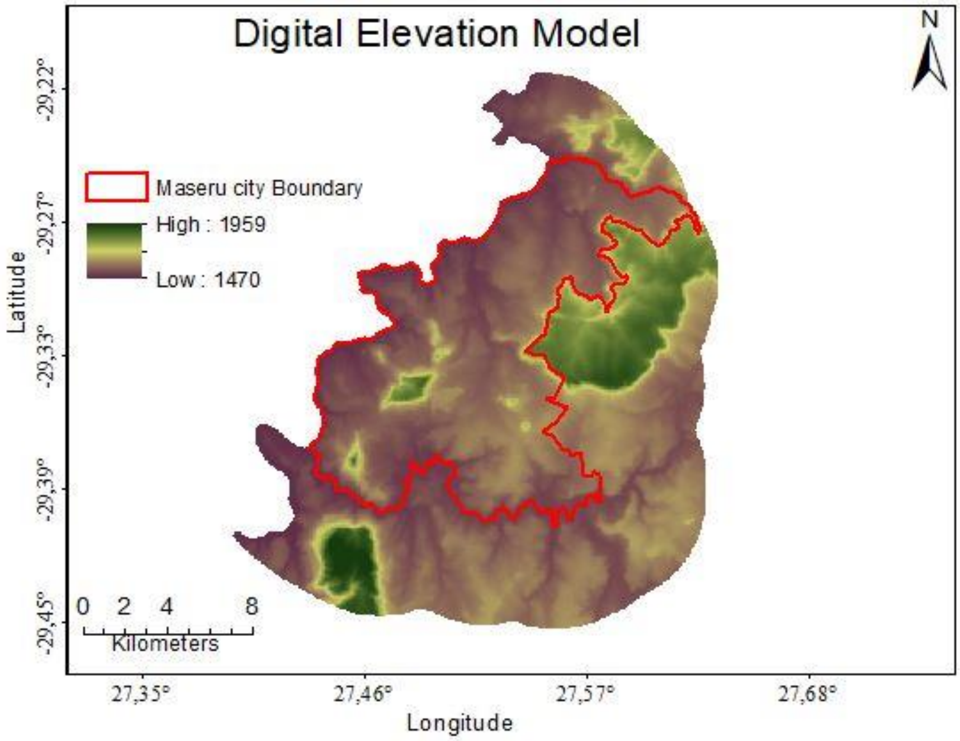


Fig. 11a: Digital Elevation Model (DEM), units are in m

Slope was used in the suitability analysis for a dump site. Slope was derived from DEM in degrees. A ‘slope’ tool in ArcGIS was used to derive slope. The slope ranges from 0-59^0. Figure11b shows the values of slope.

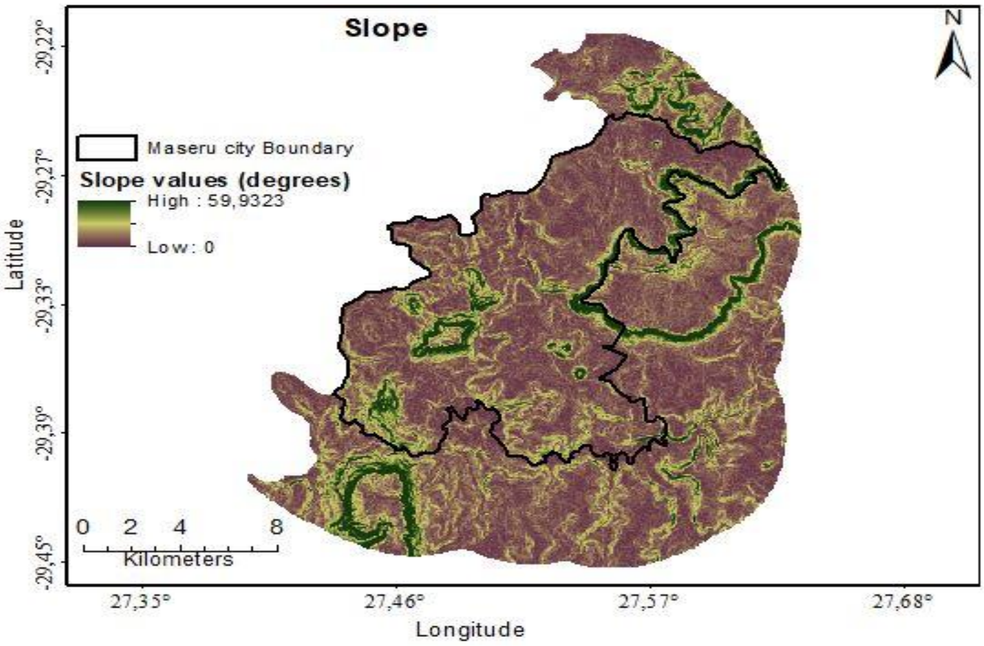


Fig. 11b: Slope ranges

Ground water depth. To determine Ground water depth, two inputs were used: elevation values and water table values. Water table values were subtracted from elevation values (Ground water depth = elevation – ground water table). Inverse Distance Weighting (IDW) was used to interpolate ground water depth (difference from elevation and water table values). Spatial interpolation means deriving the z-values at a new location based on the existing or known values (Jensen, 2015). The rationale behind interpolation is that on average, values at points close to each other in space are more likely to be similar than those further apart. A total of 89 boreholes from Ministry of Water were used in the analysis. The data was in the excel format containing attributes such as water table levels (m) and elevation. The excel data was converted to shape file in Arc GIS using XY tool. The value range for ground water depth was adopted from Arkoc (2014) as their ground water values were much deeper as this study. Arcok's values range from 0-70m, while this study's values range from 0-142. As per literature, higher values for ground water depth the more suitable. Using Arcok's range greater than 70 m value were considered highly suitable, while values less were considered unsuitable. Figure 12a shows spatial distribution of boreholes and figure 12b shows ground water depth.

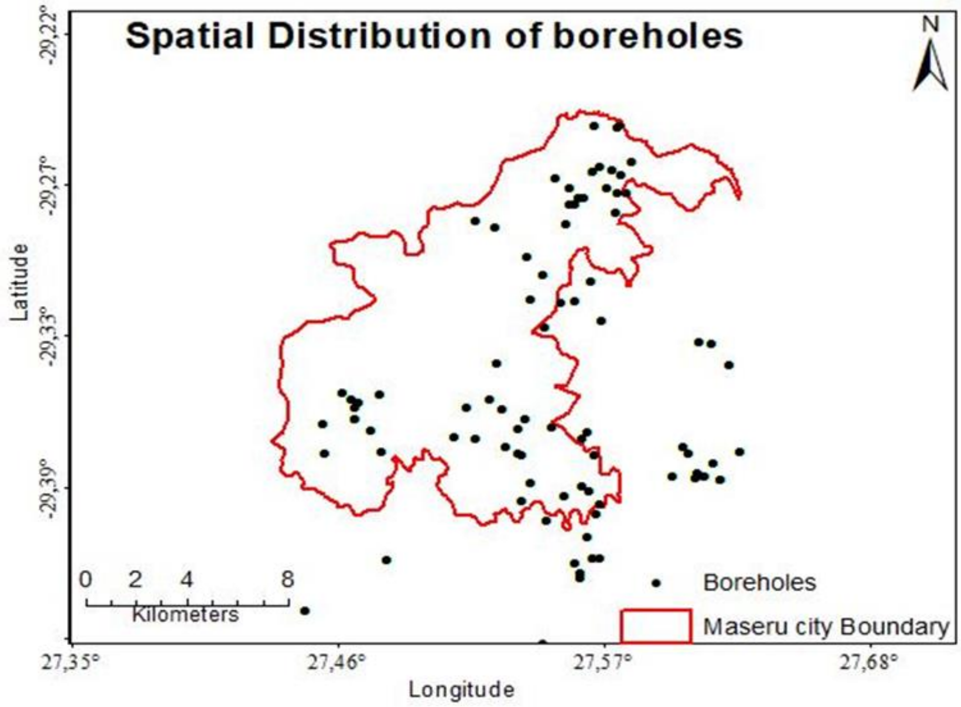


Fig.12a: Spatial distribution of boreholes

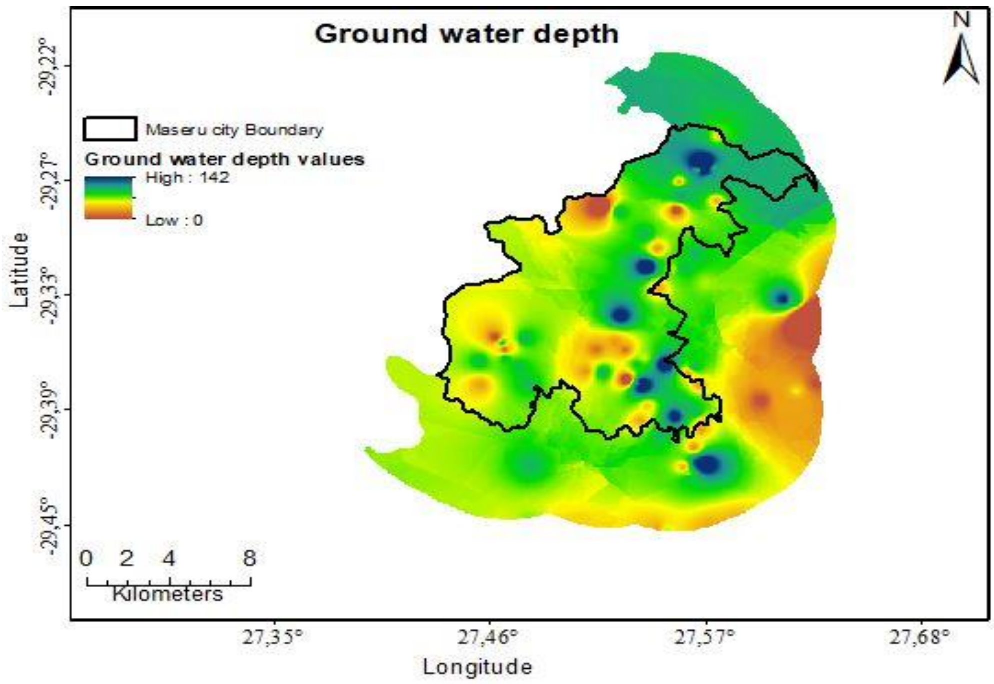


Fig. 12b: Ground water depth

Soil texture: The soil texture was adopted from Arcok, (2014). The soils texture was classified into Vertisols, lithosols, fersiallitic and claypan soils. High permeability soils such as sand and gravel are considered unsuitable, while low permeability soils such as silty clay and clay are highly suitable. Since Vertisols and claypan soils are soils that are composed of rich clay particles, they were both scored 5, while Fersiallitic soils were scored 1 as they are composed of high coarse sand. Lithosols were scored 3 as they are mixed soils. Figure 13 shows soil texture.

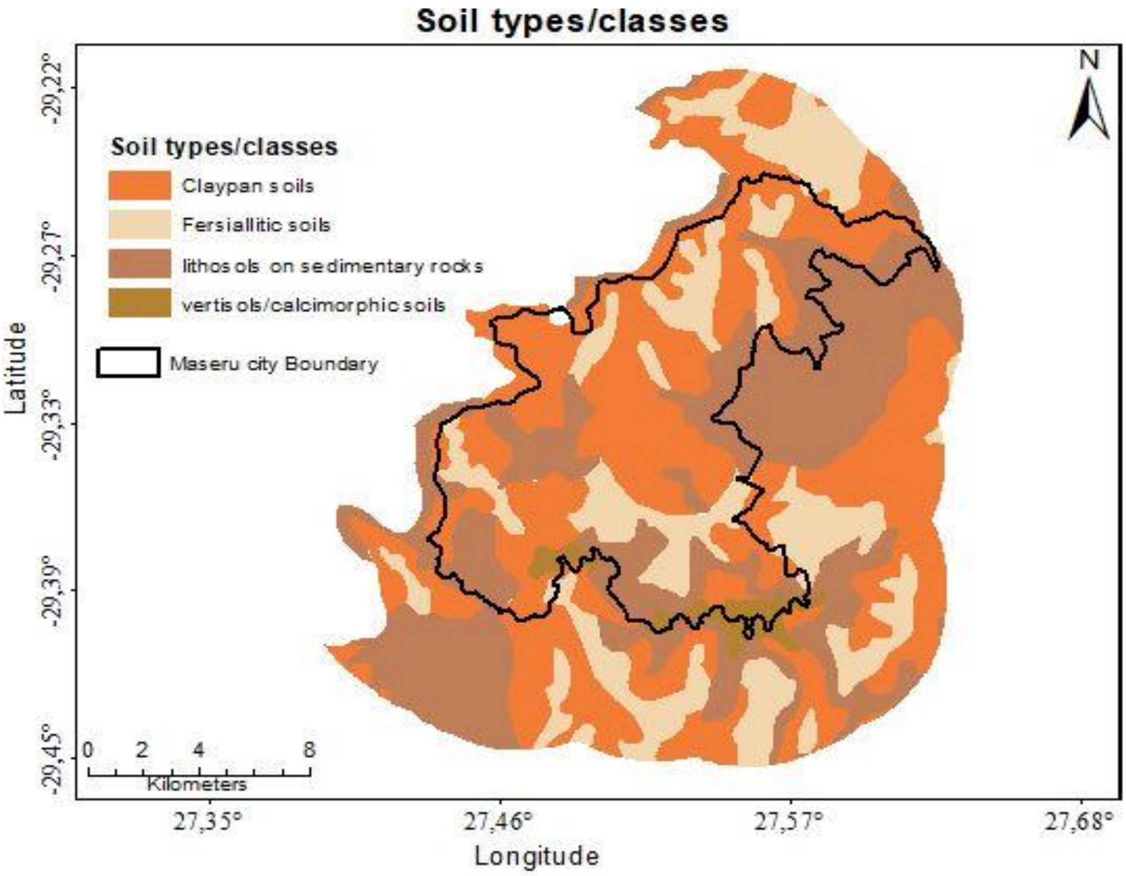


Fig. 13: Soil texture

Geology: Geological/lithology strata was adopted from Arcok, (2014). Looking at the contents of the rocks, they resemble the same characteristics of soils, therefore they were both given the same category adopted from Arckoc (2014), although they were rated differently. The rock types were categorized into Clarens, Elliot, Molterno and Tarkastad. The rock types were rated and classified according to their composition. According to literature, Clarens rocks are sand stones that weathers into rich clay, therefore, Clarens was scored 4 as rich clay seems to be a rich component in Clarens rocks and that clay is good for siting a disposal site. Elliot rocks are composed of silt and sand; therefore, Elliot type of rocks were given a score of 3. Molterno are sandstones that weathers to a stiff clay, therefore a researcher scored Molterno 2, since it is a combination of sand and clay. Tarkastad are explained mostly sandstone and shale, it was given a score of 1 since sand stones are highly permeable. The geological factor was assigned a weight of 14. Figure 14 below shows the geological content of the study area.

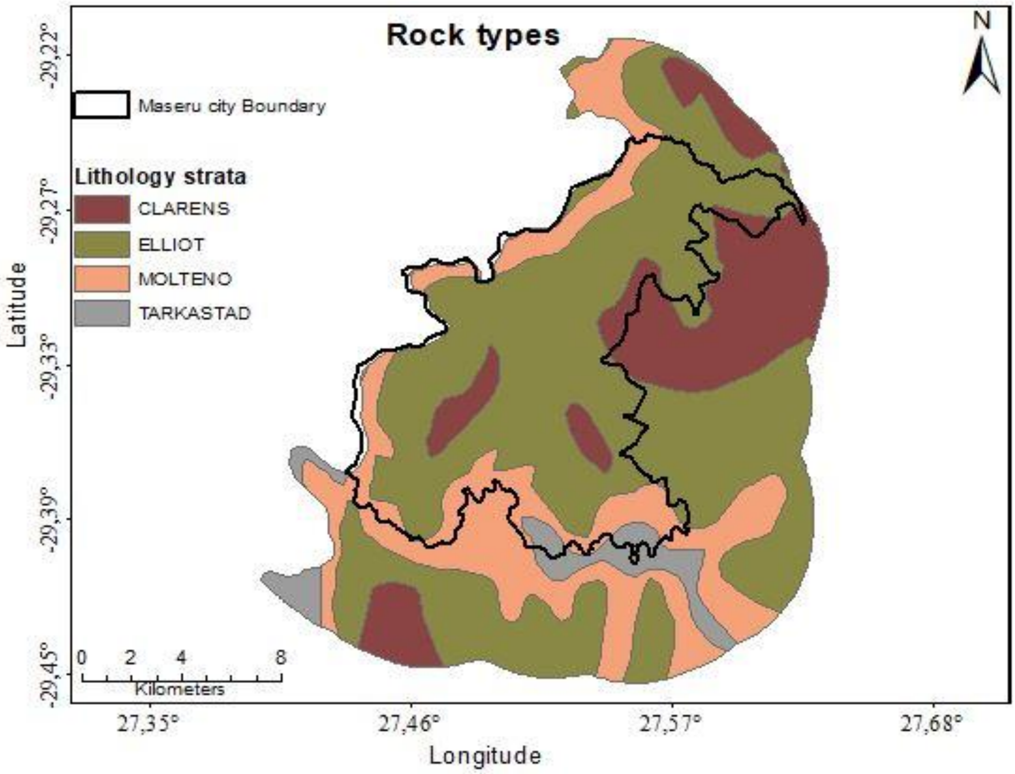


Fig. 14: Geology

Streets: Streets were digitized from screen by the researcher using a high-resolution aerial photograph. Euclidian distance of 250m from streets was calculated and reclassified into five classes where the higher the distance from roads/streets the–higher the suitability distance ranges from 0-243(m). The value range was adopted from Uyan, (2014). Figures

Fig.15a and 15b shows streets of Maseru city and distance to streets respectively.

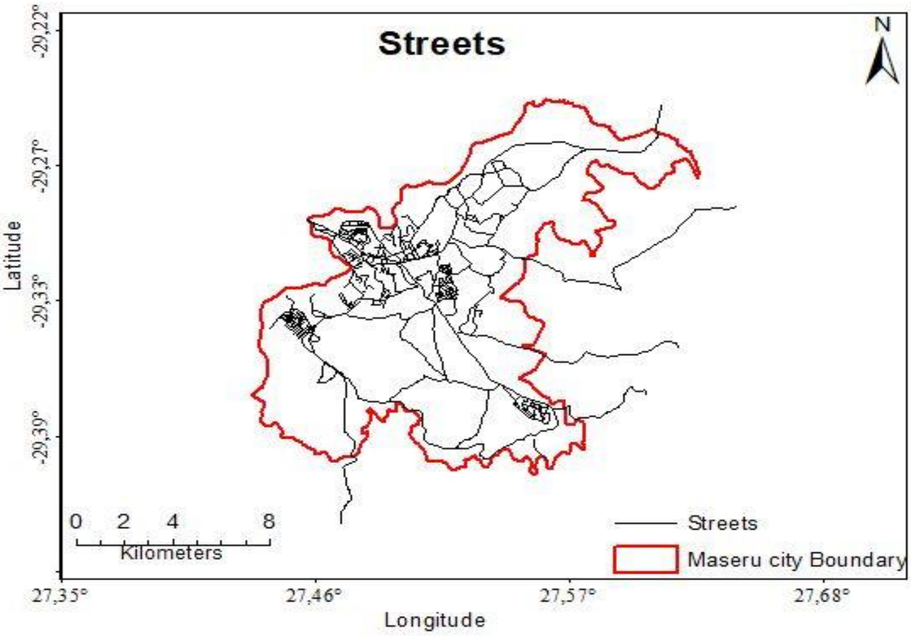


Fig. 15a: Streets

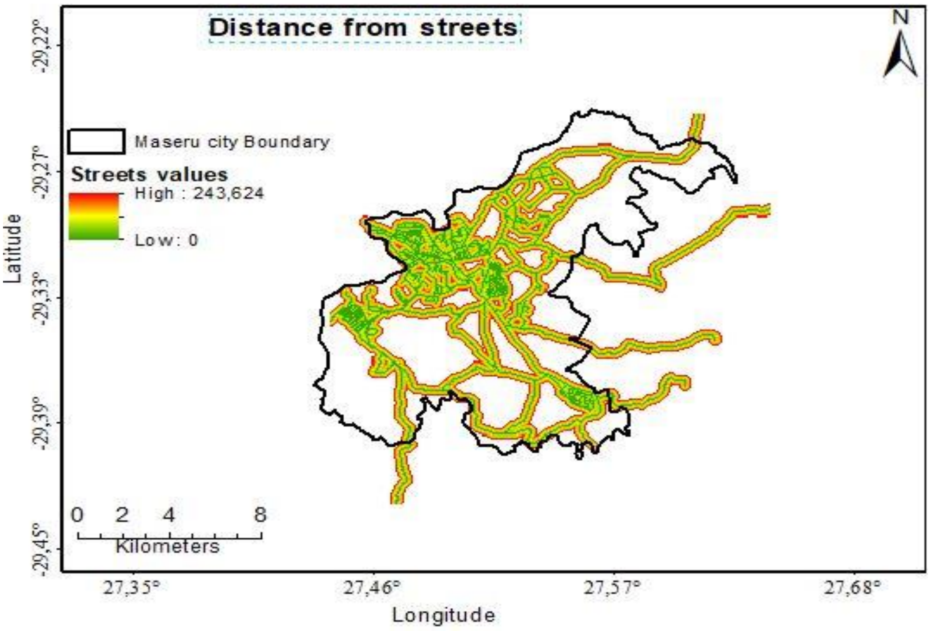


Fig. 15b: Distance to Streets

Streams: Data set of streams was obtained from Ministry of Water Affairs. Euclidean distance of 300m was calculated and streams were reclassified into five classes where the higher the distance from the streams the lower the suitability. The stream range was adopted from Uyan (2014) because their range is much closer to this study. The ranges for streams for this study ranges from 0-3087m. The higher the values the more suitable. Figures 16a and 16b show streams and distance to streams respectively.

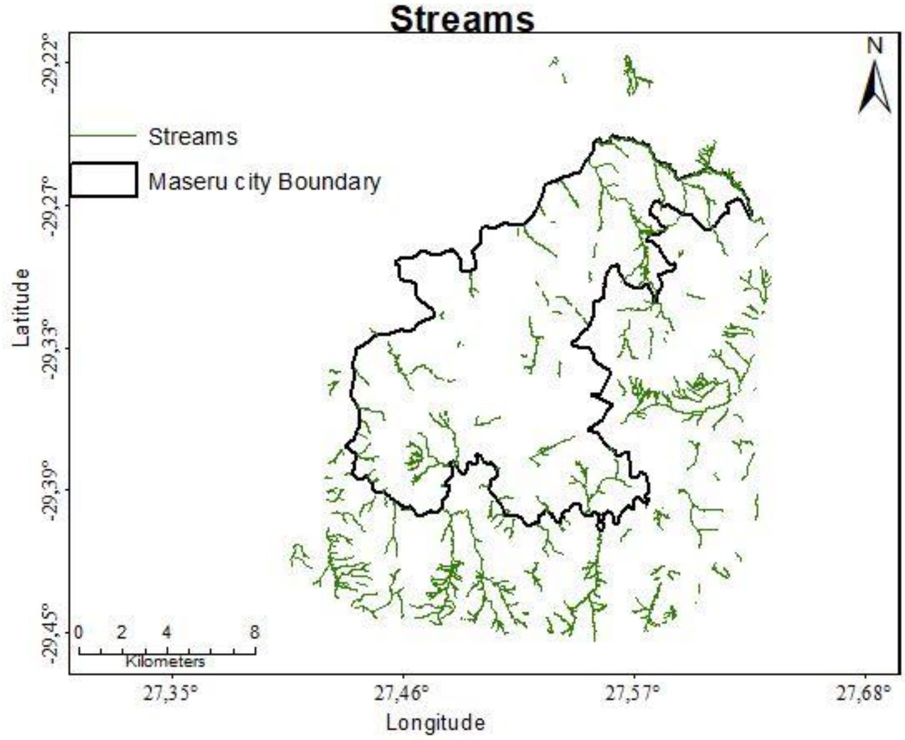


Fig. 16a: Streams

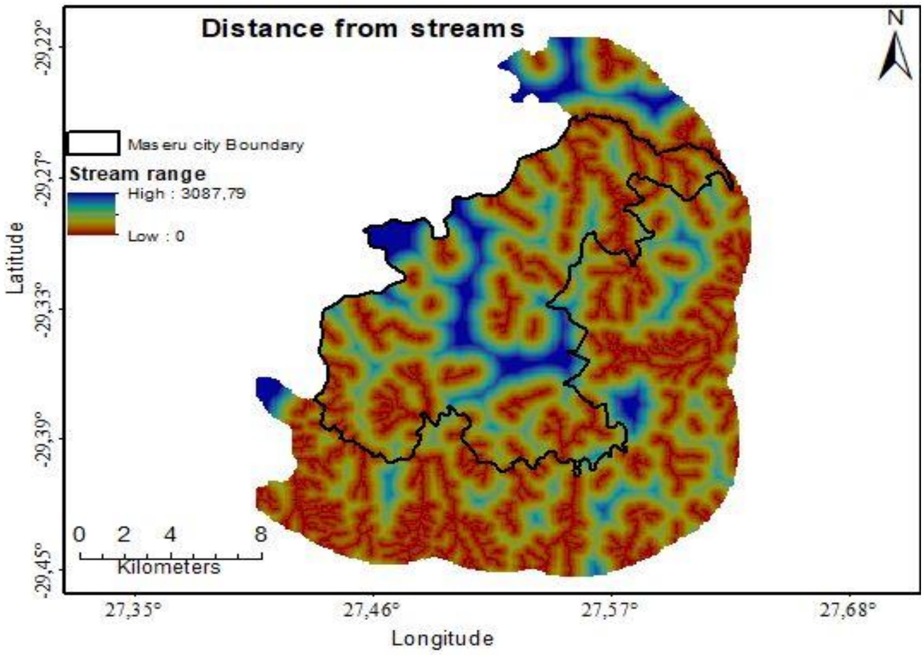


Fig. 16b: Distance to Streams

Land cover: Land cover data set was gathered from Ministry of Local Government and Chieftainship, Department of Lands, Surveys and Physical Planning. Land use/cover composed of 8 classes. The classes included Built-up (Residential, Commercial), Trees, Surface water, Bare land, Bare rocks, and Agricultural lands (Agriculture in dry and wet land). As for the scoring of classes, all classes according to literature were unsuitable for locating a disposal site except the bare lands which were considered highly suitable for locating a disposal site (Chabuk et al., 2017; Bulane, 2009; Kontos, Komilis & Halvadakis, 2003). All classes were scored 1 which is unsuitable and bare land was scored 5 which is highly suitable. Figure 17 below shows Land use/cover classes.

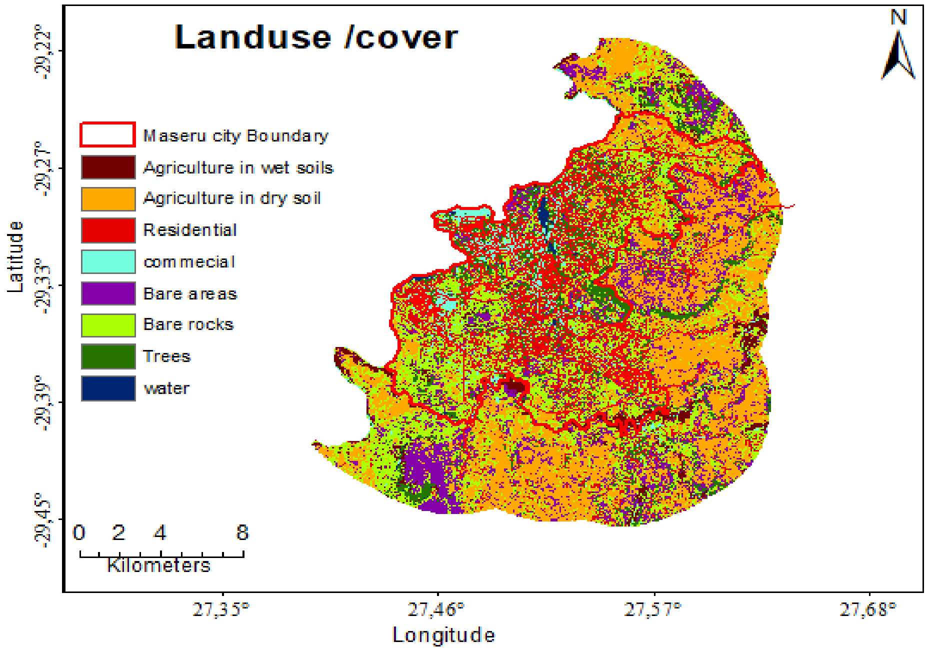


Fig 17: Land use/cover

3.3.3 Overlaying Method

In this study, suitability analysis raster was developed using Weighted Linear Combination (WLC) Model. WLC was chosen among others because the model meets accuracy requirements for the current study and because of its popularity in modelling suitability analyses and has been used by several researchers (Chabuk et al., 2017; Al-Hanbali, Alsaaideh & Kondoh, 2011; Afshari, Mojahed & Yusuff, 2010). It is also the simplest and easy to do (Afshari, Mojahed & Yusuff, 2010) and provides better site selection because of its flexibility in selecting optimum sites (Al-Hanbali, Alsaaideh & Kondoh, 2011). Weighted site selection is also used as the researcher requires a continuous suitability scale which means the site selection method included options for viewing next bet sites. Raster cells were transformed to a common scale of 1-5. A scale of 1-5 was adopted from Arkoc (2014). Where 5 (Very highly suitable), 4 (Highly suitable), 3 (Medium), 2 (Low suitable) and 1(Unsuitable). All the attributes of input data were given scores. The scores represented land constraints for siting a dumps site. Scores were adopted from literature. Reclassify tool was used for discrete data such as land cover classes and continuous data such as slope. The transformed values were weighted and then combined using Weighted Overlay tool and weights were based on the relative percentage of 100 percent. The weights were adopted from Kamdar et al. (2019). The following equation was adopted from Kontos, Komilia and Halzadakis (2003) and was used in selecting a suitability raster adopted from literature.

$$\boldsymbol{S = \sum_{i=1}^{n} w_i C_i} \qquad (5)$$

Where $\boldsymbol{S}$ is the suitability of waste disposal site, ($\boldsymbol{W_i}$), is the weight for a criterion i and ($\boldsymbol{C_i}$) is the criteria for suitability and for restriction. This allowed the overlaying of the factors to produce the result. N is the number of criteria used.

The Model Builder was used to develop the WLC Model. The following model was used to create suitability analysis. Figure 18 below shows the Methodology for Conducting WLC by Model Builder.

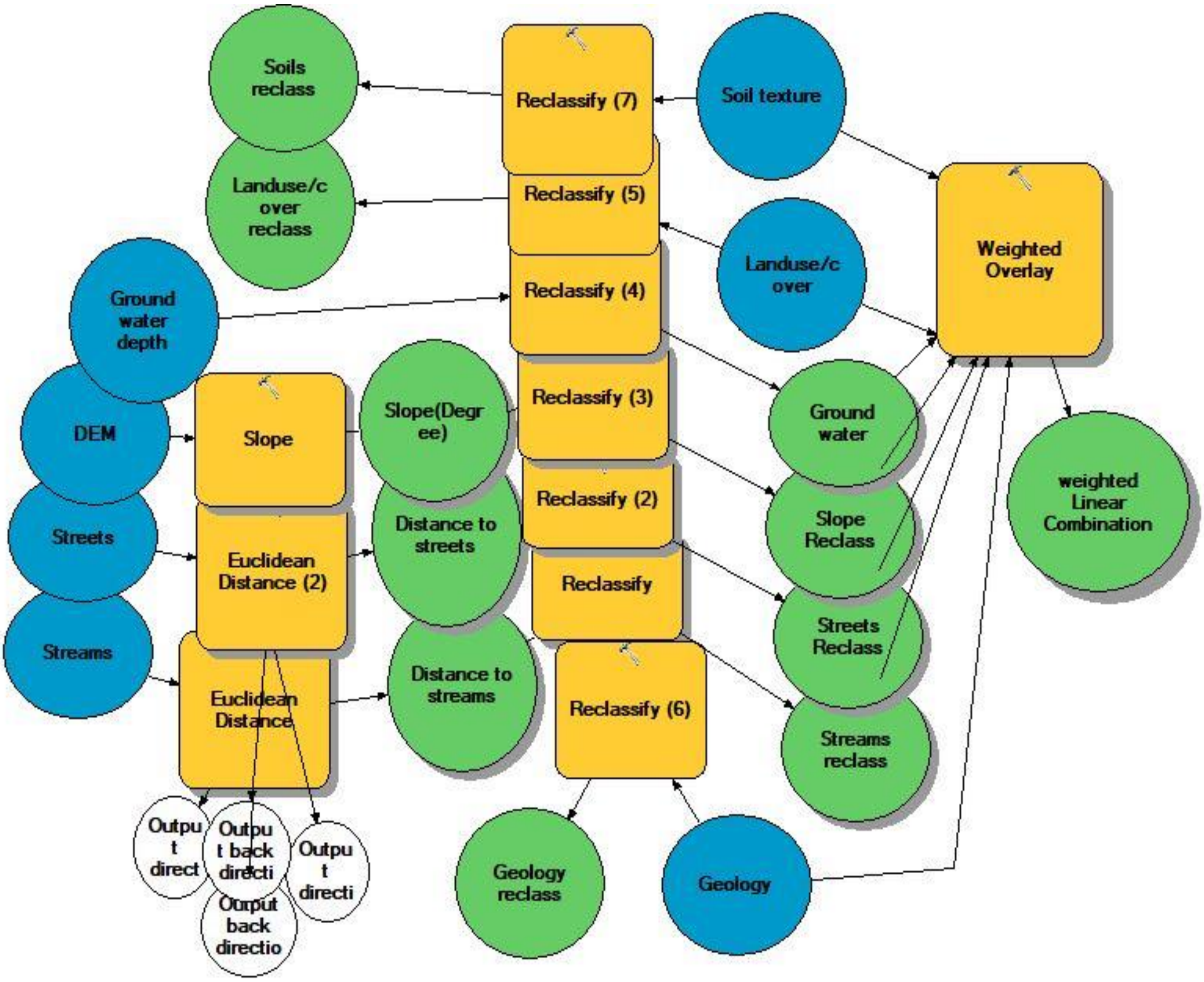


Fig. 18: WLC developed by Model Builder

3.4 Determining suitable solid waste collection points for Maseru City

The methodology for determining solid waste collection points was presented below in figure 19 below. Determination of solid waste collection points used no-spatial data (population and generated solid waste in households). Location-allocation was run to locate demand points (collection points) to the facility (dump site). Figure 19 below demonstrates the methodology for determining solid waste collection points.

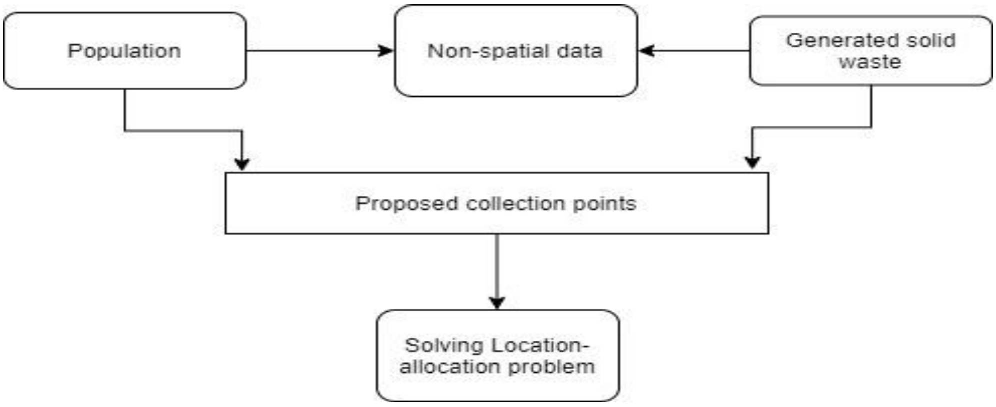


Fig. 19: Methodology for determining solid waste collection

To determine solid waste collection points, the rate of solid waste generation per week per person must be known, determination of number of people that can be served by a service area were presented. Secondly population of the service area also must be known. The capacity of the solid waste collection point must be known too. Suitable Solid waste collection points were determined using population and solid waste generation per week per constituency. Since in Maseru City solid waste was collected once a week in households, solid waste per week was used. After determining solid waste generation points, location-allocation problem was run.

3.4.1 Determining the rate of solid waste generation per week/person

To determine rate of solid waste generated per week per person, a total of solid waste generated per week and the population of the city needed to be known. Solid waste generation was gathered from a sample of 130 households in Maseru city by weighing solid waste from each sampled household per week. A selected household was informed to store solid waste for a period of a week for easy weighing. The solid waste generation per week per person was obtained from the total generated solid waste from households per week and total population of the city. Population was gathered from a village list from Ministry of Planning, Department of Bureau of Statistics. Equation 6 was adopted from Ntarangwi and Odera (2017) for determining rate of solid waste generation.

$$\boldsymbol{SWG = \frac{TW}{P}} \tag{6}$$

Whereby ***SWG*** was the rate of solid waste generation, ***TW*** was the total solid waste gathered from households and ***P*** was the total population for Maseru City.

The capacity of each collection point was determined based on the capacity of the Rear Loader Compactor Truck when full. The capacity of the Rear Loader Compactor truck was 330liters. 1 liter = 1kg. The capacity of each point was taken as 330kg which was the capacity of the Rear Loader Compactor truck when full.

3.4.2 Determining the number of the collection points per Constituency

The objective function of the development of network analysis for Maseru City was to minimize number of routes and total distance travelled during collection and disposal of MSW. The plan for solid waste collection for Maseru City to propose solid waste collection points whereby the trucks could not haphazardly collect solid waste in Maseru City but collect according to the optimal schedule to minimize distance traveled. The method by Ntarangwi and Odera (2017) was adopted and used in this study as it suited this study and was found easy to understand. Equations 7, 8 and 9 were adopted from Ntarangwi and Odera (2017). Since we know the population of each constituency and the solid waste produced per constituency per week, the rate of solid waste per person per week can be determined as solid waste in Maseru city was collected once a week in the households. Equation 7 adopted from Ntarangwi and Odera (2017) was used to determine the number of collection points per Constituency. From the population of each Constituency, and the total waste generated in each Constituency per week, the number of solid waste collection points per constituency was obtained as:

$$\boldsymbol{CPS = \frac{P \times SWG}{Ct}} \tag{7}$$

Where ***CPS*** is the number of collection points per constituency, ***P*** is the population of a constituency and ***SWG*** was the rate of solid waste generation per person per week and $\mathbf{C_t}$ was the capacity of the compactor truck when full. The capacity of the truck was taken as 330 liters.

3.4.3 Solving location-allocation problem

The location-location problem was solved in ArcGIS 10.7.1. with Network Analyst extension tool enabled. To effectively run location-allocation algorithm, sample points are needed as inputs. The total number of collection points in Maseru City were taken as inputs and the dump site. The 'Create Random Points along the line' tool in ArcGIS 10.7.1 was used to generate a total number of points for the whole city along the roads. Collection points were located along the roads based on the criteria some of the MCC management indicated on question10c. Maseru City has put restriction standard of 25m on both sides of the road so that no development could take place in such buffers on roads in the City so that no development could take place within that buffer. The collection points were located randomly in the study area. Inputs that are needed to run location -allocation problem were facility and demand points. However, the points were located along the roads with no buffers. Demand points represent the area or location where service is required. In this study, demand points were collection points in Maseru City. A Facility represent a layer where demand would need a service from. In this study, a facility was a dump site (Ts'osane dump site). The output was a layer showing a facility serving several demand points. The points were chosen points. The model was set as 'Demand to Facility'. The 'minimize impedance' was used as the problem type. A facility was created as a feature class. A total number of collection points were used to solve location-allocation problem.

Equations 8 and 9 were adopted from Ntarangwi and Odera (2017). The maximum number of people that could be served by a collection point was determined by:

$$\boldsymbol{NPC = \frac{Cp}{SWG}} \quad (8)$$

Where ***NPC*** is the number of people that can be served by a collection point, ***Cp*** was the capacity of the collection point and ***SWG*** was rate of solid waste per person per week.

To know how many demand points (collection points) to be served by a facility (dump site). The capacity in terms of household was given by:

$$\boldsymbol{HC = \frac{NPC}{APH}} \quad (9)$$

Where ***HC*** was the capacity of a household, ***NPC*** was the maximum number of people that can be served by a collection point and ***APH*** was average number of people per household. The average number of people per household was derived from this study which was 4 people. The average number of people was determined by averaging the ranges of people living in the households and getting the average of the results.

3.5 Developing an optimal route

In this study the optimal routing problem was addressed in a static transportation network in that it did not consider real world problems which could include randomness and dynamism hence Dantzig and Ramser (1959) argued that non-probabilistic and static problems do not resemble the real world. It was also deterministic in that routes and collection points visited by the travelling salesman, were known prior, once executed, did not change. Network elements such as travel times, restrictions (roadblocks, accidents, construction), speed limit and hierarchies were not taken into consideration. According to the findings of this study, solid waste was collected at different times due to obstacles such as administration hurtles, therefore, time windows was not used as there could be time violation problem. Also, the researcher did not get attributes related to road network from the relevant Ministry /Department. The routing was developed such that the solid waste was collected from both sides of the vehicle because the researcher found out through observation, that inhabitants put waste on either side of the road. The curb approach was left hand side as it was how driving was conducted in Lesotho. Also, MCC management stated that among factors to consider when locating a collection point were along the roads and near road intersection. Collection points were randomly located. The figure below shows methodology for developing network analysis. Figure 20 below shows the methodology for developing network analysis.

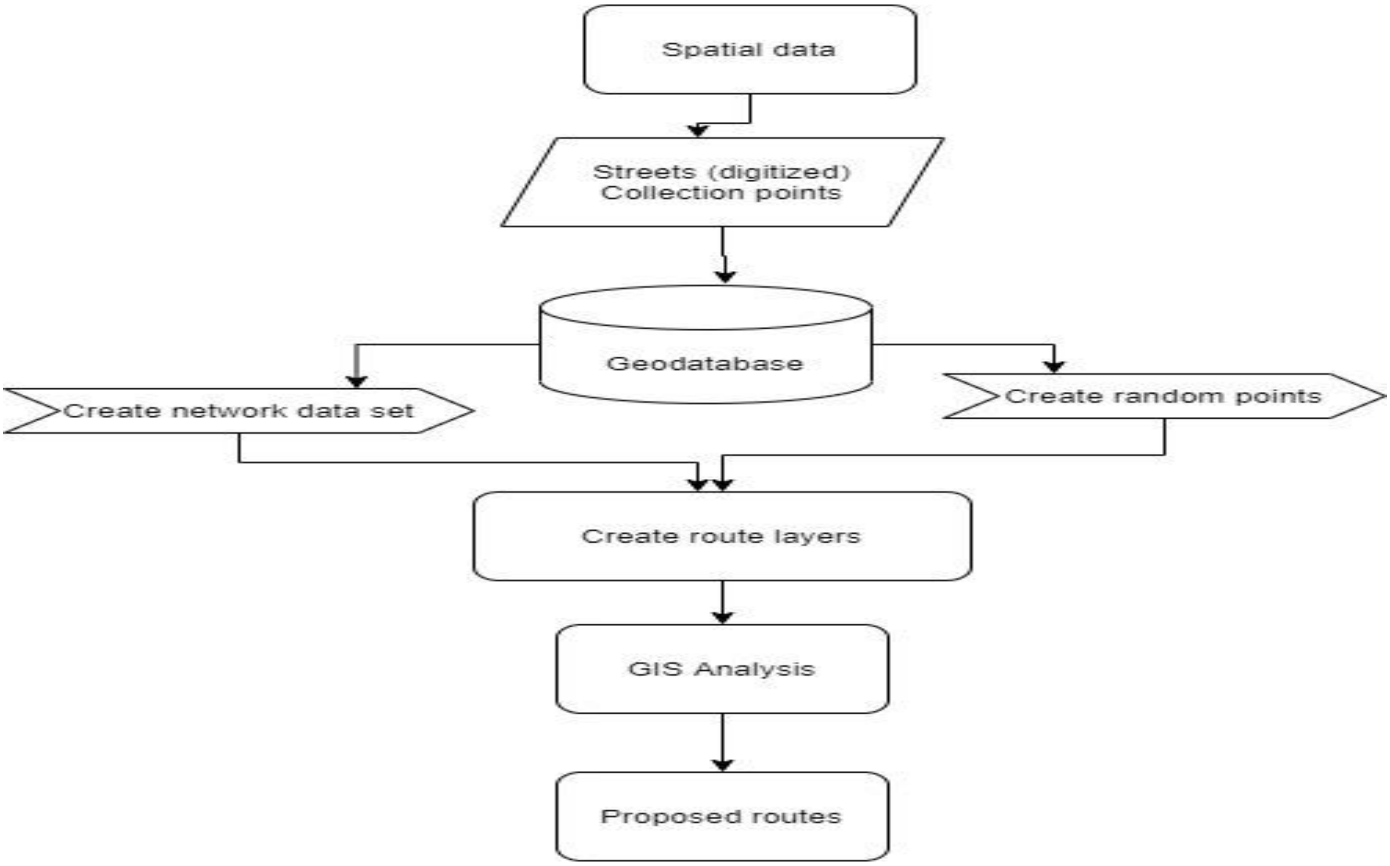


Fig. 20: Methodology diagram for developing network analysis

3.5.1 Road network construction

In order to develop road network analysis, a good street network representation in vector data is key for a successful analysis. To create road network data, two types of data were used. Vector and Raster. A vector data is a spatial feature depicted as discrete entity using three elements such as points, lines and polygons (Lo & Yeung, 2007). In this regard, lines were used as vector data. A raster data represents a graphic object as a pattern of cells (Bhatta, 2011). Road network data was digitized from on screen from high-resolution image by the researcher and were connected to create traversibility. The road centerlines were digitized to create a network. Only tarred roads were digitized and used for analysis. After, digitizing roads, a network data set was created consisting of edges representing lines and nodes representing junctions. However, time was not included in the data set because the researcher found out that solid waste could be collected from morning to evening depending on the circumstances. The Network Analysis was conducted in Arc GIS 10.7.1 with Network Analyst extension enabled. A network is a system of interconnected elements that can be visualized as a series of lines (representing streets/roads) connecting points (representing intersections) in the city (Boskovic & Jovicic, 2015) . The route network had three elements, junctions, edges and stops. Junctions were automatically created by the system. The stops represented the collection points (demand points) which a truck could visit to collect solid waste around Maseru City.

3.5.2 Developing of Optimal route

The Routing problem of this study was Precedence Constrained problem whereby the constraint was distance and the collection points were served in a sequenced manner. The optimum routes in network analysis were determined by finding the shortest route (minimizing distance). In this study the ‘minimize distance’ was used as the problem type. To determine an optimal route, the location of all collection points was considered. All points were placed in the network. Route layers were created, whose out puts were the optimal routes for three trucks. Points were rearranged according to the direction of the truck such that the parking area for the trucks became the starting and the end point since the deport was where the trucks were to be parked at the end of the business. Also, some points were re arranged to suite the routing analysis. To rearrange, points were used as chosen points. Three trucks were used in the routing analysis: Truck 1, Truck 2 and truck 3. The first truck collected to the Northern part, the second truck goes to Central part and the Third truck goes to Southern part. Since there was no current routing system for solid waste transportation, the proposed routes and collection points served as the optimized routes and collection points. Ts’osane dumping site was used in the analysis as it was the one currently used by MCC.

CHAPTER FOUR: RESULTS

This chapter presented results from data gathered from stakeholders (Households, MCC management and drivers, and community waste pickers). Stakeholders' data was analyzed using tables and graphs. The results for locating a disposal site, solving location-allocation problem and developing network analysis were also presented and analyzed in Arc GIS 10.7.1. Results were also discussed. The fees were in Maluti of which 1 USD =Maluti 15.27 at the time of study.

4.1 Outcome of assessment of the current solid waste management in Maseru City

The outcome assessment of the current solid waste management in Maseru City, was presented in terms of graphs and tables and discussion. The following graphs presented data on methods of solid waste collection, time of collection, availability of collection points, routes, quantity of solid waste generated, percentage of generated solid waste, days taken to fill storage and number of people living in the house. Figure 21 represents methods of solid waste collection by different stakeholders.

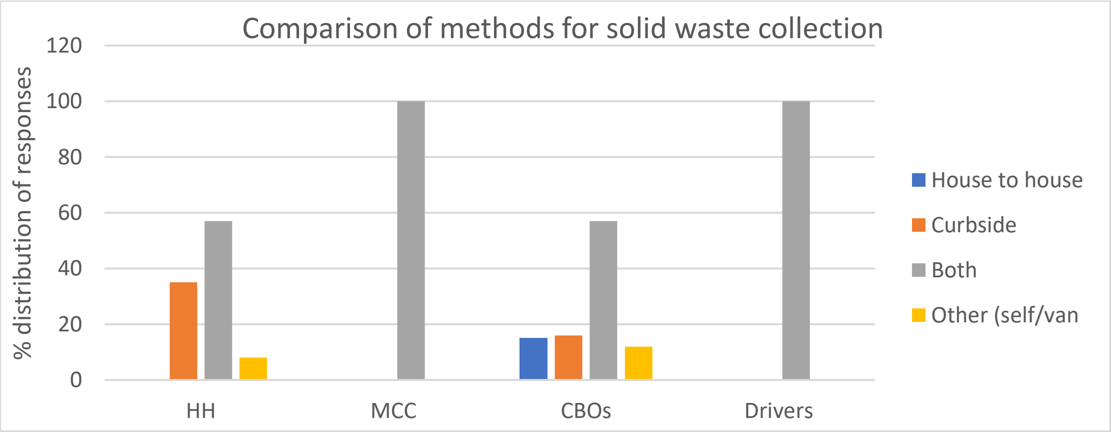


Fig. 21: Methods of solid waste collection

Time for solid waste generation was important in the study. Fig. 22: shows the time solid waste collection is done.

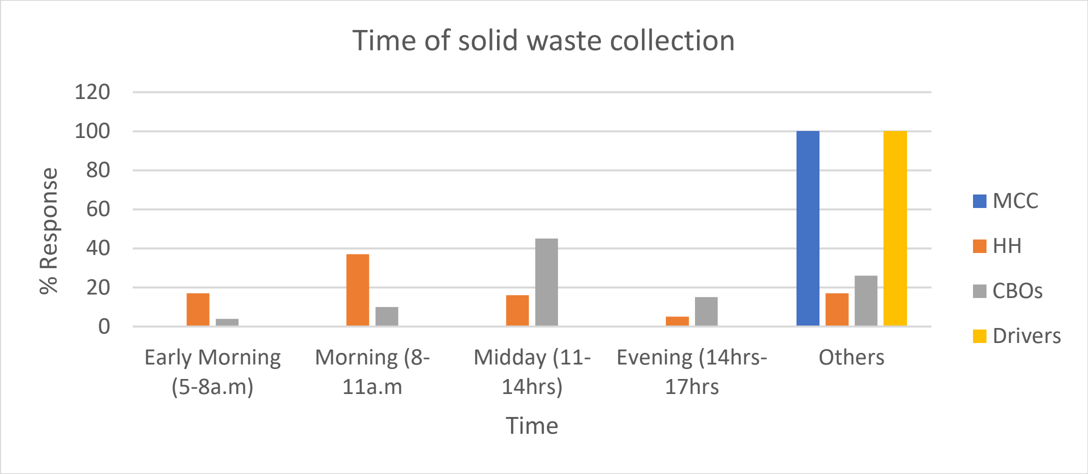


Fig. 22: Solid waste collection time

Knowing whether there were designated collection points was useful for the researcher to be able to come up with a realistic modelling and planning. Figure 23 shows data on whether there are designated collection points in Maseru city.

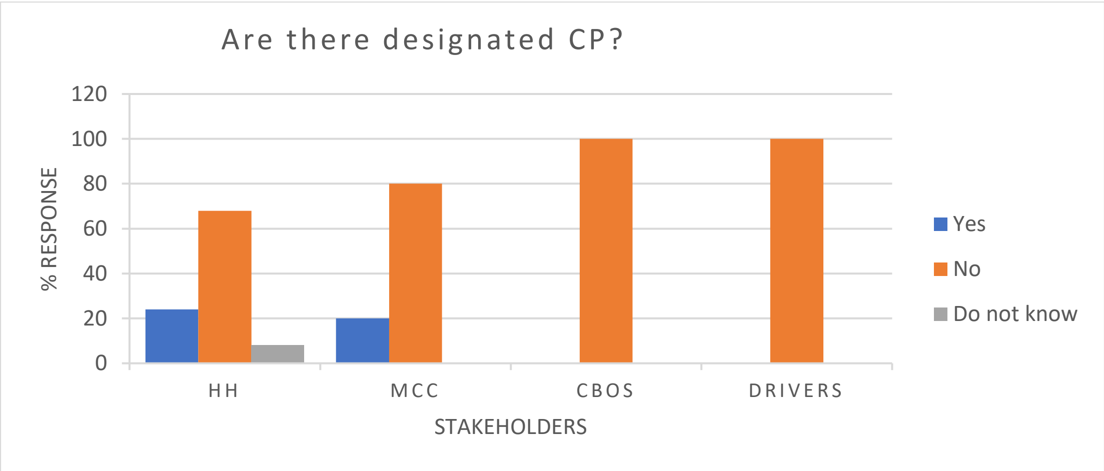


Fig. 23: Responses on designated collection points

Knowing whether there were existing transport routes was critical to assist the researcher to conduct a realistic modelling of routes. Figure 24 shows data on whether there are transport routes for collection of solid waste in Maseru city.

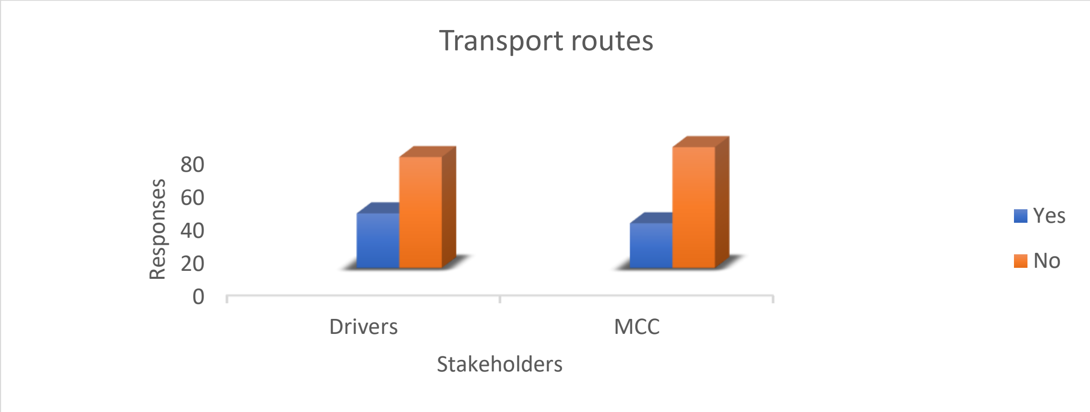


Fig. 24: Responses on transports routes

The quantity of solid waste generation per week gave the researcher the insights of where solid waste was generated. Figure 25 shows the quantity of solid waste generated per week/Constituency as waste was collected per week.

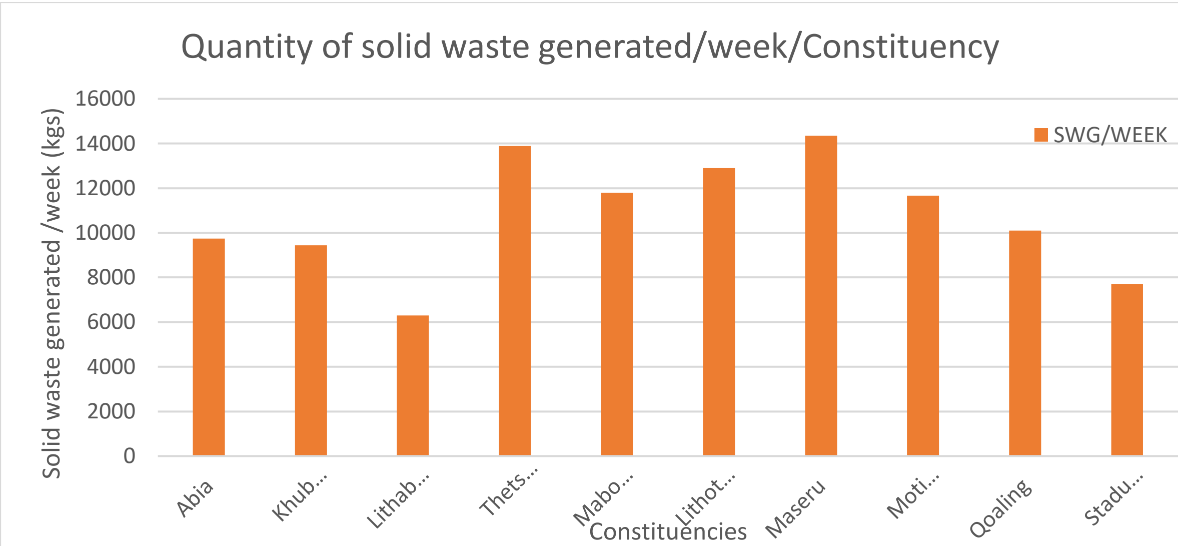


Fig. 25: Quantity of solid waste generated per week per constituency.

The percentage of solid waste generation assisted the researcher to know how much solid waste was generated by how many people per week. Figure 26 shows the percentage of solid waste generated by households per week.

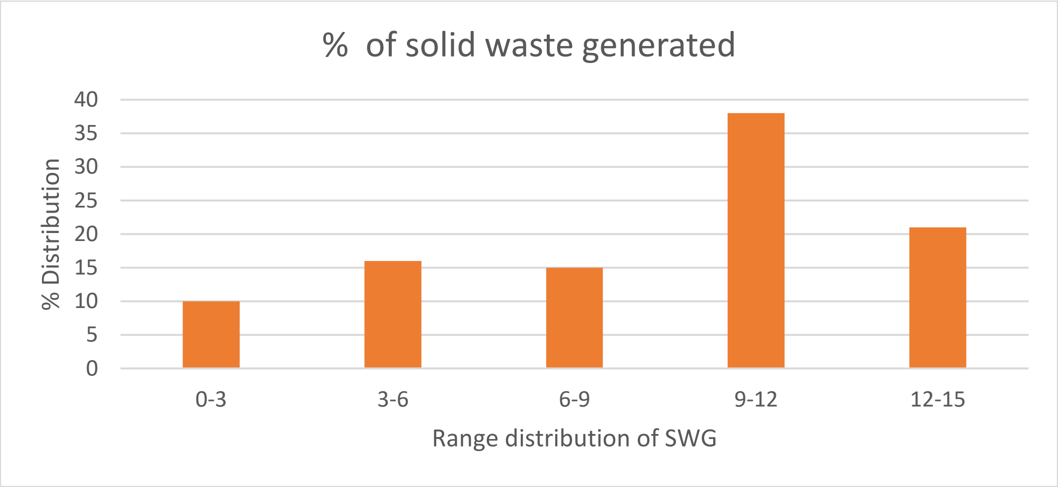


Fig. 26: percentage of Solid waste generated

Knowing days taken by households to fill their storage of solid waste was useful to know so that it could be possible to estimate the generation of solid waste. Figure 27 represented estimation of days taken by households to fill their storage with solid waste.

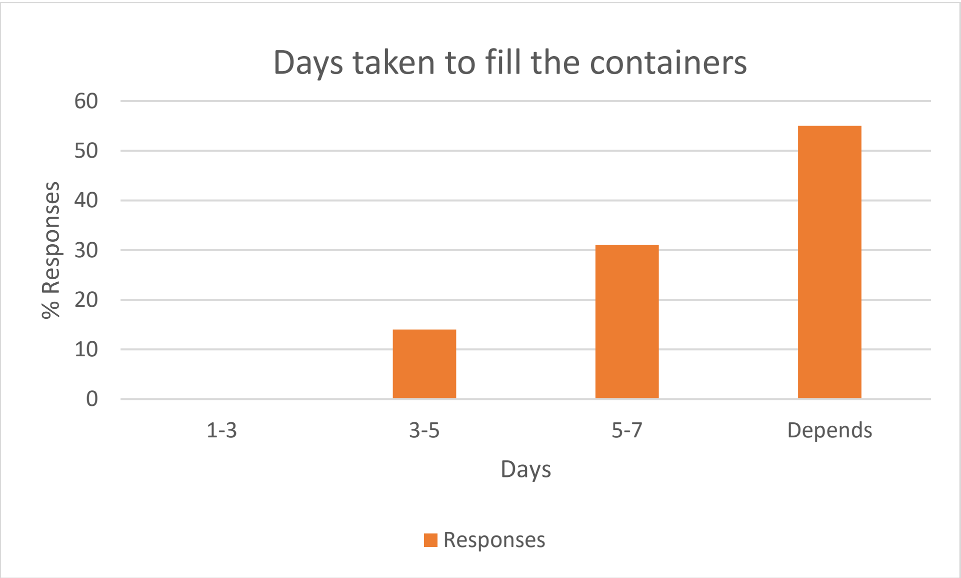


Fig. 27: Estimation of days taken by households to fill their storage.

The number of people living in the house was helpful to know so that the researcher could have an idea of the relationship between solid waste generation and the population. Figure 28 shows estimation of number of people living in the house.

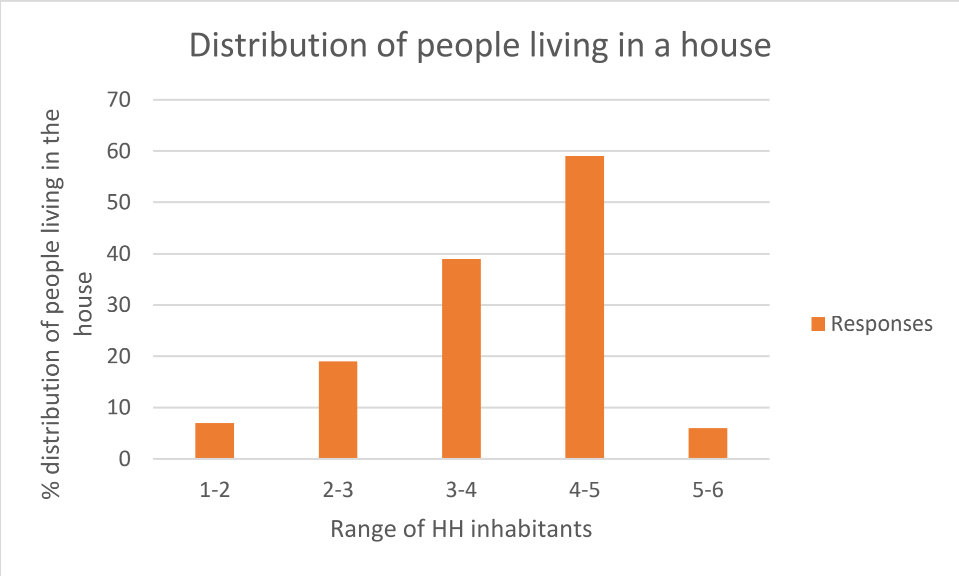


Fig. 28: percentage distribution of people living in the house

In figure 28 above, more waste could be generated for 4-5 people as to 5-6 people due to economy reasons. Some households could be wealthier than others and could buy more food than less wealthy people. The economy issue could apply for all ranges in the households.

Spatial distribution of solid waste in Maseru city was done to show how solid waste generation was across the city. Figure 29 below shows spatial distribution of solid waste generation for Maseru city per week

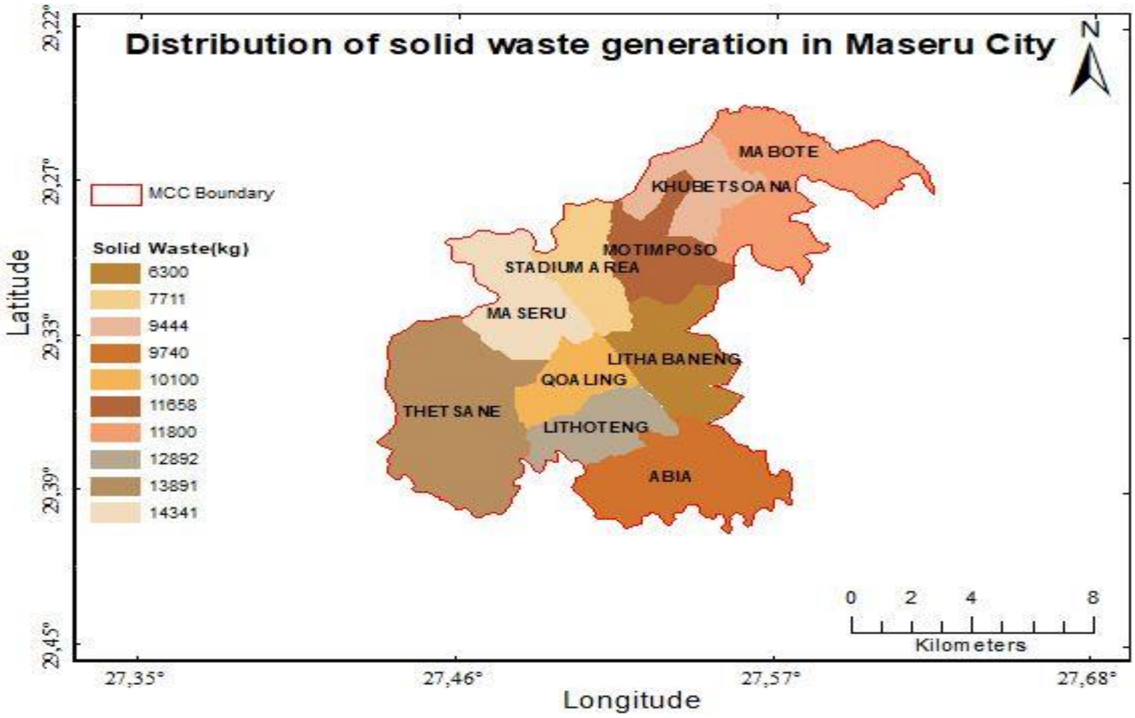


Fig. 29: Spatial distribution of solid waste generation

Collection points determined for each Constituency were determined using solid waste generated in each Constituency and relevant population. Equation 7 was used to calculate proposed collection points. A total of 334 proposed collection points was determined and calculated. The rate of solid waste generation was used. Table 13 shows distribution of proposed collection points for Maseru City

Table 13: Solid waste generation and estimation of collection points

Constituencies	**Size (m^2)**	**Population**	**SWG per week (kgs)**	**Proposed CPS**
Abia	20494409	30630	9740	33
Khubetsoana	10396080	13467	9444	15
Lithabaneng	14755587	40282	6300	44
Thetsane	31267133	51729	13891	56
Mabote	23451566	10092	11800	11
Lithoteng	10058798	36460	12892	40
Maseru	14760294	37138	14341	41

Motimposo	11873589	26641	11658	29
Qoaling	8572691	34214	10100	37
Stadium Area	10415593	25514	7711	28
Total		**297225**	**107877**	**334**

The reason for disparity on the solid waste generation differs in different Constituencies could be that some households are wealthier than others though the population could be small. This could mean that wealthier households are able to buy more grocery than others. Based on the equation or method used to calculate collection points per Constituency, population is one of the criteria. Therefore, some Constituencies might have more population than others but generates less waste or vice versa.

4.2 Suitable solid waste dump site for Maseru City

In order to develop suitable dump site for Maseru city, data was reclassified and categorized.

Continuous data such as slope, ground water depth, streets and streams were reclassified. Discrete data such as land cover, geology and soil classifications were categorized.

4.2.1 Reclassified Criteria Maps

The following Figures show the reclassified and categorized criteria maps for suitability analysis. The raster maps were reclassified.

Slope: Slope raster shows ranges from $0\text{-}59^0$. The slope range was such that $0\text{-}10^0$ is highly suitable and greater than 60^0 is not suitable. Figure 30 shows the reclassified slope of Maseru city.

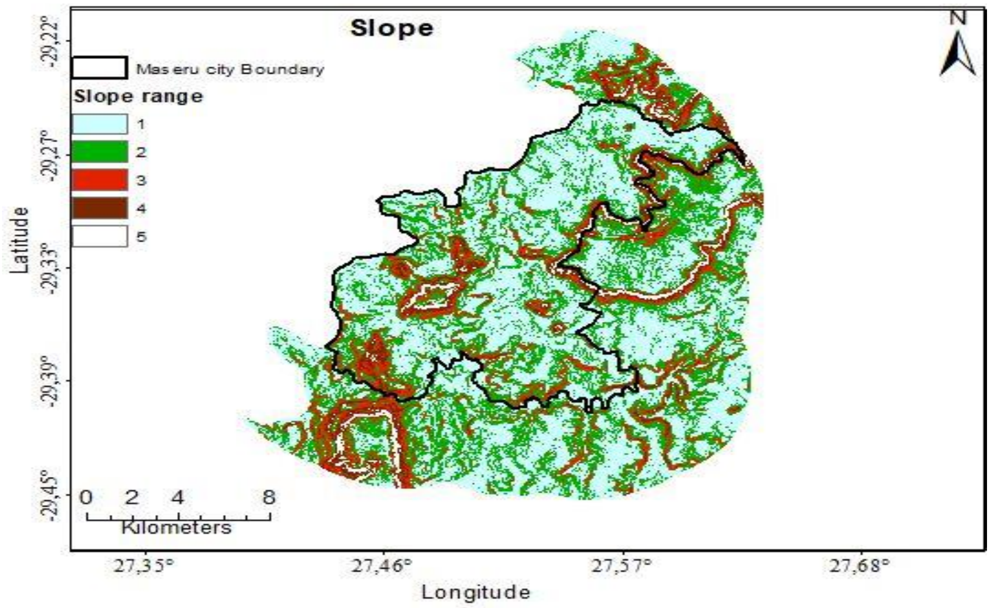


Fig. 30: Reclassified slope

Ground water depth was determined by water table values and elevation values. Shallow ground water depth values were considered unsuitable while higher values were considered highly suitable for a dump site. Figure 31 shows Classification for ground water depth.

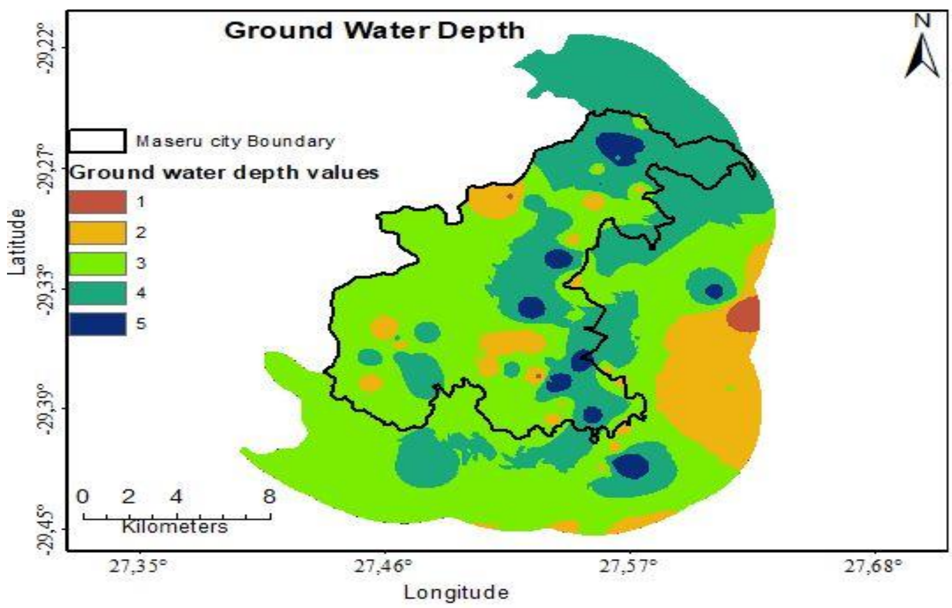


Fig. 31: Reclassified ground water depth

Distance from streets was determined from calculating Euclidean distance from streets. The 250m was put around the streets such that the closer to the streets the more unsuitable. Figure 32 shows classification for distance from streets.

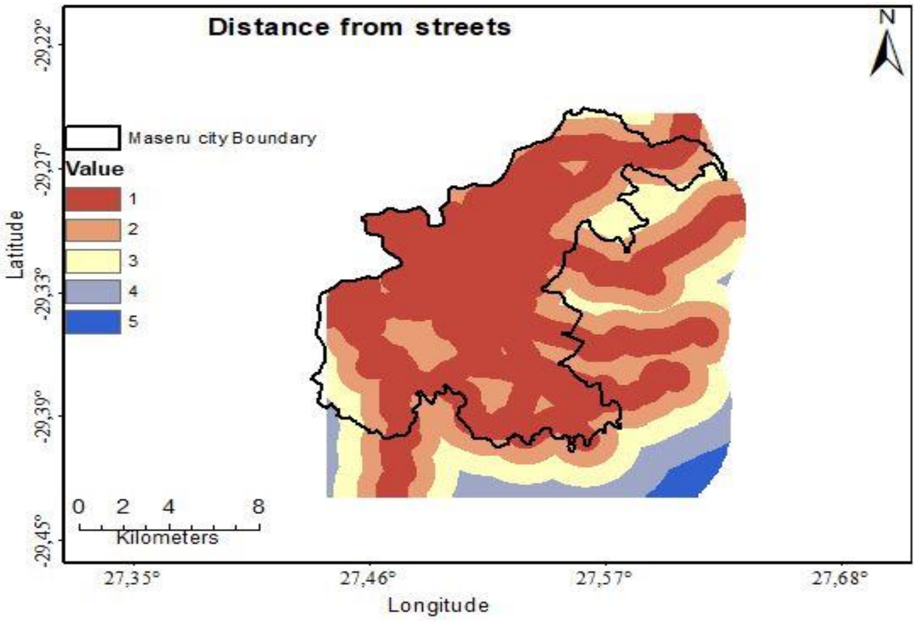


Fig. 32: Reclassified distance to streets

Distance from streams was calculated from Euclidean distance of 350m. The lower the values the less suitable. Figure 33 below shows classification for distance from streams.

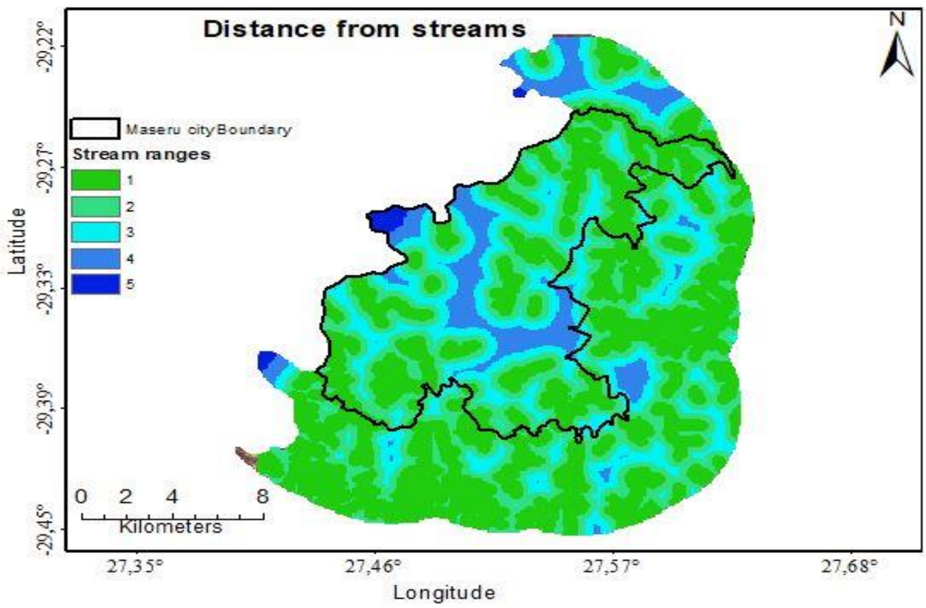


Fig.33: Reclassified distance to streams

4.2.2 Categorized criteria data maps

Geology strata was very important in locating a suitable dump site. The lithology strata were rated based on the content in them. The geological classifications were classified same as soils since the contents of the rocks are same with the soils. Figure 34 shows the geology stratum for the study area.

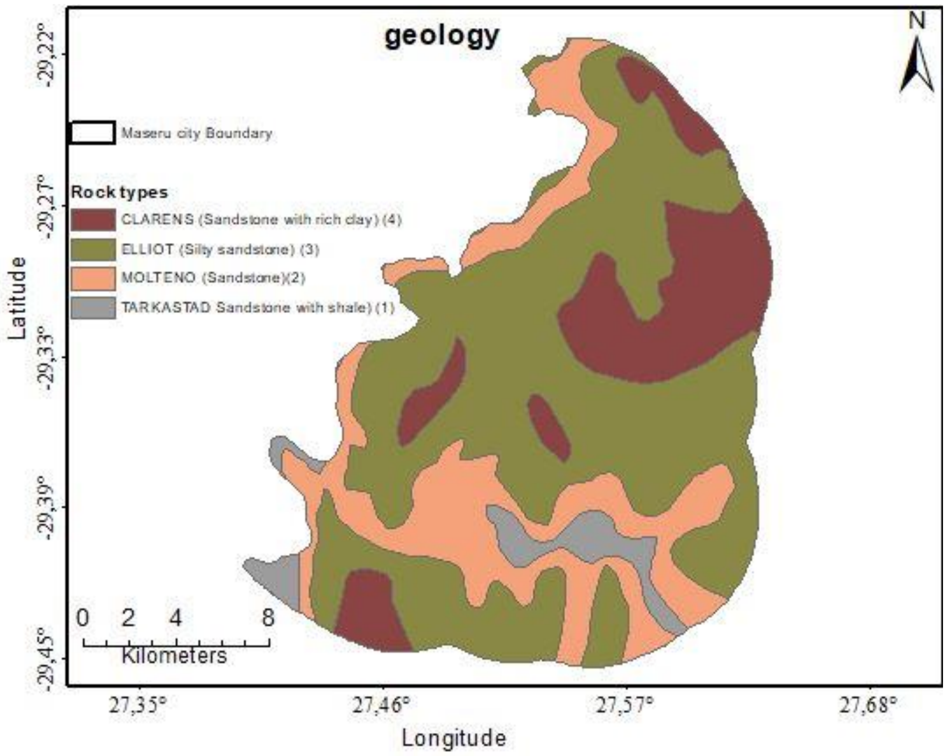


Fig. 34: Reclassified geology

Soil texture was also important for locating a dump site. Soil texture was scored based on the content where the clay soil were highly suitable and porous soils such as sand were scored low. Clay content soils were scored high. Vertisols and clay pan soils were scored 5 since they are clay texture. Vertisols were rated 4 as there was a rich content of clay though there was a content of some other soils. Figure 35 below shows the classification of soil texture.

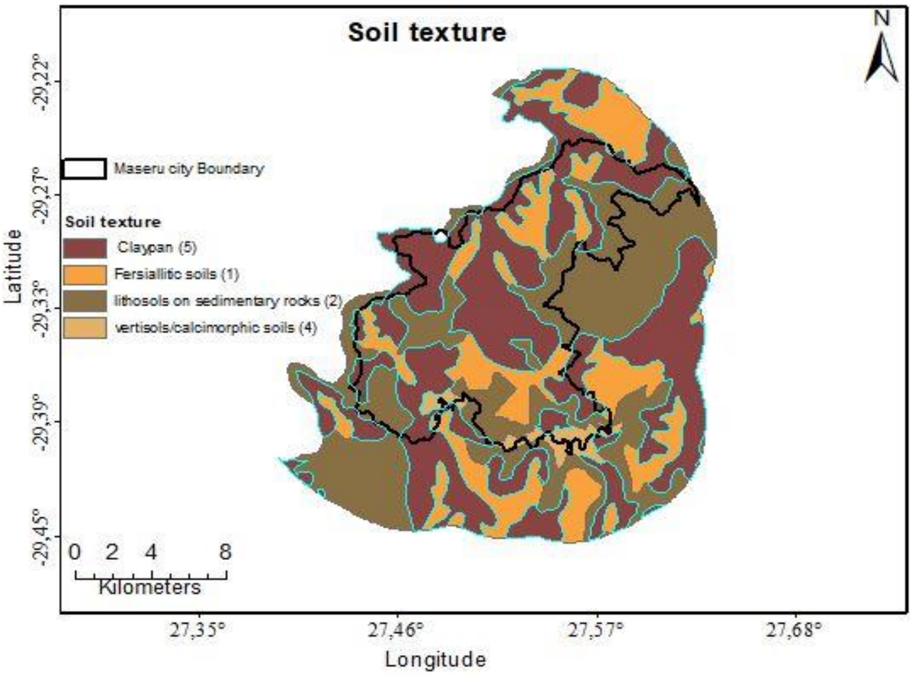


Figure 35: Reclassified soil texture

Land use/cover classes were used to locate a dump site. Land cover classes used were agriculture, built up (residential, commercial), trees, surface water, bare areas and bare rocks. The scoring of the land cover classes was scored based on the suitability of locating a dump site. All land use /cover classes except bare areas were rated 1 which is unsuitable while bare areas were rated 5 which is suitable. Figure 36 shows land cover /use classes.

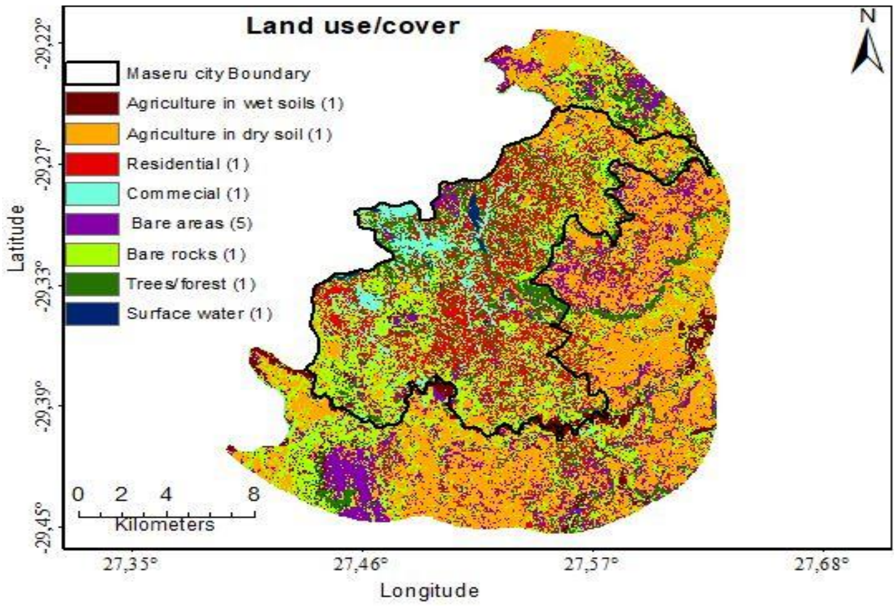


Fig.36: Reclassified land use/cover

4.2.3 Suitability analysis

The final suitability maps were derived from weighing factors using Weighted Overlay tool, at a scale of 1-5. Combination raster was created based on the criteria such as land cover/use, geology, soils texture, ground water depth, distance to streets, distance to streams, and slope. Euclidean distance from streets and streams was calculated so that the closer the distance, the more unsuitable it was for locating a dump site. The score of factors added up to 100%. After running the model, each pixel value indicated how suitable the location was for a disposal site. Pixels that were 1 were unsuitable, and 5 were highly suitable. Figures 37a and 37b below show the weighted overlay results which shows the suitability of the current dump site.

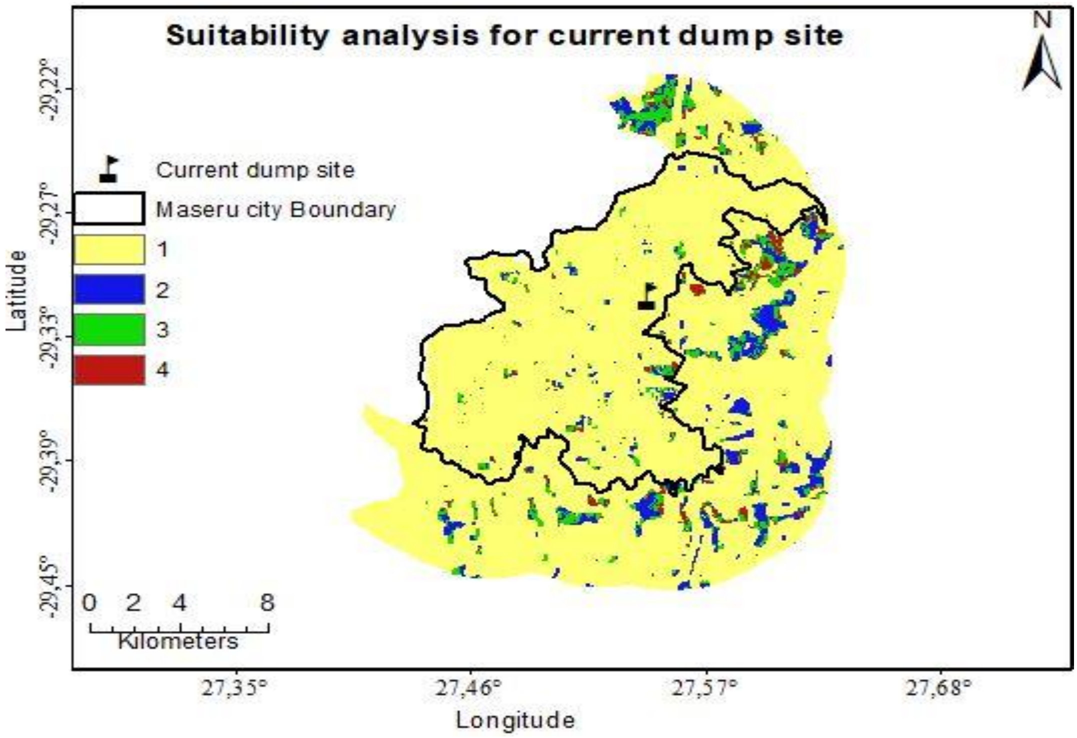


Fig. 37a: Suitability analysis for current dump site

The ‘Set null tool’ was used to take out the most unsuitable areas. The following figure shows the final suitability map showing areas from highly suitable to low suitable. The current dumpsite falls within unsuitable area (Figure 37b). Looking at the results after nullifying the unsuitable areas, the city is mostly unsuitable.

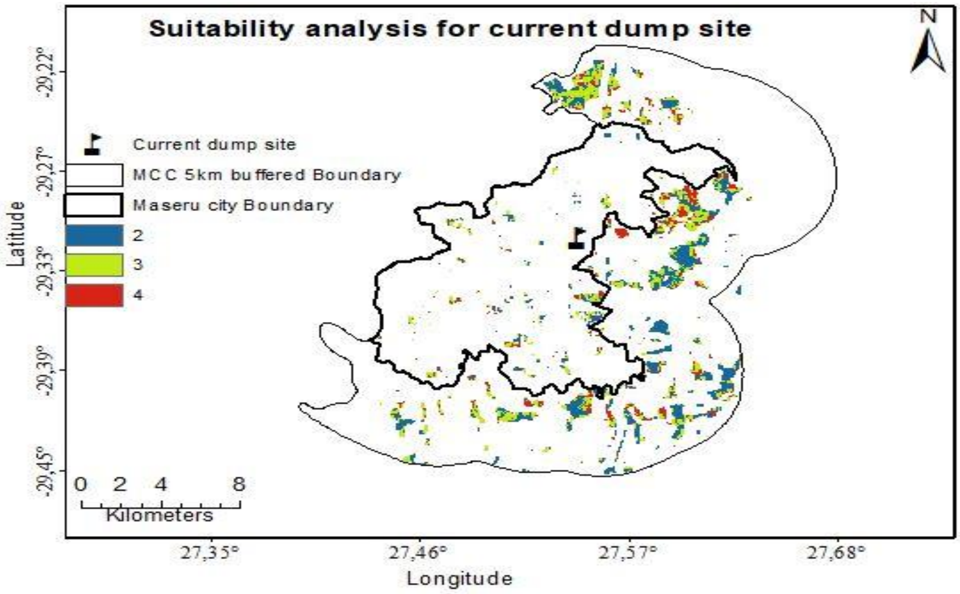


Fig 37b: Final Suitability Analysis for current dump site

4.3 Proposed Collection Points

Proposed collection points for Maseru city were determined for efficient collection of solid waste in Maseru city. Equation 6 was used to calculate rate of solid waste generation while equation 7 was used to calculate proposed collection points. A total of 334 collection points was determined. However, MCC demands that no development within 25m on both sides of the road. The highlighted 'red' collection points were those falling the proximity of 25m from the road. A total of 65 points fell within 25m proximity of the road and were used for routing analysis. The collection points which are 25m off the road are more suitable and easier for trucks to transport solid waste from different places. The 25m proximity is a standard from MCC. The 'create random points' tool was used to locate points in Maseru City. The points fell randomly across the city of which some fell in places where there are no tarred roads or very far from the road. Figure 38 shows the location of proposed collection points for Maseru City and those falling within 25m off the road.

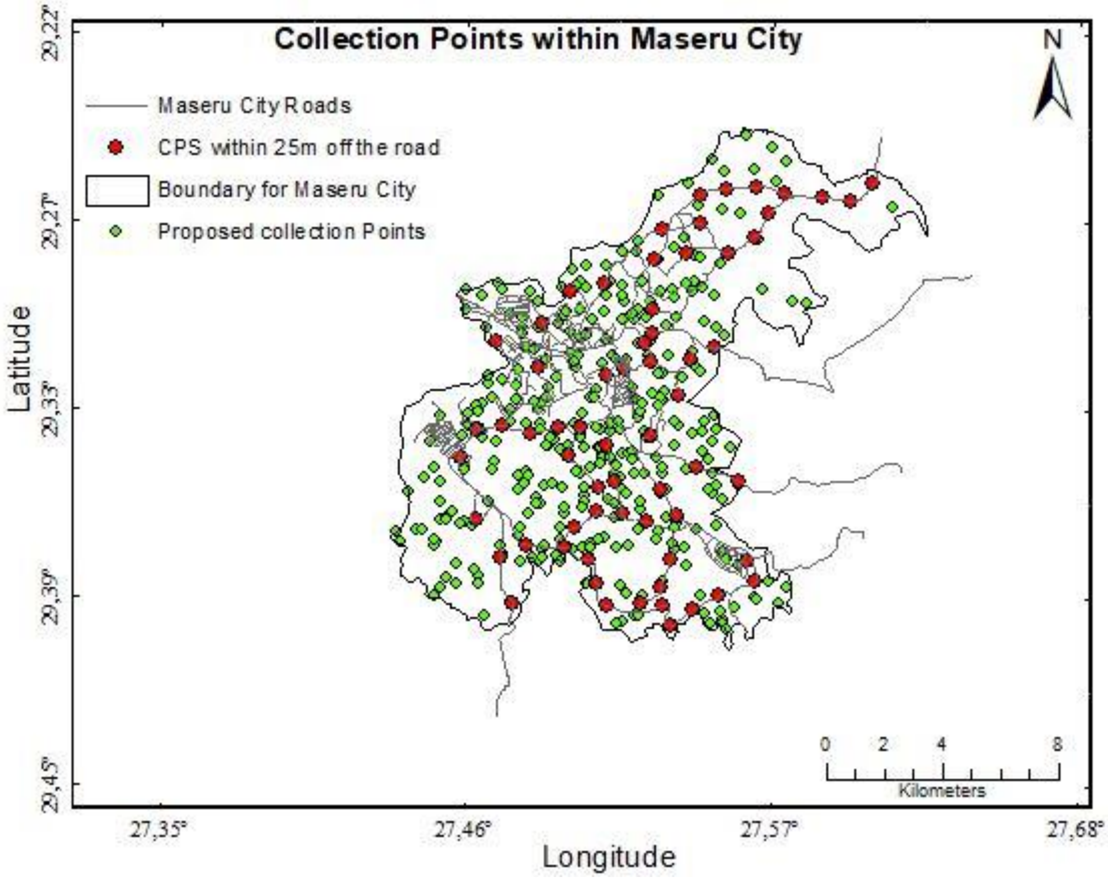


Fig. 38: Proposed collection points.

4.3.1 Solving Location-allocation problem

Location-allocation problem was run for optimum collection of solid waste in Maseru city. The dump site was the facility while the collection points were the demand points. The current dump site (Ts'osane dump site) was used in the analysis. Figure 39 shows the location-allocation problem solved. The Location-allocation was solved using 65 which fell 25m off the road. The problem type was 'minimize impedance' while the 'impedance was length. The travel was from the demand to the facility. As suggested by MCC management collection points are best put along the roads.

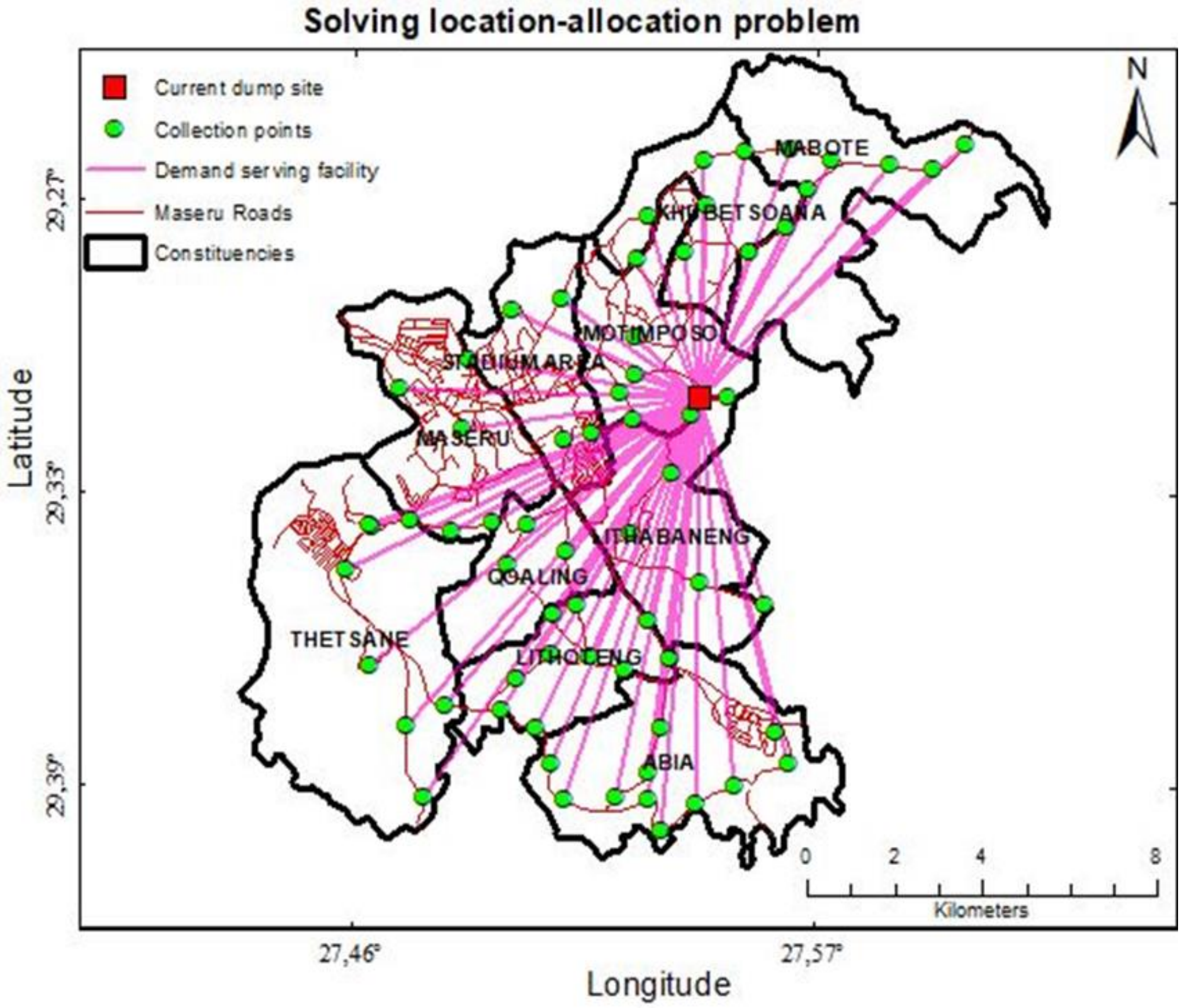


Fig. 39: Location-allocation

The maximum number of people that could be served by a collection point were 917. In terms of household, several collection points to be served by a facility is 229.

4.4 Optimal route network for solid waste collection and disposal for Maseru City

The optimal routing for collection of solid waste collection and disposal was important to try to solve the haphazard collection of municipal solid waste currently done in Maseru city to minimize costs. Optimal routing for Maseru city could be one truck or more. The route planning was conducted using one truck. Figure 40 shows the proposed route planning for Maseru city

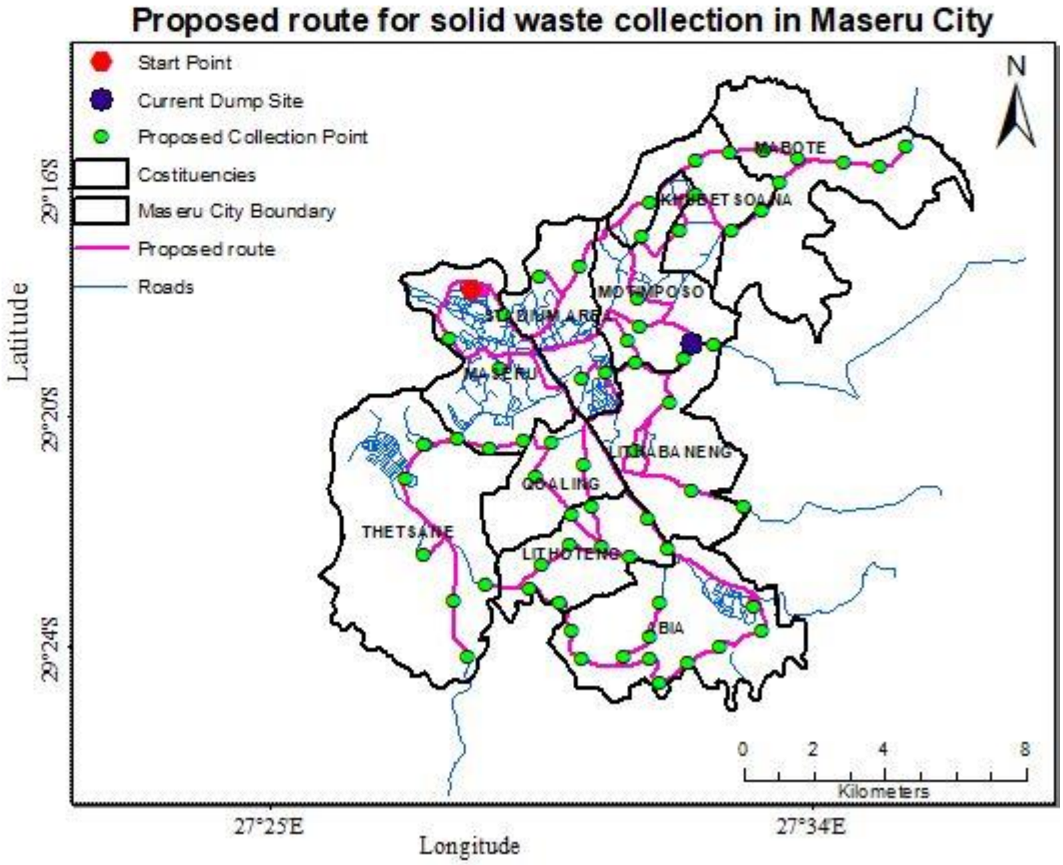


Fig. 40: Proposed route planning for Maseru City

CHAPTER 5: DISCUSSIONS

The discussions Chapter deals with the findings of the study and how it relates to literature. In this Chapter, discussions on solid waste management, suitability analysis, location of collection points and route planning will be discussed. First, the discussion on solid waste management is discussed.

5.1.1 Solid waste management

The stakeholders for solid waste collection in Maseru city was MCC, Government, Households and CBOs.

General methods are employed in different countries such as Jarkata, Mozambique and Nigeria (Pasang, Moore & Sitorus, 2007; Agunwamba, 1998; Parrot, Sotamenou & Dia, 1989). In Jarkata, collection of solid waste was done through door to door, and curb side methods. The methods were also employed in Maseru City. The waste collectors in some countries such as Jarkata are generally volunteers who were not paid. However, in Maseru City, residents paid collection fees. In developing nations in Africa such as Jarkata, and Nigeria, waste was transported using wheelbarrows or animal-drawn carts. CBOs also used wheelbarrows and some small trucks which could move in and out of community streets. In Jakarta, temporary transfer stations were used (Pasang, Moore & Sitorus, 2007). However, in Maseru city, there were no transfer stations although a study by Bulane (2009) proposed transfer stations. Solid waste was transported straight to the dump site.

Vehicles used to transport solid waste included rear loading compactor trucks and container trucks which are rigged with compactors to allow the bigger quantity of waste to be loaded into the container either, manually or mechanical (Gukhool, 2015). Container vehicles are used to exchange waste to other containers. MCC used Rear loading Compactor trucks, and smaller trucks and a tractor. According to Gukhool, (2015), a vehicle transporting consisted of a driver, and from two to eight crew members. At MCC, transporting vehicle also consists of driver and two to six crew members.

Proper waste disposal could either be open dumping, controlled dumping and landfill (Hoornweg & Bhada-Tata, 2012), of which MCC used controlled dumping where solid waste was dumped then covered with soil. Although, burning waste poses threats to human and environment (Hoornweg & Bhada-Tata, 2012), some residents in Maseru City burned waste. In low-income countries, where landfills are not yet available or well managed, open dumping is most prevalent with about 93% of waste burnt, dumped in roads, open spaces or water ways (Kaza et al., 2018). In Maseru City, solid waste was dumped illegally and disposed on open spaces or dumped in roads.

From Figure 22, it can be observed that stakeholders use both house to house and curb side methods of solid waste collection. However, those using others such as self and van contribute a very low percentage. Through observation on the field, the researcher noticed that drivers also went from selected houses which had paid for collection. Even the CBOs stated that although they mostly used house to house method, curb side was sometimes used as in some households they were not allowed to enter the houses. As per Figure 23, MCC management and drivers stated that collection of solid waste was done from morning to evening as drivers go from place to place, so, in some places they reach late. However, majority of the CBOs stated that they collected from 11-14hrs because that is the time when people could be found in their houses, while some CBOs stated that collection depended on some factors such as weather conditions, and other social factors. Majority of households stated that solid waste was collected in the morning between 8-11a.m and few stated that solid waste was collected in the evening (14hrs-17hrs). Majority stated that they were much satisfied about efficiency of the collection. CBOs also collected solid waste on weekends when people are available and towards midday when gates were mostly open. Since CBOs indicated that they use their own equipment such as wheelbarrows and trucks/vans, it became strenuous and tiring and sometimes equipment gets broken and had nothing to collect waste.

About whether collection was done the whole city, a greater percentage of both MCC and drivers indicated that collection was not done in the whole city due to lack of capacity and improper roads for truck to maneuver around the streets as the trucks collecting solid waste were big in size. A very low percentage was covered. As per figure 24, CBOs and drivers indicated that there were no designated collection points, while few said there were. Figure 25 illustrates the availability of designated routes. Majority of drivers and MCC stated that there were no routes, while few said there were. According to the researcher's observation, there were no designated collection points nor routes, but there were illegal collection points which were used mostly along the roads. However, households who said that there were collection points, majority did not know how far it was and that most people preferred the collection point to be between 50-75m arguing that they did not want collection points to be near their houses to avoid bad smell and pollution. Very few preferred 0-25m. Some households stated that they did not know whether there were collection points. Collection was mostly done once a week per community hence drivers went to work to collect everyday as their daily job. Figure 26 illustrates the quantity of solid waste produced in different Constituencies. Thetsane and Maseru Constituencies produced more solid waste than others. Lithabaneng and Stadium Area produced lesser solid waste than other Constituencies. The study was conducted during December holidays. When asked to estimate the time taken to fill solid waste storage, majority of households stated that amount of solid waste depended on many factors such as time of the year and events. However, no households could fill their storage between 1-3 days. Figure 29 illustrates the number of people living in the house. Majority of people living in house were between 3-4 and 4-5, and less households were between 1-3 and 6-7 people in a house. The average people per household was taken as 4.

The challenge of some residents not paying collection fees has resulted in inconveniences in collection although most of them were satisfied. There seem to be a lot of variation as to the amount of fees people pay per constituency. Solid waste was disposed at Ts'osane dumping site. The dump site was about five kilometers from the Central Business District (CBD). As seen from google Earth, (figure 5), the dump site was located at the vicinity of the settlements and very close to the roads. CBOs indicated that they did not work for MCC, that since they used their own equipment for collecting solid waste, they should be paid by the residents.

The challenges faced by stakeholders included lack of proper roads, equipment and staff which they thought it was good to increase staff and provide equipment. Although, MCC and CBOs stated that since households did not want to pay collection fees, the efficiency was hampered by such behavior as collection was expensive. However, some households on the contrary stated that collection fees were expensive and needed to be lowered. Lack of political willingness to support planning and funding has been another challenge. The public lack awareness with regards to solid waste management. One challenge was that there is lack of policy that exclusively support location of disposal sites. The criteria as indicated by MCC management to select the disposal site was random and only based on the literature or common sense as it is not supported by policy. On the issue of the whether there were routes for transporting solid waste, some indicated that there are designated routes and stated that there was no specific criteria but used ‘common sense’,. The common sense meant that they could just visit the area without using scientific methods, and look for the space, which is unoccupied, not agriculturally used and not near the settlements. The solution was to construct roads to ease transport. The drivers indicated that going street by street was a great challenge as the system wasted fuel and indicated that that there was need to come up with a defined routing system such that trucks do not go street by street but collect Big chunks of waste from smaller streets.

The findings from different stakeholders have also shown convergence in that some answers to the same question were the same, and that developing both suitability and network analysis assisted in expanding on the quantitative results in that the dump site was not suitably located and that solid waste was haphazardly collected and transported.

5.1.2 Suitability analysis

The suitability analysis was done through combination of factors and were discussed below. Figures 31 (slope), 32 (Ground water depth), 33 (Distance to streets), 34 (Distance to streams), 35 (Geology), 36 (Land cover) and 37(Soil classes/types) illustrate the criteria maps used in combination to develop suitability of a dump site in Maseru City.

Slope

Figure 30 represents the reclassified slope of the study area. The slope range was 0-59^0. The reclassification was done into five classes. The most unsuitable areas were those in the hilly areas such as small mountains and platues and had a greater share of 48.4%. On the contrary to Bulane (2009), study, the platues has been considered as potential site for location of a transfer station. The researcher was of the view that a solid waste site cannot be located on platues as it is on top of the mountains, and it is considered as hilly area and could increase construction costs (Wang et al., 2009).

The suitable areas which were scored 5 covered the lowest percentage of only 2.2%. which were unsuitable for a dump site while areas which were scored 2 covered 31.9%. Medium and Highly suitable covered 11.8% and 5.7% respectively. The analysis showed that most of Maseru city was unsuitable for locating a disposal site as most of the city’s coverage is hilly. As indicated by several researchers, a slope in degrees between 8-10 is considered highly suitable for construction of a disposal site (Kamdar et al., 2019; Chabuk et al., 2017; Effat & Hegazy, 2012). According the analysis, highly suitable areas only covered 5.7%. Bulane, (2009) used slope as criteria for suitability analysis and indicated that areas with slope less than 18^0 were suitable. The researcher also used the criteria areas less than 20degrees were suitable.

Ground water depth

The ground water depth was represented in figure 31. The range values of ground water depth were from 0m to 142m. The reclassified range of ground water depth was represented in figure 32. The values which were lower were not suitable for siting a dump site while higher values were highly suitable as it was stated in the literature, while greater values were scored Very high. Medium range covered 51%, while values which were scored 5 (Very highly suitable) only covered 2%. Unsuitable values covered a very low percentage of 0.6. Ranges scored 4, covered 33%. A greater percentage of 50.8% was score medium. Since the boreholes did not cover entirely the whole study area, this caused a lot of extrapolation especially in the Northern part of Maseru, however, the extrapolation scenario was catered for by other factors used in the analysis As stipulated in the literature, ground water greater than 70m is highly suitable (Arkoc, 2014).

Streets

Distance from streets was very important in locating a disposal site. Figure 15b illustrates distance from streets, while figure 32 shows the reclassified values of streets into five classes. Euclidean distance for streets was calculated such that the farther the cell was from streets the more suitable it was and vice versa. A distance less that 250m as stated in the literature is not suitable and the longer the distance is highly suitable (Kamdar et al., 2019; Uyan, 2014).

and the highly suitable covered 19%. The most covered distance was medium range with 21%. The very Highly suitable covered 19% while the highly suitable covered 20%. This analysis meant that the very highly suitable distances covered the less percentage while the medium covered most and the suitability could be medium.

Distance to Streams

Distance from streams was an important factor to be considered in locating a disposal site. Euclidean distance for streams were calculated such that the further a cell was to the streets the more suitable and vice versa. Distance from ranged from 0-3088m. Figure 33 shows the reclassified range of distances from stream into five classes. The percentage coverage for distances for streams for ranges 1, 2 and 3 covered 19%. The very highly suitable distance covered 21% while highly suitable covered 22%. The analysis meant that suitability was generally high as the higher coverage was for highly and very highly suitable. The studies by Yal, ((2013) and Uyan, (2014) indicated that distances greater than 5000, 2000 were highly suitable.

Soils and Geology

Figures 34 and 35 illustrates soils classes and geology. Figure 14 was described based on the lithology and figure 13 as soils classification stratum. Geology was firstly described. Greater coverage of 55% was Elliot type of rocks. Since Elliot rocks consisted of both silt and sandy shales, it was given a medium score of 3 as it consisted of mixed soils of silt and sand. Molteno covers 23% and Molteno beds are type of sandstone rocks which are composed of calcium and weather to form a rich stiff clay. Areas covered by Molteno was scored 2 as the composition of Molteno is a sandstone with clay. Clarens covered about 18% of the area and was rated very high as it is a sandstone with rich clay and was classified suitable since it is mostly clay. Tarkastad (Upper beaufort beds) rocks cover a very low percentage of 1 since it is mostly sandy. The low coverage of sandy soil would put Maseru city into an advantage as sandy soils are considered restricted for a disposal site suitability (Kamdar et al., 2019; Arkoc, 2014; Demesouka, Vavatsikos & Anagnostopoulos, 2013; Pandey, Sharma & Nathawat, 2011). The greater percentage of soils that covered most of the study area were claypan soils which covered about 44% of the study area. Soils consisting of clay is highly suitable for locating a disposal site. Vertisols/calcimorphic soils covered about 2% and were mostly located in the Southern part of the study area. Vertisol/Calcimophic and claypan soils were given a very high score of 5 as they consist of rich clay. Fersiallitic soils cover about 20% and were scattered within the study area and were developed from Molteno rocks. Since Fersiallitic soils consisted of coarse sand, these areas were given low score as sandy soils were not suitable for locating a disposal site due to their high porosity (Kamdar et al., 2019; Arkoc, 2014; Demesouka, Vavatsikos & Anagnostopoulos, 2013; Pandey, Sharma & Nathawat, 2011). Maseru city was mostly covered with clayey soils which were highly suitable for locating a disposal site.

Land use/cover

Figure 36 illustrates land use /cover of the study area. Agricultural areas consisted of 19% of the study area. The built up in general covered 32% (Residential area covered 24% and commercial covered about 8%). The built-up area was completely not suitable for locating a disposal site. Bare areas covered about 13% and were highly suitable for a disposal site while bare rocks covered 27%. Surface waters such as dams, rivers, cover about 1% and about 9% was covered by trees. All land use/cover classes except bare areas were rated 1 as they are not suitable for locating a disposal site. Bare areas were the only places allowed to locate a disposal site as a result was rated 5. Based on the literature reviewed, agricultural land which covers a higher percentage of coverage is unsuitable (Asefa Bedasa, & Mindahun Wondwossen, 2019; Kamdar et al., 2019; Mugo & Odera, 2019; Arkoc, 2014; Pandey, Sharma & Nathawat, 2011). In this study, agricultural areas, trees, surface water, (Streams, dams) bare rocks were considered unsuitable while bare land was highly suitable. Bulane, (2009) also used land cover as the criteria for selecting transfer stations.

Final Suitability analysis

Figures 37a and 37b show the suitability analysis for the current dump site. The results for suitability analysis show that the bigger area was unsuitable with 88% coverage. Only 2% was highly suitable. Medium and low suitable covered 4% and 5% respectively. Since most of the area was unsuitable including the current dump site, the best next sites which were rated 3 in figure 37a, could be an alternative hence WLC. Although there are several methods to site a disposal site which includes Nonlinear Combination methods and linear combination methods with differing advantages and disadvantages, (Chabuk et al., 2017; Lane & McDonald, 1983; Hopkins, 1977). Linear combination methods such as weighted Overlay method has an advantage that a user can locate next best sites and that there is no integration or effect between the layers and in an attribute and any additional unit remains constant at any level of that attribute. However, for Maseru City, it has been found that linear methods are not applied but nonlinear which can fall short of nonlinear disadvantages as mentioned by Hopkins (1977). Nonlinear methods are not suitable for locating suitable sites (Hopkins, 1977), as land cover types are determined by implicit judgments rather than explicit rules.

However the researcher used Linear Combination method to suitably locate a disposal site because of its popularity, its advantages such as viewing next best sites and that it is recommended in the literature for suitability analysis by several researchers (Chabuk et al., 2017; Lane & McDonald, 1983; Hopkins, 1977). The slope was used to avoid construction cost (Wang et al., 2009) , and to prevent drainage of pollutants such as leachate to flow from the landfill site to the surrounding environment (Lin & Kao, 1998). Ground water depth was used to avoid contamination of ground water through percolation of leachate from the disposal site (Kamdar et al., 2019). Soils and rock types become very important as some soils or rocks are porous, soils such as gravel, and sands are unsuitable, because of their high porosity and high-water permeability, therefore, quality of underground water could be affected (Arkoc, 2014). It was very crucial to use ground water as the constraint as water is the source of life as to avoid adverse impacts to the water table. It was also important to use land cover as a constraint since it reflects the existing cover and its spatial distribution (Tavares et al., 2009). Proximity to roads, streams became paramount and surface water to avoid contamination.

Although Bulane (2009), used more or less the same criteria and used WLC method for locating the transfer stations, the results for the analysis differ to this study. The results from Bulane's study (2009), indicated that the suitable sites for the disposal of waste were found inside the boundary of Maseru city. However, in this study, most of the alternative sites in this study were located outside the city and few as small patches were located inside the city in the North East and South. The disparity could be that more development has taken place within the city from 2009 to 2021. This could mean that MCC could consider looking for another site to dispose solid waste. Although it was necessary to conduct ground truthing, the researcher could not do it because of Financial constraint and Covid 19 restrictions. The suitable site according to researchers should be located in an open, bare or space, or unused land which qualifies through the criteria mentioned (Mugo & Odera, 2019; Chabuk et al., 2017; Alanbari et al., 2014; Demesouka, Vavatsikos & Anagnostopoulos, 2013). In this study, the suitable site was in an unused or bare land. The suitable sites for this study were found on the open space category.

5.1.3 Proposed collection points and Location-allocation problem.

Figure 38 shows proposed collection points located randomly across the city of Maseru. Figure 39 shows location-allocation for 334 collection points whereby collection points were 'demand points and the dump site a 'facility'. The collection point would mean that a truck could take a full solid waste from a collection point to the dump site taking the shortest route. When asked about which factors could be stipulated to locate a collection point, MCC management stated that solid waste collection points could be located along the roads or near the intersection to allow easy collection. Although the location of collection points were located randomly, as adopted from Ntarangwi and Odera, (2017), The points which fell 25m from the road were used for routing. The restriction of 25m from the road has decreased collection points significantly in many Constituencies. For example, in Thetsane, as one of the bigger Constituency, it has got only 7 collection points while Abia has 11 points which would make a shortfall of this study as it might not resemble reality. One of the shortfalls for randomly located collection points was that some of them fell on places where there were roads. However, the shortfall could implicate that there should be an extension of the tarred roads to accommodate all collection points and to extend to other places.

Solid waste generation differed from household to household. In some cases, it was found out that more solid waste generation was generated in less populated household than those with more population. On the contrary to the findings on the study, Ntarangwi and Odera, (2017) found out that wards with more population had more waste, however, in Maseru City, some areas such as Thetsane had more population but generated less waste. The reason could be that some households could be wealthier than others. In Lesotho there are mixed housing.

Collection points according to Ntarangwi and Odera, (2017) are determined using variables such as population waste generated. A minimum distance constraint was used by several researchers (Erfani et al., 2017; Ntarangwi & Odera, 2017; Vijay et al., 2005). However, a minimum distance constrained was not used in this study. Since in Maseru City, collection was haphazard, it was not possible to calculate distances travelled by waste vehicles before modelling, however, it was well believed by the researcher and MCC drivers that abstaining from haphazard collection to a well-planned system would drastically reduce cost and distance travelled. In their study, Ntarangwi and Odera (2017) used a restriction of buffering and some collection points were eliminated from analysis.

Ntarangwi and Odera (2017) used a cut off distance of about 200m and a buffer of 200m was applied around roads such that any collection point falling outside the buffer was eliminated in the analysis. However, no buffer was used but points were located along the roads. As the researcher adopted equation '4' from Ntarangwi and Odera (2017), the number of collection points used in the analysis were 334. A service area of 200m was used by Ntarangwi and Odera (2017) while Khan and Samadder (2016), used a service area of 100m. Although MCC management based on the criteria on locating the collection points in question 10c, indicated that collection points could be located along the road or junctions or on the open accessible areas within villages collection points were located randomly across the city, however a restriction of those falling 25m on both sides of the roads were used. Ntarangwi and Odera (2017) also located collection points randomly across the study area and used a buffer of 200m from the road as a restriction.

5.1.4 Route planning

Network analysis was conducted based on the collection points allocated and were 25m from the roads. Figure 40 represents the routing analysis for Maseru City. The routing analysis was created to calculate the shortest distance where length was an impedance. In the routing analysis, the routes cut across the constituencies for trucks to collect waste. The trucks have to collect solid waste in a sequenced manner where the Starting point was the deport where trucks were parked and also used as the end point. Due to the random nature of location of collection points, some points fell in places where there were no access roads for collection. This could implicate that there was need to improve road infrastructure so that most places were accessible for collection. In some places, as there are only gravel roads which were not part of the analysis, it could be advisable to improve the roads from gravel to tarred. The trucks could start from the deport to collect waste in Constituencies starting from Constituencies near the deport. Since MCC use three trucks, one could collect on the West, while the other could collect on the North while other collects other type of waste. However, in the analysis one truck was used. Although the researcher could not get existing routes and collection points as Ntarangwi and Odera (2017), had, in their study, the route planning was also based on the discretion of the researcher, since drivers only suggested that waste can be collected anywhere if the trucks could enter the road. The researcher's subjectivity in this matter became one of this study's drawbacks as the route planning could be misleading for decision makers. Although there was a need for trucks to collect solid waste all around the city, some places (Constituencies) lacked good roads and routing was not done in such places as only tarred roads were used for routing. The customers (collection points) were known prior and once the route was executed could not change. The Central part which consisted of Maseru Central, Stadium Area, and some parts of Thetsane and Abia were well planned and had good road infrastructure. Some other constituencies such as Khubetsoana and Mabote were fairly planned and some areas such as Lithabaneng, Lithoteng and Qoaling had poor road infrastructure which meant that routing was limited in such places although it was highly needed to plan routing for such areas so that MCC could be able to collect solid waste all around the city. However, in future, there is need to establish route planning for the CBOs such that communities have their own collection system which can be integrated to the system of MCC. The disposal site used in route planning was Ts'osane dumping site which was then used. It is the believe of the drivers and the researcher that though there was designated collection points and routes, for collecting solid waste, the new routing plan could minimize distance travelled by trucks, cost of fuel and time as going street by street was said to be costly and time spent in the field.

However, the routing was not realist since it did not take into consideration real life situation such as roadblocks and traffic (Dantzig & Ramser, 1959). Although some researchers used other methods for route planning (Apaydin & Gonullu, 2013; Vijay et al., 2005), the researcher adopted the GIS methods engaged by other researchers routing (Ghose, Dikshit & Sharma, 2006 ; Ntarangwi and Odera 2017). Not applying scientific technological advances in selection of routes results in poor and expensive collection systems (Tavares et al., 2009). The current schedule for collection of waste was a complicated one as collection of solid waste was mixed with other institutions such as banks, bus stops, shopping complexes and police stations.

CHAPTER SIX: CONCLUSIONS AND RECCOMENDATIONS

This chapter presented the concluding remarks and report to highlight the surfacing issues from study based on the research question, aims and objectives and making reflections regarding obtained results and some challenges met. The recommendations were also presented for the study. The conclusion chapter ended by suggesting further research.

6.1 CONCLUSIONS

In conclusion of this research, the author would like to start by making reflections on the study. The research question of the study was '*How can MCC improve solid waste management using geospatial techniques*. The study had four research objectives and three aims. First, the research objectives were stated as follows:

(i). To assess the current solid waste management in Maseru City.

(ii). To carry out suitability analysis for the dumpsite using geospatial techniques.

(iii). To determine suitable solid waste collection points

(v). To develop an optimal route network for MSW collection and disposal in Maseru City using geospatial techniques.

The aims of the study were stipulated as follows:

(i). To get an understanding and address the challenges faced by relevant stakeholders in waste management for Maseru City.

(ii). To minimize adverse environmental impacts due to unscientific location of a disposal site.

(iii). To minimize transportation costs and time during collection.

The first objective *'To assess the current solid waste management in Maseru City'*. The aim of this objective was to *understand and address the challenges faced by relevant stakeholders in waste management for Maseru City.* To achieve the objective and the aim, the researcher engaged in comprehensive data collection on relevant stakeholders such as MCC solid waste drivers, MCC management, solid waste pickers, both house to house and those who pick waste from illegal dumpsites to the main dump site (Ts'osane dump site), which is the only legal dump site in Maseru City. Data collection through surveys were done through questionnaires, face to face interviews and direct observation. Data was analyzed using tables and graphs and discussed. Both Qualitative and quantitative data was not coded but was presented as questions in the questionnaires. Qualitative data was quantified. Reliability and validity of the study was met by asking 'how' and 'what' questions and making sure that the scale measured what was inquired from the study. However, validity was compromised due to the difficulty of getting hold of some respondents such as community waste pickers. It was difficult for the researcher to reach all the participants due to COVID 19 restrictions and that not all communities had CBOs as a result, external validity was threatened. To gain more in-depth knowledge of collection and disposal of solid waste, the researcher physically went to the field with the drivers, though they were just a mere observer. Face to face interviews that were conducted gave the in-depth information on the collection and disposal of solid waste in Maseru city. It was found useful to answer research question one as the researcher was able to get in-depth knowledge of solid waste management issues and challenges which has led to conducting analyses to solve such problems. Also, estimation of solid waste generation per week in households led to estimation of number of collection points needed for the whole city. The researcher has gained an in-depth understanding and knowledge of how solid waste was managed and the challenges. Some challenges and insights have sent a strong message of interference and more planning by MCC.

For research objective 2, *'To carry out suitability analysis for the dumpsite using geospatial techniques',* the aim here was *'To minimize adverse environmental impacts due to unscientific location of a disposal site.* To achieve the objective and the aim, the researcher engaged in qualitative data collection from relevant Government ministries, departments and other sources to acquire data to conduct suitability analysis. Suitability analysis was carried out using seven factors: Land use/ cover (Agriculture, Trees, Bare areas, Bare rocks, Built up (Residential, commercial), Surface water, Geology, Soil texture, Slope, Distance from streets and roads and Ground water depth.

Although the results of suitability analysis from this study and from Bulane, (2009) showed that Ts'osane dump site was not suitable, but the location of suitable sites differ for two studies while more or less factors and method used. The reason for the disparity could be that from 2009 when Bulane's study was conducted to 2021, more development has occurred, so that would mean different classification results hence different results. The findings from both studies should be used as an eye opener that unscientific location of disposal sites poses threats to the environment (Hoornweg & Bhada-Tata, 2012). It was found useful to conduct suitability analysis for the current dump site to determine its suitability for better decision making. The researcher regretted that she could not use more data as factors due to lack of spatial data, as a result the researcher was limited to using fewer factors. However, it was useful for conducting suitability analysis as the results for suitability analysis could highlight relevant authorities such as MCC on the future thought on areas that could be suitable for a dump site and the results revealed the suitability of the current dump site. This could give a thought on the status of the current dump site. The best method for locating the dump site for this study was Weighted Linear Combination as the researcher wanted to see the next best sites.

Research objective 3 and 4, '*To determine suitable solid waste collection points'*, '*To develop an optimal route network for MSW collection and disposal in Maseru City using geospatial techniques'*. The aim here was to *'minimize transportation costs and time during collection'*. In this regard, to address the objectives and the aim, the researcher engaged in conducting a routing analysis whereby network data set was developed, and collection points were determined using population and solid waste generated in each Constituency. Based on the above variables for determining collection points, some Constituencies were allocated more collection points than others though some were bigger and had more population than others which brought the disparity. The total collection points were 334 for the whole city. Data used in this analysis was secondary, as roads were digitized from screen using the aerial photos by the researcher since road network data was not found from the relevant Ministry. Only tarred roads were digitized. However, during analysis as most of the collection points were located randomly, some were located on places where there were no roads, which gave a signal that MCC should improve road infrastructure for it to collect the whole city. Location-allocation problem was solved using demands points as collection points and Facility as the current dump site whereby all collection points could be served by one dump site. Route planning was used to optimize the distance travelled to collect the solid waste from the optimal collection points to the dump site. According to the MCC policy, no development along the roads of 25m on both sides. The collection points which fell within 25m from the road were selected and used in the route planning. The researcher found it useful to determine collection points as they serve as intermediaries between the generation points (households) and the dump site and this could minimize the distances travelled with the current system. It was challenging for the researcher as the route planning was based on their subjectivity which put the study on the short fall. The trucks could go different directions to collect. Conducting route planning was important as it could also save costs.

Solving location-allocation problem, conducting suitability and network analyses, were done using ArcGIS 10.7.1. with its extensions. For many researchers, ArcGIS has been used to analyze, store, display and model geo referenced spatial data and has shown to be the best application for modelling suitable disposal site using multi criteria analysis and network analysis. It was found out that MCC was not covering enough for the city due to lack of financial, staff and equipment. As it was reported that poor road infrastructure was a challenge even in some countries such as Nigeria, (Agunwamba, 1998), routing did not cover the whole city as a result. The researcher found it important to develop network analysis and running location-allocation problem as it was visible that costs in terms of distance could be minimized if routes were planned accordingly rather than haphazard collection, and the analysis could also give relevant authority a thought on solid waste transport planning.

Solid waste was collected using door to door and curbside methods and was disposed at Ts'osane dump site. Based on the results for suitability analysis, the current dump site was found not suitably located. Also, from Google Earth, Ts'osane dump site was at the proximity of houses which was on contrary to the suitability analysis criteria. Solid waste was normally collected from morning to midday, and it was the responsibility of each resident to have their own storage for their waste. Most people who used MCC and CBOs for collection were much satisfied with collection and frequency and felt that it was enough. Most people did not know how far it was to their collection point and felt that they could travel as shorter distance as possible to the collection point.

The study conducted an explanatory Sequential Mixed Methods approach where quantitative analysis informed qualitative analysis. Although some studies such as Howe (2016), criticized mixed methods research as lacking cohesion and epistemologically incompatible the use several methods of data collection and analysis to conduct a research to address the incompatibility issue and sought peoples' opinions about the phenomenon (Greene, 2006; Tashakkori & Treddie, 1998) was adopted. As a result, the study was pragmatic and constructionist. The research ethics were adhered to, before and during data collection.

Conducting Explanatory Sequential Mixed Method approach was found useful as the researcher was able to conduct analyses based on the insights gotten from assessing the current issues on solid waste management as research question one, which were used as a baseline for conducting suitability and network analyses.

6.2 RECOMMENDATIONS

The recommendations for this study were based on the results found by the researcher coupled with the literature. It was recommended that MCC improve roads since the researcher found it difficult to conduct routing for the whole city area due to lack of proper roads. It is also recommended that Government put in place clear guidelines about location of disposal sites and collection points as stipulated in researches (Ntarangwi & Odera, 2017; Khan & Samadder, 2016) to make it easier to conduct scientific analyses. Designated temporary collection points and routes were highly recommended to save costs and collection points could serve as intermediaries between the generation points (households) and the transfer stations as suggested by Bulane (2009). The dump site could work as the destination after waste has been segregated in the transfer stations. It could be of greater importance for MCC to capture solid waste data per year for better planning. Intervention from government, private sector, Non-Governmental Organizations (NGOs) and international organizations for financial support, equipment such as trucks so that MCC could collect waste efficiently as recommended. Coming up with strategies that could lessen the quantity of waste from point of generation is very important as waste producers would know that prevention is better than cure. Since unsegregated waste is unhealthy to waste pickers and not easy to manage at a disposal site (Kaza et al., 2018). Segregation of solid waste at the point of generation could save costs of managing heavy waste at the disposal site.

Further research was recommended to include more data or factors to conduct suitability analysis and may be use more comparable methods for better analysis to use proposed dump sites in a network analysis. Moreover, future research was needed to develop a more comprehensive routing system that would include both CBOs and MCC. The multi modal system and more detailed network data sets with attributes such as street names, class, length, type and speed limits is also needed. Also, road elevation and vehicle capacities could be of importance. There is need to research on policy so that criteria for locating solid waste disposal and location of collection points is explicitly specified in the law. Since there is no research in

Lesotho on routing problems, this study could contribute as literature on routing and could also act as the baseline for further interest in research and create ground for forward planning and decision making.

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Appendices

Appendix 1: Household data summary

Question	**Freq.**	**%**
Q1. Who collects solid waste from households?		
MCC	45	35
Community waste pickers	74	57
Private (Individual truck)	11	8
Contracted company	0	0
Total	**130**	**100**
Q2. Which method of collection is used?		
House to house	0	0
Kerbside	45	35
Both	74	57
Other (specify) Self	11	8
Total	**130**	**100**
Q3. How often is solid waste collected?		
Everyday	0	0
Once a week	119	92
Twice a week	0	0
Three times a week	0	0
Other (Specify) Self-paced	11	8
Total	**130**	**100**
Q4. Do feel it is enough?		
Yes	119	92
No	0	0
Other (Specify) self-paced	11	8
If, No explain	0	0
Total	**130**	**100**
Q5. What times of the day is solid waste collected		
Early Morning 5-8a.m.	22	17
Morning 8-11 a.m.	48	37
Midday 11-14 hrs	21	16
Evening 14-17hrs	6	5
Other (Specify) Depends on the collectors.	22	17
Collection is determined by us	11	8

Total	**130**	**100**
Q6a Do you have designated collection points?		
Yes	31	**24**
No	89	**68**
Do not know	10	**8**
Total	**130**	**100**
Q6b. If yes, how far is your collection point (meters)?		
0-5	0	0
5-10	0	0
10-15	0	0
15-20	5	4
>20	5	16
Do not know	10	72
Other (Specify) manage own waste	11	8
Total	**31**	**100**
Q7. Do you feel this is convenient for you?		
Yes	15	20
No	5	0
Other (Specify) Do not know	0	72
Other(specify) Do not use collection point	11	8
Total	**31**	**100**
Q8. How far are you willing to travel to the collection point (meters)?		
0-25	10	7
25-50	34	26
50-75	86	67
>75	0	0
Total	**130**	**100**
Q9. What type of storage do you use to store solid waste?		
Plastic bags	75	58
Plastic containers	21	16
Metallic containers	34	26
Open Air	0	0
Other (Specify)	0	0
Q10. Who provides storage?		
Private	130	100
MCC	0	0
Other (Specify)	0	0

Total	**130**	**100**
Q11. How long do you take to fill your storage (days)?		
1-3	0	0
3-5	19	14
5-7	40	31
Other (Specify) Depends on the amount of waste, time and events	71	55
Total	**130**	**100**
Q12. How many people living in the house?		
1-2	7	27
2-3	19	62
3-4	39	11
4-5	59	0
5-6	6	
Total	**130**	**100**
Q13. Estimation of solid waste generation per week (kg)		
0-3	13	10
3-6	22	16
6-9	19	15
9-12	49	38
12-15	27	21
Total	**130**	**100**
Q14. How much do you pay per month (Maluti)?		
20-30	33	25
30-40	41	32
40-50	0	0
>50	45	35
Other (Specify) Do not pay for collection	11	8
Total	**130**	**100**
Q15a. Is collection fee efficient?		
Yes	84	65
No	35	27
Other (Specify) Does not apply to us as we manage our own waste	11	8
Total	**130**	**100**
Q15b. If no, please explain		
Cannot afford	35	100

Total	**35**	**100**
Q16. Are you satisfied with the collection system?		
Yes	84	65
No	46	35
Total	**130**	**100**
If no, specify. Wish MCC could reach all residents	26	57
Collectors not reliable	20	43
Total	**46**	**100**
Q17. What challenges do you experience with solid waste collection?		
Sometimes waste is not collected on scheduled times, so it causes bad smell and scatter all over	119	100
Total	**119**	**100**
Some households are not served, so waste ends up being disposed illegally	18	14
Total	**18**	**14**
It is no longer save for house to house as some collectors steal things from houses	49	38
Total	**49**	**38**
Collection fees are expensive	35	26
Total	**35**	**26**
No proper roads for MCC to cover all the city	21	16
Total	**21**	**16**
Q18. What are your recommendations?		
Demarcate areas where residents can throw waste at the scheduled days	11	8
Total	**11**	**8**
Lower collection fees	35	27
Total	**35**	**27**
Improve roads so that collectors can move smoothly around communities	21	16
Total	**21**	**16**

The fees were presented in Maluti of which 1 USD =Maluti 15.27 at the time of study.

Appendix 2: MCC Management data summary

Question	**Freq.**	**%**
Q1. Who are stakeholders involved in SWM?		
MCC	15	100
Government	15	100
Households	15	100
CBOs	15	100

Q2. Which methods of solid waste collection does MCC use?		
House to house	0	0
Kerbside	15	100
Bin collection	0	0
Other (specify)	0	0
Total	**15**	**100**
Q3a. Does MCC collect solid waste the whole city?		
Yes		
No	15	100
Total	**15**	**100**
*Q3b*If No, explain		
No capacity (equipment, funds)	15	100
Total	**15**	**100**
No proper roads	15	100
Total	**15**	**100**
Q4. What percentage can collect based on the previous question		
20-40	8	53
40-60	5	33
60-80	2	13
100	0	0
Total	**15**	**100**
Q5a. Which times of the day do you collect waste?		
Early morning 5-8 a.m.	0	0
Morning 8-11a.m.	0	0
Midday 11-14hrs	0	0
Evening beyond 14hrs	0	0
Throughout the day	15	100
Total	**15**	**100**
Q5b.Please elaborate on your answer.		
Drivers go from one area to another throughout the day	15	100
Total	**15**	**100**
Q6. How often do you collect waste in households?		
Everyday	0	0
Once a week	15	15
Twice a week	0	0
Three times a week	0	0
Other (specify)	0	0

Total	**15**	**100**
Q7. Is your collection interval efficient?		
Yes	15	100
No	0	0
Total	**15**	**100**
Q8. Briefly discuss SW process from generation to disposal (See Discussion as a paragraph below table)		
Q9. What type of storage do you use to collect solid waste?		
Plastic bags	13	87
Plastic containers	0	0
Metallic containers	2	13
Other (specify)	0	0
Total	**15**	**100**
10a.Do you have designated collection points?		
Yes	3	20
No	12	80
Q10b. If No, please explain		
No planning for them	11	92
No space to locate them	1	8
Total	**12**	**100**
Q10c.If yes, state the criteria for selecting temporary collection points, starting the most important		
Along the roads	3	100
Total	**3**	**100**
Near intersections	2	67
Total	2	67
Open accessible places within villages	3	100
Q11.What type of vehicles were used to transport solid waste?		
Compactor trucks (3), half truck (1), Tractor and trailer (1)	15	100
Q13. What factors were considered in choosing transport routes		
Shortest distance to destination	11	73
Q14. What were the short comings of the current method of SWM?		
No support from Government to upgrade roads for accessibility	15	100
Residents not willing to pay collection fees	9	60
No capacity	15	100
Q15.Improvement		
More funding form Government or private sector	15	100

Total	**15**	**100**

Question 8

Solid waste management was collected by two different stakeholders: MCC and CBOs. MCC used its trucks to collect waste using curb side method. CBOs used door to door and curb side. Solid waste was disposed at Ts'osane dumping site. CBOs used private trucks to carry solid waste to the dumping site. For communities, waste was collected at the preferred open area, or along the road, or near junctions for the private trucks to collect. The temporary collection centres were not legal.

Appendix 3: Community waste pickers data summary

Question	**Freq.**	**%**
Q1. Who do you work for?		
MCC	73	100
Private	0	0
Q2. Which methods of collection?		
Door to door	41	56
Kerbsite	23	32
Bin collection	0	0
Others (Truck/Van)	9	12
Q3. How often do you collect solid waste?		
Everyday	0	0
Once a week	73	100
Twice per week	0	0
Three times a week	0	0
Others (specify)	0	0
Q4. What times of the day do you collect solid waste?		
Early Morning (5-8 a.m.)	3	4
Morning (8-11 a.m.)	51	70
Midday (11-14) a.m.	10	14
Evening (14hrs-17hrs)	9	12
Q5a. Which days of the week do you normally collect?		
Weekdays	0	0
Weekends	73	73

Q5b. Explain your answer		
That is when people are available in their homes	64	88
That is when collectors collect waste for transport to the dump site	9	12
Q6. What do you use to carry waste from households?		
Hand	0	0
Wheelbarrow	64	88
Other (Specify) Truck/van	9	12
Q7. Do you have designated waste collection points?		
Yes	0	0
No	73	73
Q8. Where is waste disposed		
Ts'osane dumping site	73	73
Q9. What do you use to transport waste to the disposal site?		
Private Truck/Van	73	73
MCC truck	0	0
Contracted Company	0	0
Other (specify)	0	0
Q10. What challenges do you face in solid waste collection system		
Use of own equipment such as wheelbarrows, protective clothing, face masks. Trucks sometimes break, so waste is not collected so it pollutes the environment	73	100
In some places, roads were not good for trucks to move around streets	73	100
People do not pay fees on time, or do not pay at all.	64	88
Sometimes it is hard to enter people's yards and if waste is put on the curb sometimes dogs spill it if not collected on time	73	100
Q11.Improvement		
MCC provide equipment and protective clothing	69	95
Introduce CBOs in all communities formally	43	59
With the help of CBOs, MCC should select areas inside communities for waste disposal for those who cannot afford to pay	61	84
Establish a strategy to make every resident to pay collection fees	41	56

Appendix 4: MCC Driver’s data summary

The following table represents data analysis from MCC solid waste management drivers

Table 13. MCC driver’s data summary

Question	**Freq.**	**%**
Q1. What type of vehicles does MCC use for transporting solid waste?		
Rear Loader Compactor Truck	3	100
Half truck	3	100
Tractor and a trailer	3	100
Q2. How many of each type		
Rear Loader Compactor Truck (3)	3	100
Half truck (2)	3	100
Tractor and a trailer (1)	3	100
Q3. What are the capacities of each		
Rear Loader Compactor Truck (330liters/4tonne)	3	100
Half truck (60liters/1 tonne)	3	100
Tractor and a trailer (not known)	3	100
Q4a. Do you collect solid waste in the whole city?		
Yes	0	0
No	3	100
Q4b. If no, give reasons		
No capacity (Funds, equipment	3	00
Some places are not accessible for trucks to maneuver in the streets	2	67
Q5. How often do you collect solid waste in communities?		
Everyday	0	0
Once a week	3	100
Twice a week	0	0
Three times a week	0	0
Other (specify)	0	0
Q6. Which times of the day do you collect solid waste?		
Early Morning (6-8 a.m.)	3	100
Morning (8-11a.m.)	3	100
Midday	3	100
Evening	3	100
Other (specify)	0	0
Q7. Why do you choose times you selected?		

Solid waste was collected throughout the day as we combine waste from institutions and marketplace	3	100
Q8. Where do you dispose solid waste/		
Ts'osane dumping site	3	100
Q9a. Do you have defined routes for collection of waste		
Yes	1	33
No	2	67
Q9b. If no, explain		
We take which ever route which we think it is shorter or convenient	2	100
Q10. Challenges		
Lack of resources such as equipment, staff, proper administration of vehicles.	3	100
Going street by street to collect waste, that consumes a lot of petrol	3	100
Some communities do not have proper roads for truck to go inside.	3	100
Q11. Improvement		
Provide more trucks, increase staff,	3	100
Proper management of vehicles.	3	100
Improve roads	3	100