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The selection of transfer locations for Maseru Municipality

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THE SELECTION OF TRANSFER LOCATIONS FOR MASERU MUNICIPALITY



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A research report submitted to the Faculty of Science, University of the Witwatersrand, in partial fulfillment of the requirements for the degree of Master of Science

Johannesburg, May 2009

DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the Degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has never been submitted for any degree or examination in any University or carried out by any institution before.

_____

Itumeleng Bulane

Date: _____

ABSTRACT

The management of municipal solid waste presents serious challenges for municipalities in most countries. Inadequate service coverage and operational inefficiency have led to uncollected solid waste on the roads and in other public areas which poses threats to human health and the environment. Maseru city in Lesotho faces the same challenges. Poor management has resulted in illegal dumping of waste, and littering can be seen on the public places.

Maseru City Council is constructing a sanitary landfill that will respond to the challenges presented by the poor management of the solid waste. The proposed sanitary landfill is about 45 kilometers away from Maseru. For this landfill to be effective, transfer stations have to be established within the metropolitan area for collecting, separating and sorting of solid waste. This study aimed at identifying suitable sites on which solid waste transfer stations could be located

Selecting the location of transfer facility sites is a complex process which involves technical, physical, economical, social, environmental and political requirements that may result in conflicting objectives. Such complexities necessitate the simultaneous use of several decision support tools such as Geographical Information System (GIS) and Multi Criteria Decision Method (MCDM). In this study the model was developed using GIS and MCDM to identify the possible location for construction of transfer station sites.

The criteria used included; Topography, Land use, Distance from rivers and Distance from roads. Fifteen sites with varying land suitability were identified as potential locations for required transfer stations. These sites were ranked in descending order to indicate the priority of different options available to decision makers. However, only two sites suited almost all the criteria for selection and they can be used for the construction of the transfer facilities The results achieved by this study may help urban planners and decision makers by availing a variety of options to be considered for transfer facility locations for proper waste management in the city.

DEDICATION

To my late husband NAMOLI MOLISE, our daughter KEKELETSO MOLISE and my mother ‘MALEBAKA BULANE. To all those who appreciate the role of environmental science in sustainable development and the improvement of the quality of life.

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LIST OF ABBREVIATIONS

SW	Solid Waste
SWM	Solid Waste Management
MSW	Municipal Solid Waste
GIS	Geographical Information System
UNEP	United Nations Environmental Programme
MSWM	Municipal Solid Waste Management
ISWM	Integrated Solid Waste Management
EPA	Environmental Protection Agency
WTSs	Waste Transfer Stations
CBD	Central Business District
MCDM	Multi Criteria Decision Methods
DEM	Digital Elevation Model
MCC	Maseru City Council
GPS	Global Positioning System
UNCHS	United Nations Center for Human Settlements
SRTM	Shuttle Radar Topography Mission

CHAPTER 1

INTRODUCTION

1.0 Background information of Maseru metropolitan area

Maseru is the capital city of Lesotho. It is located in the northwest region of Lesotho on the border with Free State in South Africa. Maseru initially functioned as the state's administrative capital between 1869 and 1871, before administration of Basutoland was transferred to the Cape Colony. In 1884, Basutoland was restored its status as a Crown colony, and Maseru was again made capital. In 1966 Basutoland gained its independence and became the Kingdom of Lesotho and Maseru remained the country's capital (Hansen and Vaa, 2004).

Physical planning in Maseru is carried out by the Physical Planning Division in the Department of Lands, Surveys and Physical Planning. Until the mid-1980s, in residential areas only residential uses were to be permitted. This allowed for the compression of plot sizes to achieve high densities and low infrastructural costs per plot. Rural activities, particularly the keeping of animals, were not allowed in a modern urban setting. However horticulture was allowed on a very small scale, but there was no place in planners' concepts of land-use or integrated urban functions. Control and enforcement or urban development in the mid 1980s was weak, and even the allocation and administration of land was not controlled by State authorities. Physical planning was not able to keep abreast of the demand for serviced land. Maseru was experiencing a period of rapid population growth and physical expansion (Greenhow, 1994).

Maseru district has the largest urban settlement in the country. Maseru city is located at S $29^0$18'46.51" E $27^0$29'42.52" (Google Earth), with the population size of 227, 880 (2006 census). The population of the city was at 28,000 by the 1966 census, and 110,000 by the 1986 census, demonstrating the rapid expansion of the city after independence (Romaya and Brown, 1999). Migration from other districts to Maseru in search for employment opportunities have contributed to this increased population.

Generally, the areas within Maseru are occupied by people of mixed economic status. Only few sites in the city are occupied by high income owners e.g. Ha Matala, Ha Thetsane, Maseru East, and Maseru West (Figure 1). Some residential areas are known to be occupied by members of the country's cabinet and high ranking officials. These areas are characterized by good service delivery, which include better roads than other areas, good water systems and sanitation as well as methods of solid waste collection.

Maseru city consists of extensive areas of informal settlements which are generally built on privately owned agricultural land. This land is subdivided into small stands without informing the local authorities and then sold to buyers without any legal deeds. Formal land delivery has over the years failed to satisfy demand for urban residential land. Approximately 70% of the demand for land is met outside formal systems established by the state (Leduka, 2002). The informal settlement area is mostly occupied by lower and middle income communities. The area is usually unplanned, highly populated, under developed and lacks basic services and infrastructure such as clean water and solid waste management.

The central business district (CBD) of Maseru can be divided into East and West. CBD East is the old bus station and a site for the Old Maseru Market. The CBD East is described as “a lively focus of commercial activity at the lower income end of the scale; the streets are lined with informal traders selling barbecued maize fruit, clothing, root vegetables and basic household items” (Romaya and Brown, 1999). In contrast, the CBD West, a linear commercial street known as Kingsway, contains the large government and private sector offices and modern commercial development markets. Although both CBDs produce waste, CBD East seems to produce more waste than CBD West because of street activates. The problem in CBD East is compounded by poor collection services by the municipality leading to general litter in the streets.

As a capital city Maseru has several areas designated for industrial purposes. The first major industrial site is along Moshoeshoe Road and it houses industrial activities such as flour mills, a brewing company and textile factories, to mention a few. This was chosen as the major industrial site because it has a direct road link to South Africa. The other industrial site is located at the Thetsane area on the south of the central business districts. The major industrial activities at this site include textile and footwear manufacturing companies (Romaya and Brown, 1999). It can be expected from this situation that there would be a large amount of waste produced from this area. For instance, a denim factory in the Thetsane area is expected to produce three tons of solid waste per day (The World Bank, 2005) but there is no adequate site available for its disposal. Proper waste management structures have to be in place to avoid some environmental problems.

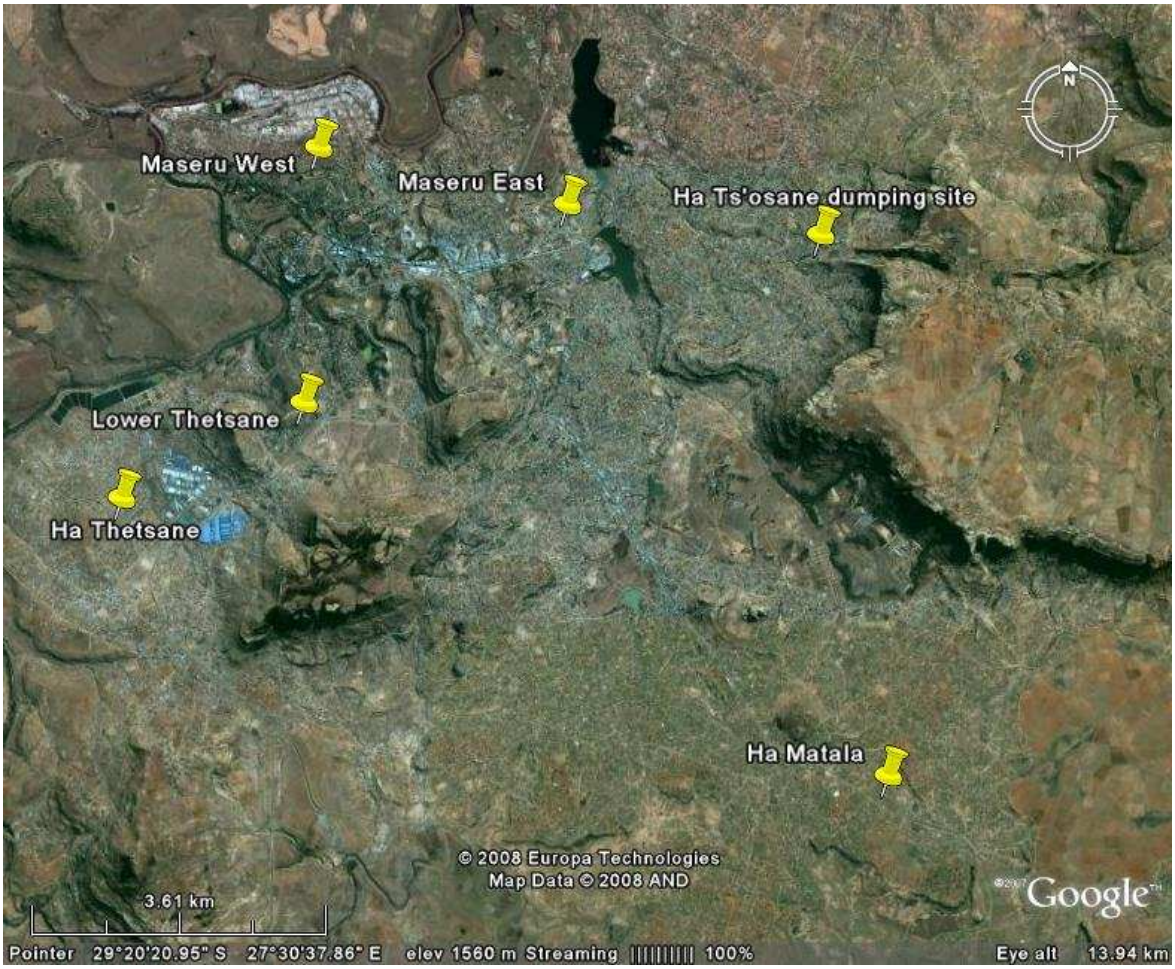


Figure 1: Map of Maseru city modified from Google Earth

The solid waste increased with an increase in the population growth of Maseru city (e.g. from 28 000 people in 1966 to 110 000 people in 1986). The Maseru City Council (MCC) is mandated with management of municipal solid waste. The council struggles to cope with the collection of all domestic and industrial solid waste. Due to frequent breakdowns of vehicles, irregular service is provided to the city where an average of only 10-15% of households is provided with regular waste collection (Chapeyama, 2004). Industrial concerns and institutions such as hospitals are provided with bigger containers for refuse disposal that are supposed to be emptied regularly. These also remained

unattended to because of transport problems. As a result, solid waste is usually dumped illegally in open spaces or burnt, resulting in widespread pollution.

Currently the City of Maseru uses the former quarry site located at *Ha Tsosane* (Figure 2) residential area which is about 5km from the city centre as a dumping site. The dump site was established in 1983 (Chakela, 1999). However, the location of the site does not allow easy access because it is on a mountain. Furthermore, the road leading into the dumping site is a gravel road that is not maintained and is too narrow to allow for two way traffic. There is no management system in place at the site resulting in dumping of all types of waste. The dump site is always on fire due to spontaneous combustion. This poses serious hazards to people who live around the site because of air pollution. There is also a possibility of groundwater contamination since the dump site is situated uphill from streams and springs of Maseru city. Leachate from the site poses a threat to this important resource.

Apart from the location problem, the site is completely surrounded by settlements. There are also some management problems because there is no one at the site to ensure proper disposal and burning of waste. The site is fenced but the gate is always open. This also promotes scavenging of waste, of which about 200 – 230 individuals were found to be self-employed as scavengers (Mhlanga & Gulilat, 1997). A lot of other solid waste including industrial waste is also found in inappropriate places, especially in the gullies and along river banks or burned, resulting in increased pollution of both air and soil.



Figure 2: Ha Tsosane Dumping site modified from Google Earth

Something certainly needs to be done about the solid waste management problem in Maseru city. The Maseru City Council which is mandated for collection and disposal of solid waste is planning to develop better waste disposal practices. The focus of the council is now on construction of a sanitary landfill that will create environmentally safe disposal of solid waste. The proposed sanitary landfill is about 45 kilometers away from Maseru city. For it to be more effective, transfer stations have to be established within the metropolitan area. The focus of this study is on locating suitable sites for construction of transfer stations for collection and sorting of waste in Maseru municipality. The study is

part of the bigger project that is being undertaken by Jones and Wagener Consulting Engineers for the Maseru City Council (MCC).

Currently the amount of solid waste generated in Maseru city is estimated to be 96,000 t/a (Environmental & Process Systems Engineering Research Group Report, 2007). It generates from household, commercial, industrial, administrative, educational and medical sectors. Table 1 show the solid waste generated in Maseru by sector.

Table 1. Waste generated by each sector in Maseru City (Environmental & Process Systems Engineering Research Group Report, 2007).

SECTOR	AMOUNT OF WASTE GENERATED (t/a)
Household	32,900
Commercial	38,900
Institutional	900
Medical	100
Industrial	17,900
Administrative	5,300

The expectation of the Maseru City Council is that the transfer stations be selected to cater for all types of waste from all sectors mentioned above.

1.1 Statement of the problem

Solid waste collection system in Maseru city is patchy even in the wealthy areas. It is also erratic in that the collection vehicles do not have specific time tables and routes. Some poor areas are not served at all even if collection vehicles can still reach such areas. Moreover, an uncontrolled manner of disposal of collected wastes such as burning the solid waste at informal disposal sites produces toxic gases, bad odour and creates air pollution. Also dumps are always full of decomposed matter, producing intolerable odours. The labor force is small and the number of vehicles for collection and transportation is insufficient. Therefore, the present situation in Maseru demanded an investigation into the field of solid waste collection and transfer systems, with the objective of improving solid waste management in Maseru city. The transfer facilities will help in sorting out of the solid waste for purposes such as recycling, reduction of solid waste that goes to the landfill and better management of scavenging.

1.2 Aim and Objectives of the study

Transfer stations will maximize the efficiency of waste collection before the final disposal. The objective of this study is:

- To determine suitable locations for transfer stations
- To provide information for the Municipality of Metropolitan Maseru, to enable them to make informed decisions about the suitable sites for construction of transfer stations.

1.3 Current progress

A sanitary landfill in which the municipal waste will be disposed has already been selected at Ts'oeneng (Figures 3 and 4). Furthermore, the municipality has already engaged a consulting firm in locating suitable areas for transfer stations. This shows that there is awareness of the problems of municipal solid waste management in the city (Maseru) by all stakeholders (community of Maseru, government officials and by the neighbouring communities).

1.4 Research question

The city's terrain makes it difficult for collecting vehicles to access most households. Establishing transfer stations at critical sites will make local waste collection more efficient. The following questions will therefore assist in locating the suitable sites:

- What are the suitable or preferred land use sites and the area topography where transfer facilities could be constructed in Maseru?

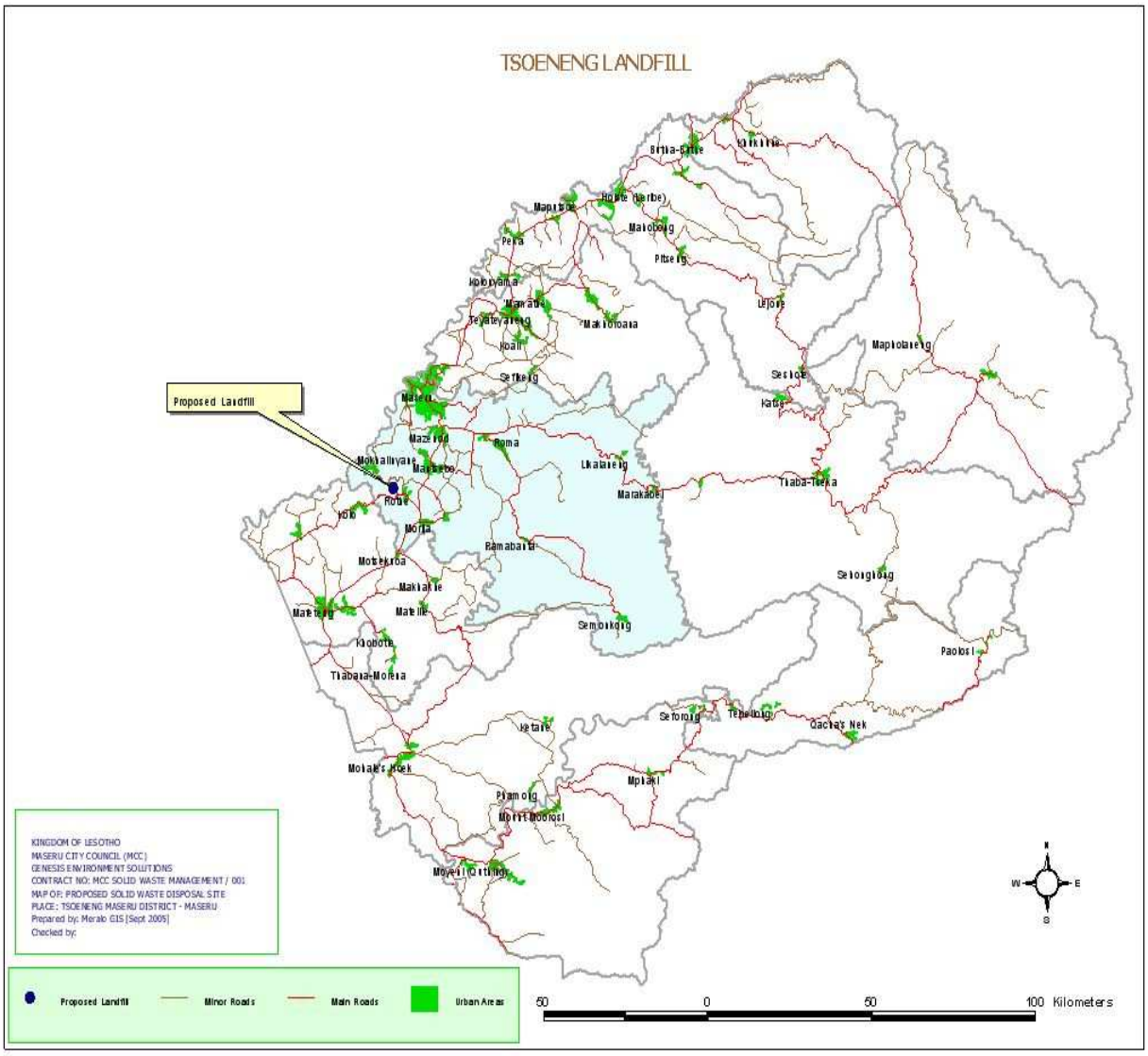


Figure 3: Map of Lesotho showing the proposed (Tŝoeneng) Sanitary Landfill from Genesis Environment Solutions (2005)

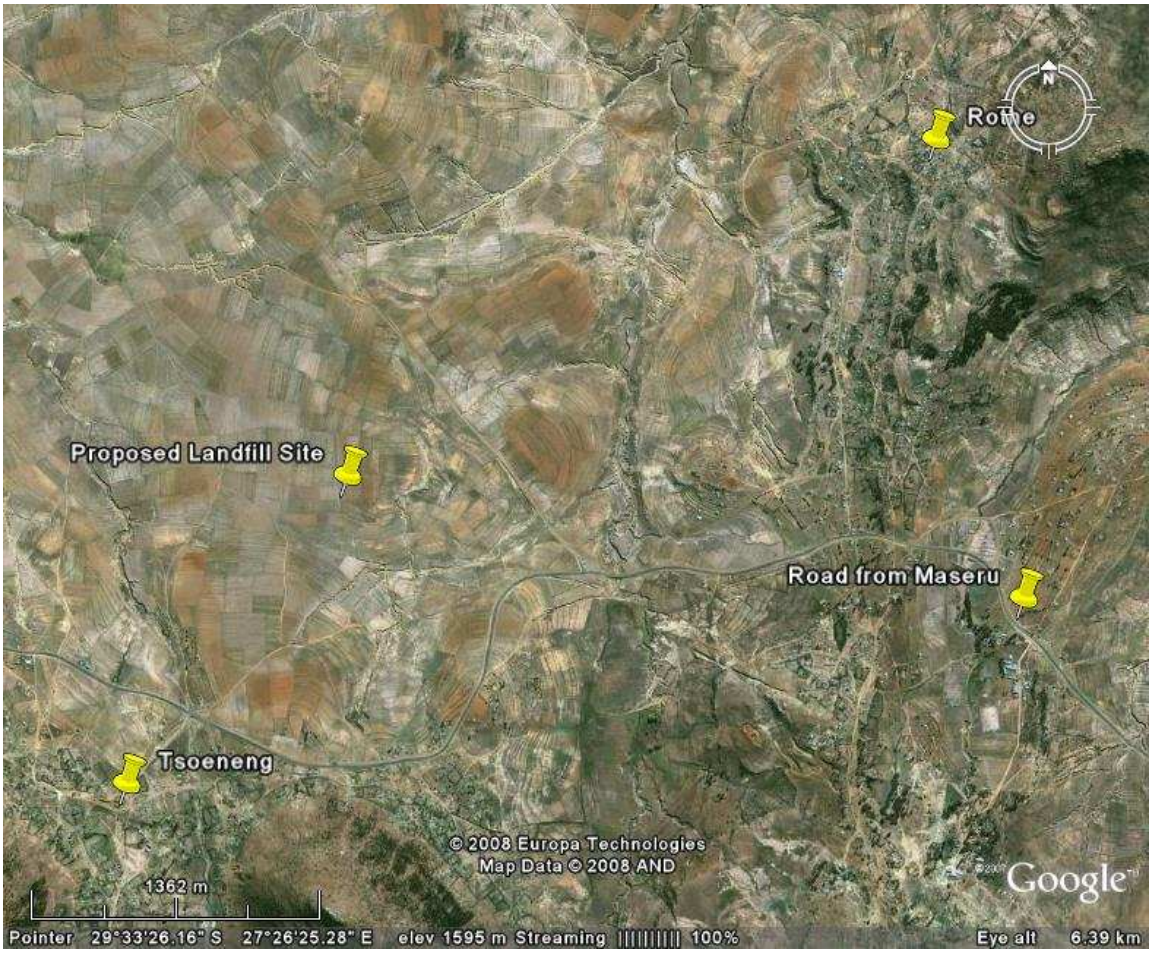


Figure 4: Ts'oeneng Sanitary Landfill Modified from Google Earth

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Municipal solid waste (MSW) management has become a major issue of concern for many developing nations. The problem is compounded by urbanization, which is rapidly taking place in many developing countries, where the majority of rural dwellers move to cities in search for jobs. Thomas-Hope (1998) indicates that 30-50% of populations in the developing countries live in urban areas. Industrial activities which are mainly based in the urban areas also increase. Consequently, solid, liquid and gaseous wastes are generated at high quantities (Jin *et al*., 2006; Rotich *et al*., 2006; Danghani *et al*., 2008).

2.1 Problems and the Challenge of Solid Waste Management

The problems that Municipal Solid Waste Management (MSWM) encounter in developing countries include insufficient service coverage and operational inefficiencies, limited utilization of recycling activities, inadequate landfill disposal, and inadequate management of hazardous and health wastes (Bai *et al*., 2002).

Furthermore, major advances in the development of new materials and chemicals have increased the diversity and complexity of the waste streams. Consequently, wastes are taking on a new economic importance, not only in terms of revenues generated by the

waste treatment and disposal industry, but also because wastes may have a residual value as a secondary raw material which can be recovered and reused.

2.1.1 Inadequate Service Coverage

Solid waste collection schemes of cities in the many countries generally serve only a limited part of the urban population. The majority of people especially in slum areas remain without waste collection services. These are usually the low-income earners living in peri-urban areas, who usually cannot afford to pay for collection services. Furthermore, the municipalities do not have enough funds to cover all the areas in their jurisdiction and hence concentrate their services on those areas where people can afford the fees (Zurbrugg, 2003).

2.1.2 Operational inefficiencies

Some of the causes of operational inefficiencies include inefficient institutional structures, inefficient organizational procedures, or deficient management capacity of the institutions involved as well as the use of inappropriate technologies (Agunwamba, 1998; Rotich *et al.*, 2006). For instance, lack of servicing of municipal solid waste collection vehicles, poor infrastructure and the lack of adequate funding prevent optimisation of MSW disposal services (Rotich *et al*., 2006)

The equipment used to collect solid waste (SW) needs trained operators because the equipment is sophisticated. Many developing countries do not have the people with the

required skills due to lack of specific training. They also lack funds to purchase up to date equipment for proper solid waste management. Those developing countries which managed to purchase the modern equipment face the problem of maintaining such equipment and may lack trained mechanics (Da Zhu *et al.,* 2008). All these problems cause operational inefficiencies as they result in frequent mechanical breakdown of service vehicles resulting in reduced number of vehicles in operation (Agunwamba, 1998; Zia and Devadas, 2008). For example, UNEP (1996) estimated that in cities in West Africa, up to 70% of collection/transfer vehicles may be out of action at any one time.

2.1.3 Hazardous wastes

Healthcare wastes are generated as a result of activities related to the practice of medicine and sales of pharmaceuticals. They are classified into non hazardous and hazardous waste. Non hazardous solid wastes coming from health institutions are municipal solid waste (Chaerul *et al*., 2008).

The remaining wastes pose a serious health hazards because of their physical, chemical and biological nature, and are known as hazardous health wastes. Some of dangerous items in health care waste are needles from syringes and drips. If they are not managed properly they can prick and transfer diseases to people who come into contact with them (Misra and Pandey, 2005; Chaerul *et al*., 2008) Figure 5.



Figure 5: Hospital waste discarded in the street of Teyateyaneng Lesotho

The key to improving health care waste management is to provide better methods of short term storage and to train the staff to adopt safer working practices. This would include separation of hazardous healthcare wastes from the general health care wastes (Rao *et al*., 2004; Chaerul *et al*., 2008).

2.1.4 Human health risks

There are some human health risks associated with solid waste handling and disposal in all countries. However certain problems are more acute and widespread in underdeveloped nations. For example, Cointreau (1982) has classified these into four

main categories: 1) presence of human fecal matter, 2) presence of potentially hazardous industrial waste, 3) the decomposition of solids into constituent chemicals which contaminate air and water systems, and 4) the air pollution caused by constantly burning dumps and methane release.

Solid wastes from developing countries include human fecal matter because of poor sanitary facilities (especially shantytowns and over-crowded municipal districts). These include lack of appropriate management of municipal sewerage or on-site septic systems. In areas where such facilities are lacking, the amount of human fecal matter present in the solid waste stream is likely to be higher (Cointreau, 1982; Boadi and Kuitunen, 2005). This presents a potential health problem not only to waste workers, but also to scavengers, other users of the same municipal drop-off point, and even small children who like to play in or around waste containers (Yhdego, 1991; Boadi and Kuitunen, 2005). Furthermore, because of poor waste management some waste containing fecal matter ends up in water sources. Any people using such contaminated water can contact diseases like cholera.

Waste pickers are highly susceptible to disease. It has been proposed that they should be provided with low cost or free protective gear, such as gloves, boots and clothing, to prevent contact injuries and reduce pathogens (Ojeda-Benitez *et al*., 2002; Wilson *et al*., 2006; Hina and Devadas, 2008). Experience in Calcutta, India, however, has shown that most gear is simply sold by the workers, and they continued to work without protection

(UNEP, 1996). It is important that awareness of their susceptibility to diseases is increased.

2.1.5 Environmental Issues

The common source of environmental pollution is mainly due to decomposition of waste into its constituent chemicals. These chemical can be either organic or inorganic (Schrab *et al*., 1993; Kim *et al*., 2007). Most organic materials are biodegradable and can be broken down into simpler compounds by aerobic and anaerobic microorganisms, leading to the formation of gas and leachate. These byproducts of the decomposition process can harm the environment. This problem is mainly experienced in the developing nations because they have few existing landfills which meet acceptable environmental standards, (Ojeda-Benitez *et al*., 2000; Henry *et al*., 2006). In the landfills which do not meet the acceptable standards, there is usually no leachate management and gas control (Johannessen and Boyer, 1999).

Landfill leachates are mainly generated by excess rainwater penetrating through the waste layers. The water seeping through the waste layers washes away pollutants which are produced during physical, chemical and microbial processes (Christensen *et al*., 2001). These pollutants include dissolved organic matter, inorganic components and heavy metals (Kjeldsen *et al*., 2002; Slack *et al*., 2005). The leachate pollutants pollute both groundwater and surface waters (Kjeldsen *et al*., 2002). The risk of groundwater pollution is probably the most severe environmental impact from landfills. This is because most landfills were built without engineered liners and leachate collection

systems. Furthermore leachate surface water pollution results in depletion of oxygen in the surface water body leading to changes in the aquatic fauna and flora as well as ammonia toxicity (Kjeldsen *et al*., 2002).

Methane production is another major environmental concern resulting from decomposition of garbage. This gas is a byproduct of the anaerobic respiration of bacteria that exists in landfills with high amounts of moisture (Wang *et al*., 1997; Ojeda-Benitez *et al*., 2000; Hao *et al*., 2008). For example, Cointreau-Levine, 1996 mentioned that methane concentrations can reach up to 50% of the composition of landfill gas at maximum anaerobic decomposition.

Methane is flammable and produces a lot of energy when burnt and this is the reason why it is recovered from landfills for domestic purposes. However, due to its flammability it can also result in explosions when it mixes with air thereby starting fires at the landfills (El-Fedal *et al*., 1997). Therefore it is very important to control methane gas at landfills to avoid unnecessary fires.

Landfill gas moves along routes that will allow it to escape from the landfill either by venting through the cover or by moving through the sides to the surrounding soil. The gas migrating from the landfill penetrates through the buildings and other facilities near the landfill site where it forms gas pockets that are potentially explosive. The gas may travel long distances away from the landfill before discovery, depending on the soil texture.

This has resulted in incidents of fires and explosions away from the landfills (Raybould and Anderson, 1987; El-Fedal *et al*., 1997).

At closure, many landfill sites are converted to parks, golf courses, agricultural fields, and in some cases, commercial developments. Vegetation near such sites is negatively affected (Arthur *et al*., 1985; Gilman *et al*., 1985). The damage occurs mainly due to lack of oxygen in the soil resulting from direct displacement of oxygen by landfill gas. If there is no proper gas control, landfill gas can migrate upward due to concentration and pressure gradients, and escape into the atmosphere by venting through the landfill cover. During this process, oxygen in the soil is displaced by high concentrations of carbon dioxide and methane resulting in death of plants (El-Fadel *et al*., 1997). Other commonly reported factors that may affect growth of plants at landfill sites include the presence of trace toxic compounds in landfill gas and cover soil characteristics such as thickness, composition, compaction and moisture (El-Fedal *et al*., 1997).

Methane and carbon dioxide are also known greenhouse gases that contribute significantly to global warming. Therefore, their control at the landfill is important in combating this environmental problem. Recently methane has received more attention because it contributes to global warming (El-Fedal *et al*., 1997). It is more effective at absorbing and emitting infrared radiation (Bingemer and Crutzen, 1987). Moreover, it has greater residence time in the atmosphere compared to other gases such as carbon monoxide (Gardner *et al*., 1993).

2.2 Strategies and Options for Sound Solid Waste Management

The problems discussed in the previous sections pose challenges to solid waste management authorities. Therefore, there is a need to implement a sound solid waste management system. Sound practice of solid waste management embodies a reasonable balance of feasible, cost-effective, sustainable, environmentally beneficial, and socially sensitive solutions to SWM problems. In other words, sound practices function together to achieve defined solid waste policy goals, while appropriately responding to the entire set of conditions that constrain the choices available in specific MSWM decisions (UNEP, 1996). This means that a sound practice does not only achieve a specific goal in MSWM, but it also takes into account the demands of the specific situation where a proposed solution is to be implemented.

Several practices can be followed in order to achieve sound solid waste management. These include waste reduction, recycling, composting, using appropriate dumping sites, incineration and implementing an integrated approach (EPA, 2002; Agarwal *et al*., 2005).

2.2.1 Waste Reduction

The easiest and most effective way to manage solid waste is to reduce the amount of waste to be disposed. This is a strategy that seems simple in concept and has shown promise. However, the amount of waste produced, even in developed countries, is often a function of culture and affluence (UNCHS, 2001; Eugene *et al*., 2004). For example the industrialised countries have developed, a “throw away culture”, since consumer goods are cheap, and this results in a significant increase in MSW (Zerbock, 2003).

The strategies that can be employed to achieve reduced solid waste include the following: manufacturers can design durable products that can last longer and can be reused instead of being thrown away. A waste exchange program can also contribute to reduction of waste sent to the landfill as it encourages the exchange of waste of one industry to another for re-use or recycling. In any of the reduction strategies public education and involvement are crucial and imperative (UNEP, 1996; Heimlich *et al*., 2005; Maldonado, 2006). For instance, in South Africa the packaging and shopping plastics are durable enough to be reused and are paid for by the consumer this therefore reduces litter and hence the amount of solid waste taken to the landfill.

2.2.2 Recycling

Recycling is the waste management approach which involves separating and sorting of waste generated and eventually using it to form other products. It has the advantage of reducing costs of the disposal facilities thereby prolonging the life span of the site. Recycling also reduces the environmental impacts resulting from disposal of recyclable items such as fridges and computers which produce inorganic substances that are largely to blame for the leachate pollution and methane problems (Slack *et al*., 2005).

Separating and sorting of waste materials begins at the household level. At this stage the house dwellers select valuable and reusable materials (Agarwal *et al*., 2005). Furthermore, waste-pickers also select items that they find valuable before garbage enters the landfill or for incineration, especially in the lower and middle-income areas of many municipalities (Yhdego, 1995; Ojeda-Benitez *et al*., 2000; Hassan, *et al*., 2002; Supriyadi

et al., 2002) Figure 6. The selected items are either reused or sold for cash. This results in significant reduction of volume of waste to be disposed of by municipal authorities.



Figure 6: Waste-Pickers in Johannesburg who have selected valuable and reusable materials from household garbage bins to be sold at collection points and sent for recycling (e.g. cardboard).

At disposal sites, separation and sorting of solid waste for recycling occurs. For sound solid waste management, municipalities should not only recognize the trade in recyclable items, they should embrace it, by allowing small enterprise to engage in the process. This can save funds, create jobs and save space in the landfill (Agarwal *et al*., 2005; Batool *et al*., 2008). For example, The Laos Chareon Recycling Center is the biggest recycling centre in Viangchan, which was established as a small enterprise with a capital of US$10,000. It has

more than 100 employees and has claimed to have generated a significant income of about US$18,000 within a short period of time (Dethoudom, 2004).

Some key factors that affect the potential for resource recovery are the cost of the separated material, its purity, its quantity and its location (Kroyer, 1995). The costs of storage and transport are some of the factors that decide the economic potential for resource recovery. In many low-income countries, the fraction of material that is won for resource recovery is very high, because this work is done in a very labour-intensive way, and for very low incomes (Zurbrugg, 2003).

2.2.3 Composting

Composting is an aerobic decomposition process in which some of the organic material is decomposed to carbon dioxide (CO_2) and water, while stabilized products, humic substances, are synthesized (Hart, 1996). Its advantages include the reduction of the amount of waste that goes to the landfills (Sonesson *et al*., 2000). When done correctly, the end product can be used at the household or farm level to augment soil nutrient levels and increase organic matter in the soil and hence increase soil stability (Somda *et al*., 2002; Pagans *et al*., 2005). Moreover, the compost can be sold to farmers, nurseries and home owners to improve their soil for agriculture.

The waste of many developing nations would theoretically be ideal for reduction through composting, because it mainly consists of organic material (Mbuligwe *et al*., 2002; Zurbrugg *et al*., 2004; Zurbrugg *et al*., 2005; Mazumdar, 2007). For example, in

developing countries, the average city's municipal waste stream is over 50% organic material (Hoornweg and Thomas, 1999; Metin *et al*., 2003). Studies in Bandung, Indonesia and Colombo, Sri Lanka have revealed that residential waste is composed of about 80% compostable material (Cointreau, 1982). However, urban managed composting programmes have not been very successful throughout the developing world (UNEP, 1996). The main reason being that composting includes high operation and management costs, high transportation costs, poor understanding of the composting process, and competition from chemical fertilizers which are often subsidized. For example, good composting activities have been documented in China and other areas of eastern Asia, whereas composting project records have not been good throughout Africa and Latin America (UNEP, 1996). In China composting is mainly applied for treating MSW, about 80% of the total amount of MSW is composted. MSW composting is mainly composted with night soil or sewage sludge. Compost is used in agriculture, forestry and horticulture (Wei *et al*., 2000).

The major challenge facing urban managed composting programmes is the mixed nature of the waste, with plastics, metals, and raw fecal matter, especially in low income areas where sanitation facilities are lacking (Boadi and Kuitunen, 2003). The problem is furthermore increased by lack of awareness among the public that sort and separate compostable from non compostable materials especially at household level. The general population needs to be educated about the value of management of waste so that they can participate in waste management strategies. These may include carrying waste to shared containers as well as separating waste to assist in recycling activities (Zurbrugg, 2003).

2.2.4 Dumping

The dumping of solid waste in landfills is probably the oldest and the most prevalent form of ultimate garbage disposal. In the cities of developing countries many “landfills” are open dumps which are sometimes controlled (Rushbrook and Pugh, 1999; Inanc *et al*., 2004). The difference between landfills and dumps is the engineering, planning, and administration involved. Open dumps are characterized by the lack of engineering measures, no leachate management, no consideration of landfill gas management, and few, if any, operational measures such as registration of users, control of the number of “tipping fronts” or compaction of waste (Figure 7). Johannessen and Boyer (1999) examined landfills throughout the developing world in 1997-1998. They found varying amounts of planning and engineering in MSW dumping; among the various regions visited, African nations (with the exception of South Africa) had the fewest engineered landfills, with most nations practicing open dumping for waste disposal. In South Africa, they found many landfills with better engineering, planning, administration, leachate management as well as methane management. Leachate is collected through drainage or diversion systems and discharged into municipal sewage plants for treatment, while methane is controlled by being collected and burnt. Scavenging is regulated by registering waste pickers and scavengers at the tipping front. For instance at the Boipatong landfill in Gauteng, 100 waste pickers and scavengers are registered at the tipping front (Johannessen and Boyer, 1999).



Figure 7: Open dump in South Africa at De Aar.

2.2.6 Incineration

Another option for waste management is incineration. Its advantages include significant waste-reduction, which can be 80-95% in terms of waste volume (Rand *et al*., 2000; Seo *et al*., 2004; Sharholy *et al*., 2008). Incineration is another way of saving resources because it can replace other fuels such as coal and oil. For instance, in Sweden, cleaner fuels and modern incineration technology have resulted in 90% reduction in emissions of carbon dioxide since 1985 (Wolpert, 1994). Moreover, combustion of Municipal Solid Waste can produce electricity, steam and other forms of energy. For example, in Japan, electricity has been generated from waste incineration plants since 1991 (Wolpert, 1994). Reduction of solid waste by incineration has proven useful in island nations such as Bermuda and the British Virgin Islands (Lettsome, 1998).

Incineration appears to be an extremely attractive option, however, with occasional exceptions. Incineration is not a suitable option for most of low-income countries like Lesotho, because start-up and operational capital required for implementing incineration facilities are expensive (UNEP, 1996; Rand *et al.*, 2000).

Although incineration is an effective method in solid waste management, it has the following drawbacks. It produces gaseous emissions which have a negative impact on the environment. For instance, it volatilizes metals (especially lead and mercury), organics (dioxins), acid gases (sulfur dioxide and hydrogen chloride), nitrogen oxides, carbon monoxide and dust which are potentially harmful to human health (Rogers, 1995; UNEP, 1996; McGavaran, 1998; Cangialosi *et al*., 2008). Incineration can also result in high production of carbon dioxide during electricity production which is one of most significant gases in global warming (Morselli, *et al*., 2008). In order to minimize the negative impacts of incineration technology, recycling and composting can be used wherever possible to avoid gas emission from incineration.

2.2.5 Integrated approach

Integrated Solid Waste Management (ISWM) can be described as the selection and application of suitable techniques, technologies, and the management programmes to achieve sound solid waste management objectives and goals (Tchobanoglous, 1993). An integrated approach would use methods already described in the above sections. United States Environmental Protection Agency (EPA) 2002, noted that sound environmental management was achieved by implementing the following strategies in the order they

were listed. Firstly source reduction and reuse, second recycling and composting and third disposal to the landfill or waste combustors. These approaches emphasize waste reduction and appropriate disposal options as part of an integrated evaluation of needs and conditions of the area (Metin *et al*., 2003; Eriksson *et al*., 2005; Mbuligwe and Kaseva, 2006).

An integrated approach to waste management will have to take into account community and regional-specific issues and needs and formulate an integrated and appropriate set of solutions unique to each context (Schubeler *et al*., 1996; UNEP, 1996; Senkoro, 2003). This will be helpful in implementing a combination of SWM that will benefit the community and avoid unnecessary expenses. As with any other issue, solutions which work for some countries or areas will be inappropriate for others (Antonio, 2002; Themelis *et al*., 2002; Emery *et al*., 2007). Specific environmental conditions will dictate the appropriateness of various technologies. For example, lower level of industrialization and technical knowledge present in various countries and cities may constrain solutions (Wei *et al*., 1997; Chung *et al*., 2004; Mrayyan and Lo, 2006).

2.3 Waste collection and storage

The collection of waste is described by quantity of waste, number of source points, collection and the transportation method (Tin *et al*., 1995). Some of the producers of MSW are people in residential, industrial and commercial areas. Waste produced in these areas is usually colleted into small bins. What follows from here is collection of waste by relevant authorities to transfer facilities. At the transfer stations waste is sorted and

separated and transported to different end points such as recycling, composting and landfill or incineration. The process is summarised in a flow diagram in Figure 8.

In developing countries solid waste collection is not efficient. The problem for waste collection is escalated by urbanization which results in the formation of informal settlements without proper layout and planning (Korfmacher, 1997; Rotich *et al*., 2006; Alam *et al*., 2008). This has been attributed to the high population density in these areas as well as the inaccessible places.

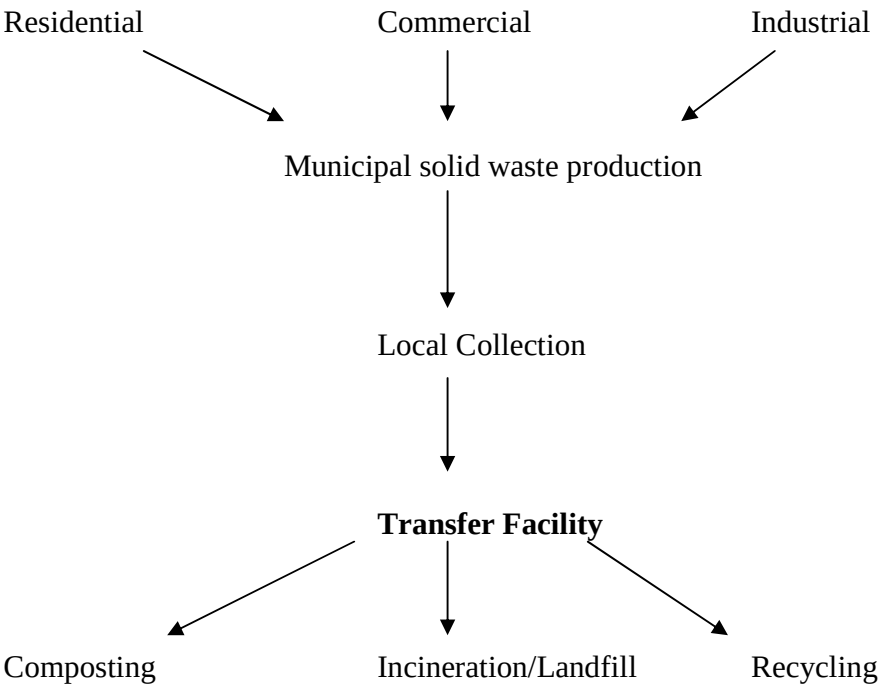


Figure 8: Municipal Solid Waste Management Flow Diagram

2.3.1 Waste Transfer stations (WTSs)

Transfer stations are centralized facilities where waste is unloaded from smaller collection vehicles and temporarily stored before being re-loaded into larger long-distance transport vehicles for shipment to disposal or processing sites (EPA, 2000). It is at this stage where waste is sorted and separated before taken to its final destination (Kirca and Erkip, 1988; Massam, 1991; EPA, 2004). Solid waste transfer stations are designed in order to avoid the direct traveling of trucks from individual collection sites to final refuse disposal sites (Yitzhak, 1993).

The importance of waste transfer stations is that they serve as the link between community's solid waste collection programme and a final disposal facility such as landfills, incinerators, material recovery and recycling plants (Eshet *et al*, 2007). Waste transfer facilities are more important when the daily average solid waste disposal area is far away from the collection point (Kirca and Erkip, 1988; Bovea *et al*., 2007). Kirca and Erkip, 1988 stated when using transfer stations, the benefits obtained include:

- Collection vehicles spend less time in transporting and more time in collecting
- Labor force is more efficiently utilized since more time is spent on collection
- The rate of response to service calls is increased as collection vehicles do not travel far from the area in which they operate
- Installation of sorting and separation facilities within transfer stations may become economical as the loss in the quality and therefore in the value of sorted material is kept at a low level by transporting them to smaller distances (compared to transporting them directly to waste processing plants)

- Main roads to landfill areas or processing plants are less congested as one transfer vehicle will replace at least three or four collection vehicles (since the size of the vehicle creates less congestion than the number of vehicles).

Furthermore, at the transfer stations waste is quickly consolidated and loaded into larger vehicles and moved off site in a matter of hours. As a result, health and environmental impacts are significantly reduced provided that the security is good (EPA, 2000; Bovea *et al*., 2007).

However, these temporary storage areas for waste can have a negative impact on the nearby community if they are not properly managed. They can result in poor air quality from idling diesel trucks and from particulate matter such as dust and glass. They can also result in bad odour, litter as well as noise pollution. Moreover, transfer facilities can serve as housing of disease-carrying vectors such as rodents and cockroaches (Kimball *et al*., 1993; EPA, 2004; Eshet *et al*, 2007).

Besides posing problems to health and environment, transfer stations can include the additional capital costs for purchasing trailers and building transfer stations, and the extra time, labour, and energy needed for transferring waste from collection trucks to transfer trailers (Wilson *et al*., 2008) especially if the collection trucks are not mechanized.

Criteria used to locate suitable sites for transfer stations

Solid waste transfer stations have negative impact on the environment such as bad odours, dirt and noise. On the other hand, for transfer stations to operate well in an

economical way, they should be located closer to the residential area they are supposed to serve.

A variety of issues should be considered when selecting a site as a transfer station. These include ecological, economical, transportation, political and geographical aspects (Yitzhak, 1993). Yitzhak, (1993), EPA, (2000), Lesotho Environmental Act, (2006) consider the following criteria ideal for selecting the site as a transfer facility:

- Transfer stations should not be constructed on any of the following; wetlands and floodplains, endangered and protected flora and fauna habitats, protected sites of historical, archeological and cultural significance, prime agricultural land, parks and preserves. All these are protected by law.

- Transfer stations should be located centrally to waste collection routes so as to maximise collection efficiency. They should not be more than 16km away from the end of all collection routes.

- The site should have direct and convenient access to truck routes, major arterials, and highways (or rail or barge access, if appropriate).

- The suitable site size for a simple transfer station is about 3ha while a high technological facility will need an area of about 4ha (Robinson, 1986), to allow for onsite roadways, queuing, and parking of waste collection trucks (Figure 9). And also the size of the site should be big enough to allow for expansion in case

the daily tonnage of waste increases or for added processing capabilities for recycling and diversion. This will be relatively cheaper than developing a new site due to the ability to use existing operations staff, utility, connections, traffic control systems, office space and buildings.

- The best sites for transfer stations are located away from areas that have midday traffic peaks and/or school buses and pedestrian traffic.

- To mitigate impact on the surrounding community, a transfer station should be located in an area that provides separation from sensitive adjoining land uses such as residences. Buffers can be natural or constructed and can take many forms, including open spaces, fences, sound walls, trees, and landscaping.

- Sites with steep slopes must be avoided as they require extra costs associated with earthmoving and retaining walls. Transfer facility site should be flat or only moderately sloped.

- Transfer stations generally require electricity to operate equipment, such as balers and compactors; lighting; water for facility cleaning, restrooms, and drinking; and sanitary sewer systems for waste-water disposal. So the site should have access to all the utilities.



Figure 9: Solid waste transfer station in Johannesburg

CHAPTER 3

METHODOLOGY

3.0 Introduction

Several factors need to be considered when determining suitable sites for a defined land use. The selection of transfer station sites involves a set of critical factors such as the demographical, environmental disciplines and economic policies. Geographic information systems (GIS) and Multi-criteria decision-method (MCDM) techniques have been used in solving site selection problems (Eastman *et al*., 1993).

Multi-criteria decision making is the technique adopted in various approaches of decision analysis. The technique incorporates explicit statements of the preferences of decision-makers. Such preferences are represented by various quantities, weighting schemes, constraints, goal, utilities, and other parameters. MCDM can be used to solve various site selection problems (Badri, 1999; Korpela and Tuominen, 1996), as it can handle various criteria. MCDM results can be mapped in order to display the extent of the best areas or index of land suitability. Geographic information systems have emerged as useful computer-based tools for spatial description and manipulation. GIS have been described as a decision support system, however, there have been some disputes regarding whether the GIS decision support capabilities are sufficient (Jankowski, 1995).

A combination of GIS and MCDM is a powerful approach that can be used in land suitability assessments. GIS enables computation of the criteria while a MCDM can be

used to group them into a suitability index. For instance, Eastman *et al*., (1993) used both GIS and MCDM to produced a land suitability map for an industry near Kathmandu using a raster GIS and AHP (Analytical Hierarchy Process) (Saaty, 1990). Pereira and Duckstein (1993) have used MCDM and raster GIS to evaluate a habitat for endangered species.

In this project a combination of GIS and MCDM were used in selecting suitable sites for transfer station construction. The process started with identification of the problem and then the study area, followed with the selection of relevant aspects of the real-world required to carry out the study. The next step was then to decide how the selected aspects are to be represented in a manner to be understood by a computer, is referred to as abstraction.

3.1 Identifying Criteria

The first step that was taken in the selection of transfer station analysis was to collect data that would be needed to meet all of the criteria. Specific criteria were selected to evaluate potential waste transfer facility sites. The criteria were identified and included factors and constraints. The criteria were selected based on guidelines from literature from other countries (e.g. South Africa). These factors included:

Topography

Topography affects land use planning. The important aspects associated with topography include elevation and of the gradient slopes. Sites on or near cliffs are not suitable for

construction of transfer stations, because the planning and construction cost are high in high slope areas compared to flat or moderately flat areas. Prohibitive costs result from constructing access roads, establishing water and electricity supplies. Digging and filling costs are less in low slope areas. Besides on steep slopes there is higher risk of run off pollution than in flat areas.

Slope defines the gradient or steepness of a surface. The smaller the slope the flatter the terrain. For the purpose of the project, slope was derived using the SRTM 90 m digital elevation model (DEM) (United States Data). Any slope lower than 18^0 would be acceptable for the development of transfer station (Booth, 2005).

Land use

This criterion concerns land cover that may be exposed by the threats imposed by transfer station adjacency. From an economic stand point, sites located on vacant land where there are no immediate plans for development (e.g. Fields, rivers and dams, industries, cemeteries, industrial dumping site and residential) are favourable. Transfer stations are sites where noise and bad odour are produced emanating from the disposal trucks and waste from the station facilities. To minimise the impact on surrounding communities, transfer stations should not be located near sensitive adjoining land uses. For this purpose, a buffer of 200 m for land uses (Fields, water bodies, Industries, cemeteries, industrial dumping site, Tsosane dumping site and Land Use Planning sites) were used. Built up areas (villages and CBD) were also buffered by 200 m. Built up areas and Land use map in Maseru is shown in Figure 10 and 11 respectively. Tsosane and industrial

dump sites could not be considered because they are located close to the built up areas. Besides Tsosane is on the mountain while industrial dump site is at the gully close to the river.

Distance from rivers

Distance from rivers has a direct effect on the suitability of land for use as a transfer station. From an environmental point of view the development of a site away from rivers banks and streams is preferable in order to avoid ground water pollution from washing water used in the station or rain falling on the station site draining directly into rivers. For the purpose of this project rivers will be buffered by 500 m. Figure 12 shows rivers and stream networks in Maseru.

Distance from roads

Transfer stations must be located close to road networks in order to facilitate transportation and to reduce relative costs. A buffer of 200 meters has been considered in this study. Road networks in Maseru are illustrated in Figure 13. However, transfer stations are not visually appealing and as such constitute visual pollution. To measure visibility of the sites from the roads, a viewshed analysis from the main roads was done using STRM 90 m DEM (United States Data). Viewshed defines the total area of land that is visible from fixed observation points.

The flow chart in Figure 14 summarizes the operations performed on the data in order to come up with the final result.

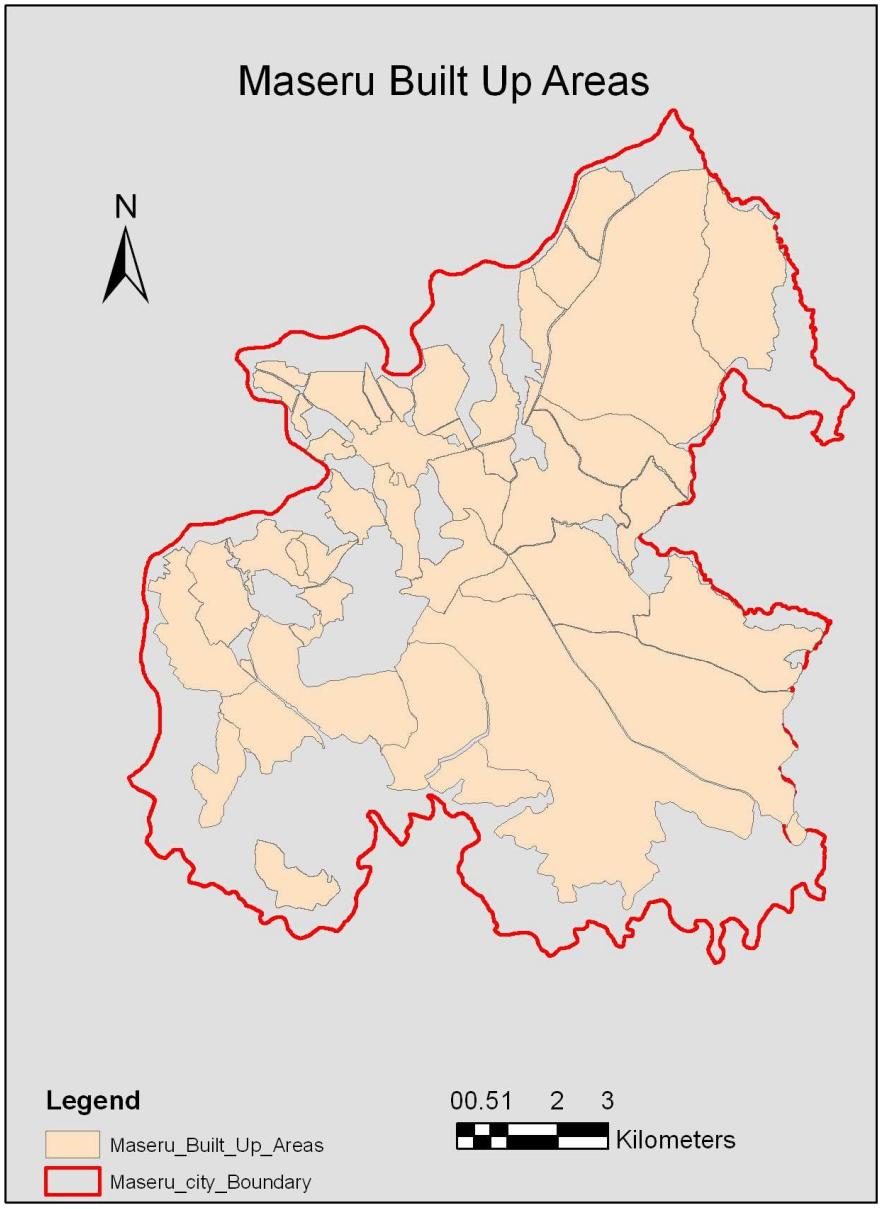


Figure 10: Map of Build up areas in Maseru city

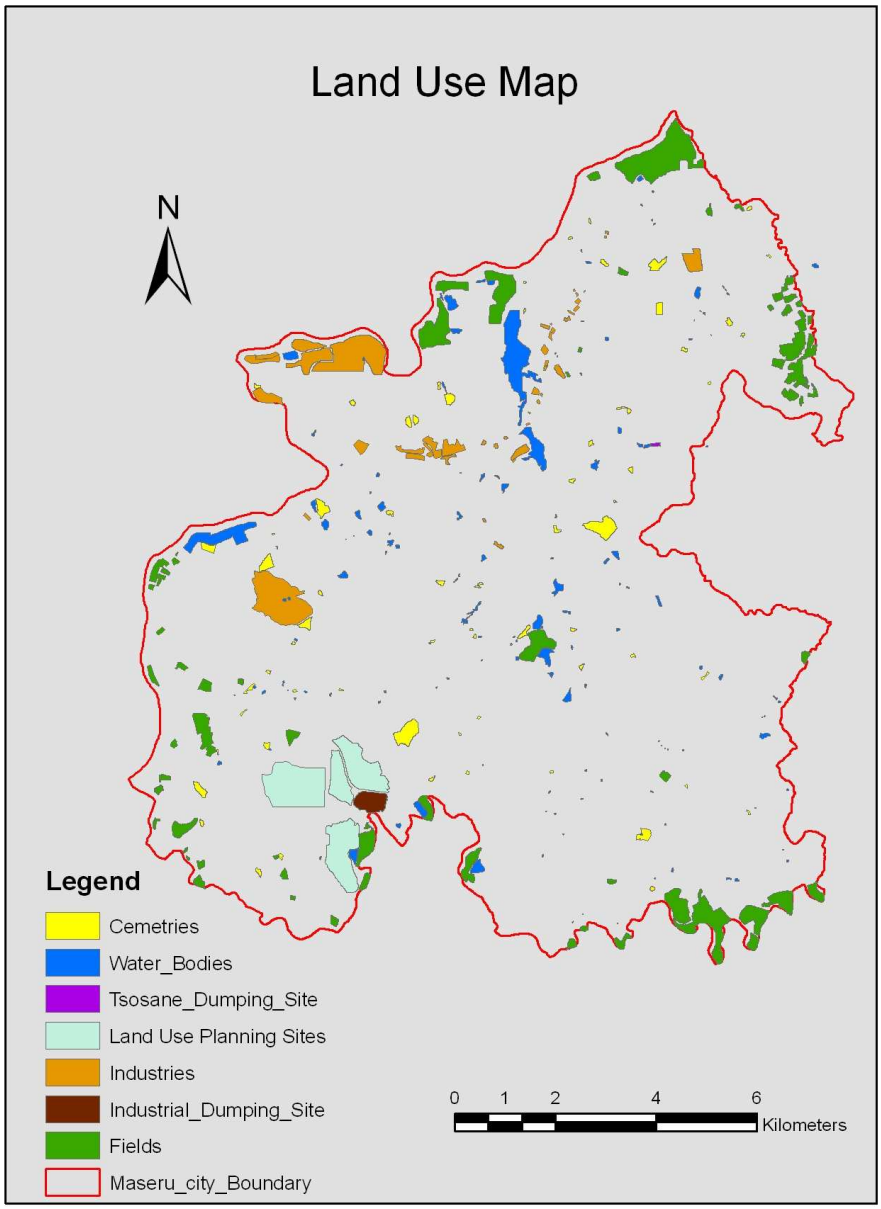


Figure 11: Layer Map of land use within Maseru City Council boundaries

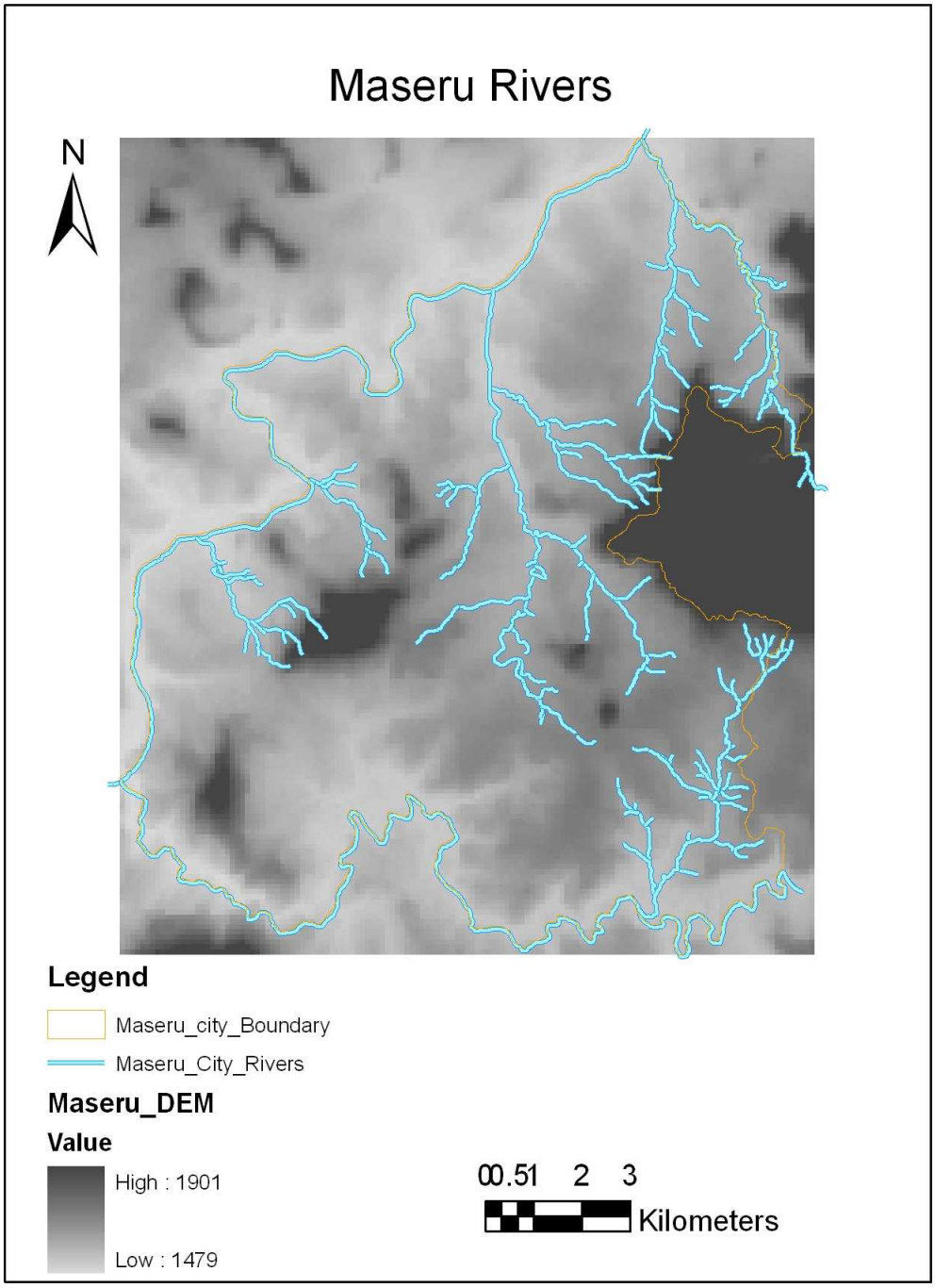


Figure 12: Layer Map of rivers in Maseru metropolitan area



Figure 13: Layer Map of the road networks in Maseru city

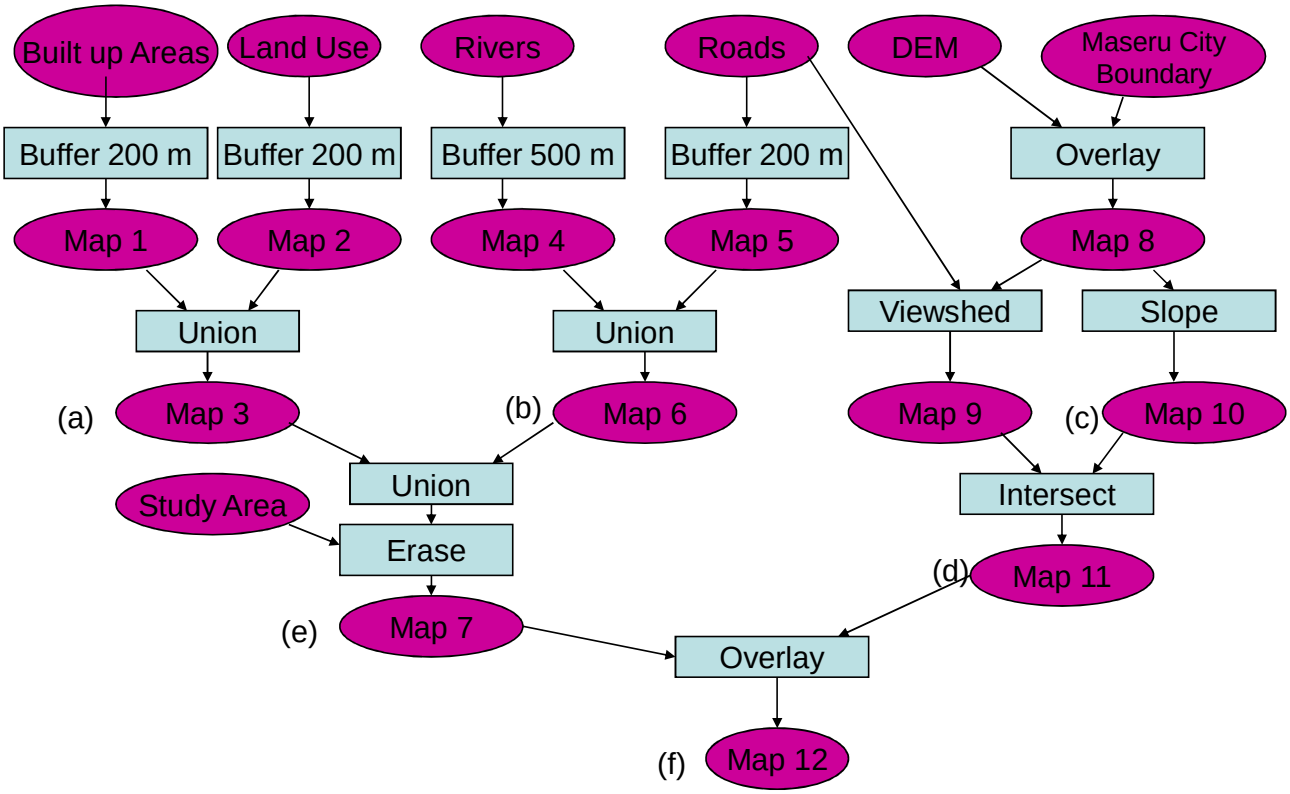


Figure 14: Land Suitability for Transfer Station Model Builder Process by eliminating unsuitable areas

(a) = Union of built up areas and land use buffers

(b) = Union of rivers and roads

(c) = Slope less than 18^0

(d) = Viewshed

(e) = Union of (a) and (b) and subtraction of unsuitable areas from study

(f) = Intersection of slope and viewshed with suitable sites

3.2 Modeling issues considered in this project

Spatial data model

There are two commonly used GIS data models: vector and raster. A vector model represents objects as geometric features. The building blocks of these features are points. Points are recorded as single coordinate pairs. Connected points form a line while closed line segments form areas (polygons). Points, lines and polygons are referred as the geometric primitives in vector modeling. Lines and polygons can further be used to derive network and surface entities which are also used in the vector model (Lecture notes 2008).

Deciding on which model to employ in carrying out a study is very important because each has both advantages and disadvantages over the other. For the purposes of this project, a **vector** model was used, because features of interest were in vector format. Converting to raster format would have resulted in inaccuracies. However, for the slope and viewshed a **raster** model was used because the data were supplied in that format.

Table 2: Table of data structuring

Dataset	Spatial Entity
Land Use: Settlements, Fields, Industrial area	Polygons
Rivers/Streams	Lines
Roads	Lines
Maseru City Boundary	Polygons
Villages	Polygon
Slope	Raster
Viewshed	Raster

The following referencing system was used.

Coordinate System: **Lo27**

Projection: **Transverse Mercator**

Scale factor: **1**

Central Meridian: **27**

Linear Unit: **Meter**

Geographic Coordinate System: **GCS_Cape**

Datum: **Cape**

3.3 Data Acquisition

The data used in this project were obtained from different custodian departments within the Government of Lesotho. Heads-up digitizing was the commonly used method of data capture because data were from mostly aerial photo images. Land use, river network, roads and built up area layers were derived from these aerial photos.

To demonstrate how the project data were derived and imported into the GIS, the following diagram, representing the data stream for each dataset is used (Figure 15).

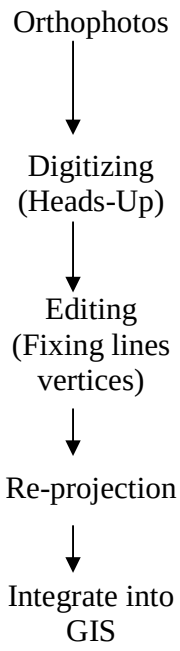


Figure 15: River, Roads, Land Use, Built Up Areas and Study Area Extent

Orthophotos were used to digitize on-screen, rivers, roads, land use, built up areas and study area layers. Since the source data set was in a geographic coordinate system, the layers of rivers, roads and land use had to be projected to the projection chosen for this study (Lo27),

but this was only done after elimination and correction of errors (e.g. digitizing). The layers were imported into a geodatabase created for the purposes of the project.

Study area extent

Maseru City Council provided the hard copy map of 'Maseru Urban Area', the study area; it also provided the administration boundary of Maseru Urban Area. The boundary layer was digitized (Figure 16).

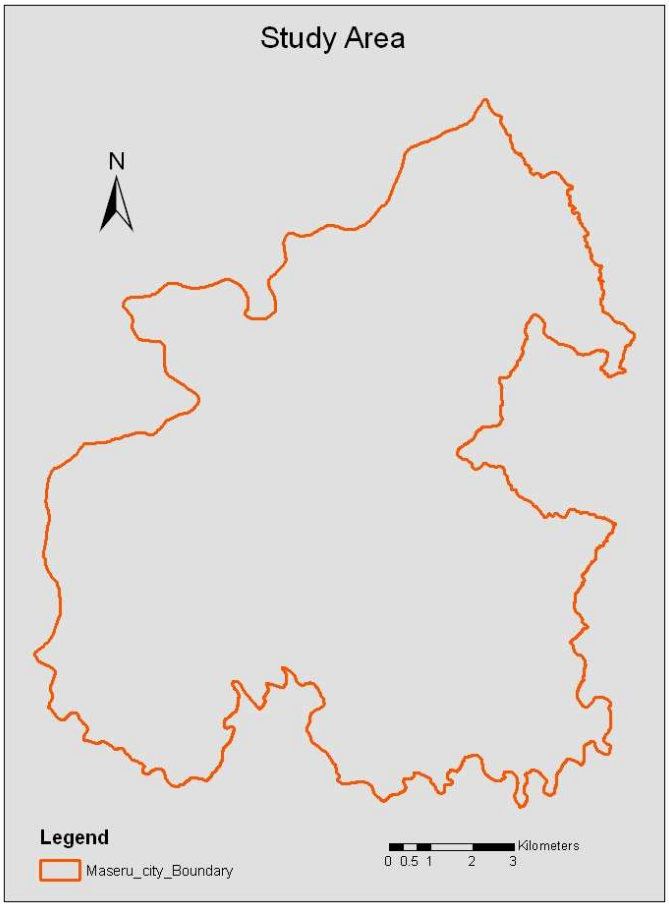


Figure 16: Map of Maseru City Council boundaries

Orthophotos of Maseru

This dataset (orthophotos) was provided by the Land Use Planning Division of the Department of Lands Survey and Physical Planning, the custodian of this dataset in the Ministry of Local Government.

3.5 Data problems

One of the major problems about the data used in this project is that the source datasets were compiled as far back as in the early 2005. The only exception is the study area extent where its boundaries have not changed. In order to overcome this problem, site visits for groundtruthing to verify the current land use on the selected sites for potential transfer station were undertaken.

3.6 GIS Analysis

The objective of the GIS analysis was to identify suitable areas using MCDM (Figure 14). The map sets (Build up areas, Land use, Rivers and Roads) were buffered at different distances to single out unsuitable areas. The suitable areas are outside of the buffer zones. Firstly union of built up areas and land use was done (Figure 14 (a)). This layer was united with a buffer union between roads and rivers (Figure 14 (b)). The united layers (Figure 14 (a) and (b)) were subtracted from the study area boundary to obtain suitable areas using vector layers (Figure 14 (e). Slope of Maseru was also evaluated from DEM of Maseru (Figure 14 (c)). The DEM raster layers for Maseru, in conjunction with the roads vector

layer were used to obtain viewshed of Maseru. Slope and viewshed criteria for the model were obtained by using Spatial Analyst. These two raster data sets were then intersected (Figure 14 (d)). (Figure 14 (d) and (e)) were overlaid to show which suitable areas are located on slopes less than 18 degrees and which are not visible from the main roads (Figure 14 (f).

CHAPTER 4

RESULTS

4.1 RESULTS

The results presented in map output steps in the transfer stations model builder process (Figure 14) are shown below. The results of built up areas, land use layer buffers and their union layer are shown in Figure 17, 18 and 19 respectively. While the rivers, road layer buffers as well as their union layer are shown in Figure 20, 21 and 22 respectively. The union of Map 3 and Map 6 in Figure 14 resulted in a map showing the suitable sites for construction of a transfer facility (Figure 23).

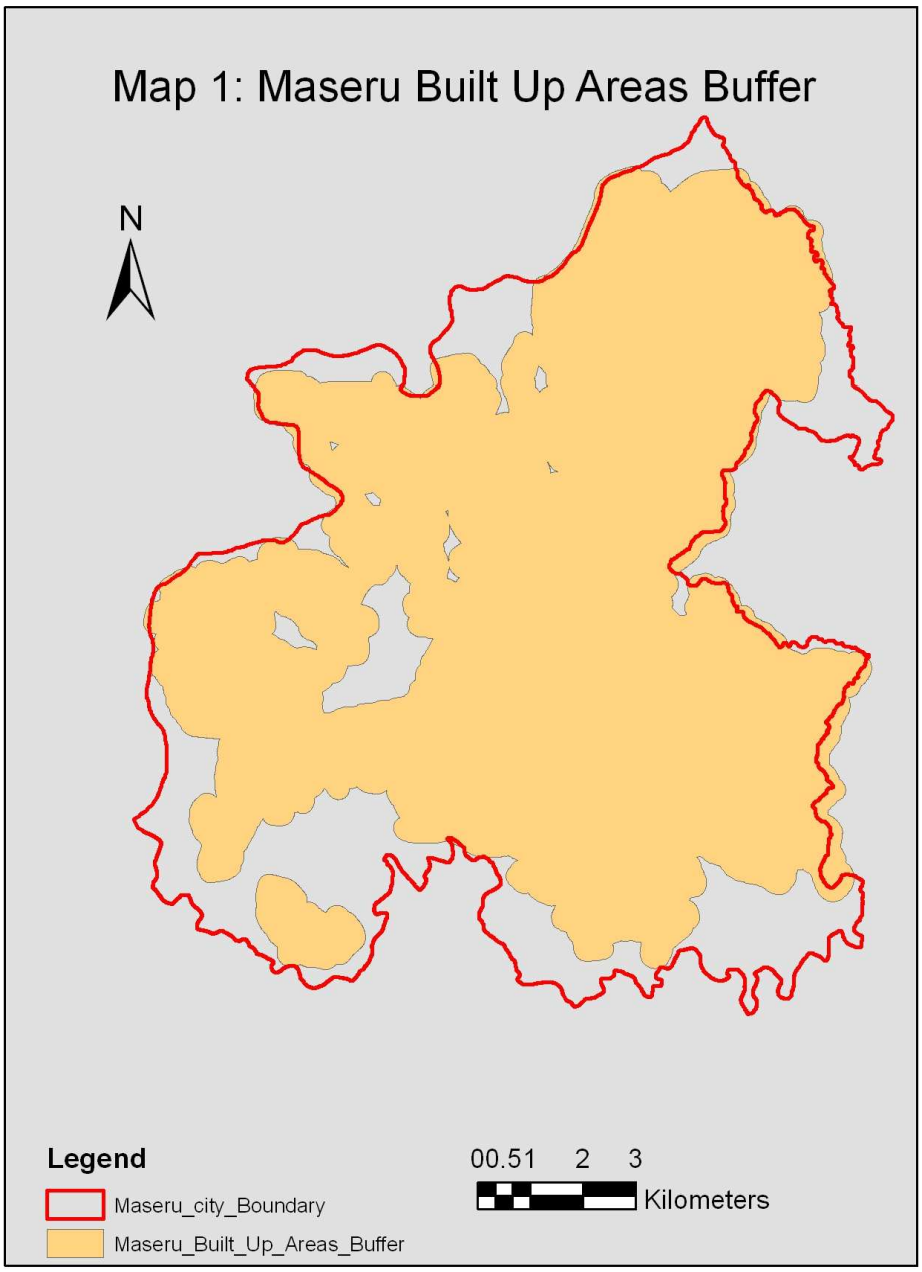


Figure 17: Maseru Built Up Areas buffered by 200 m distance

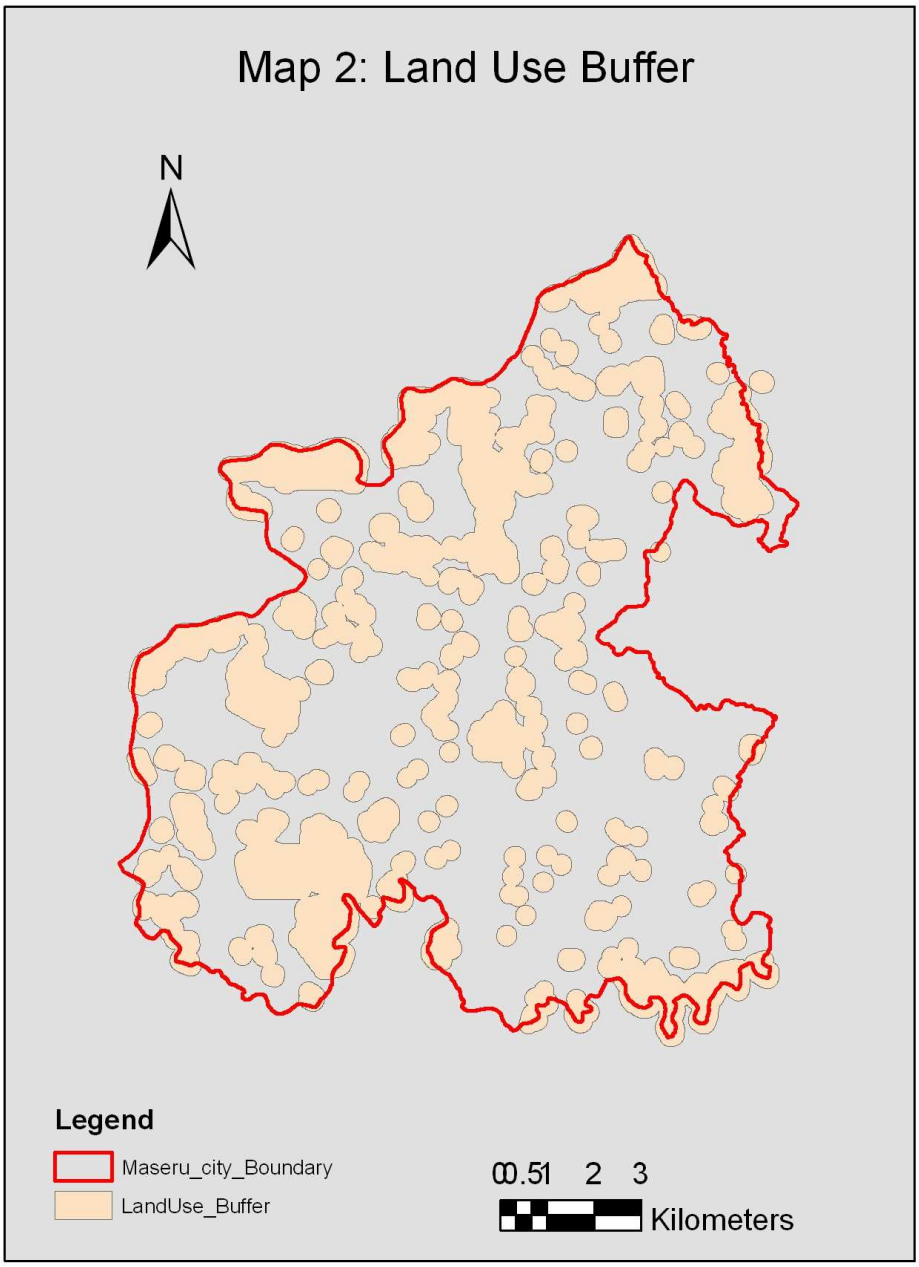


Figure 18: Land Used buffered by 200 m distance

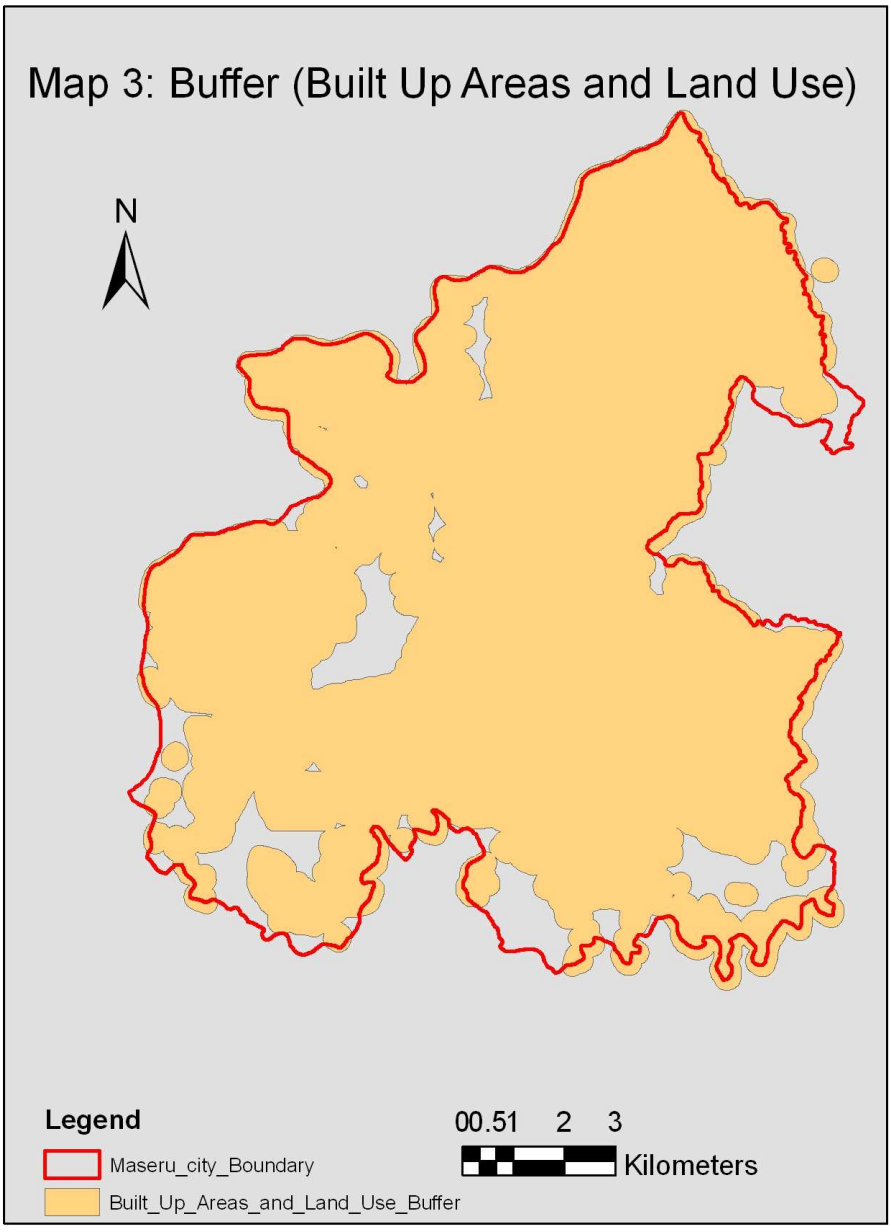


Figure 19: Union of Maseru Built Up Areas and Land Use Buffers

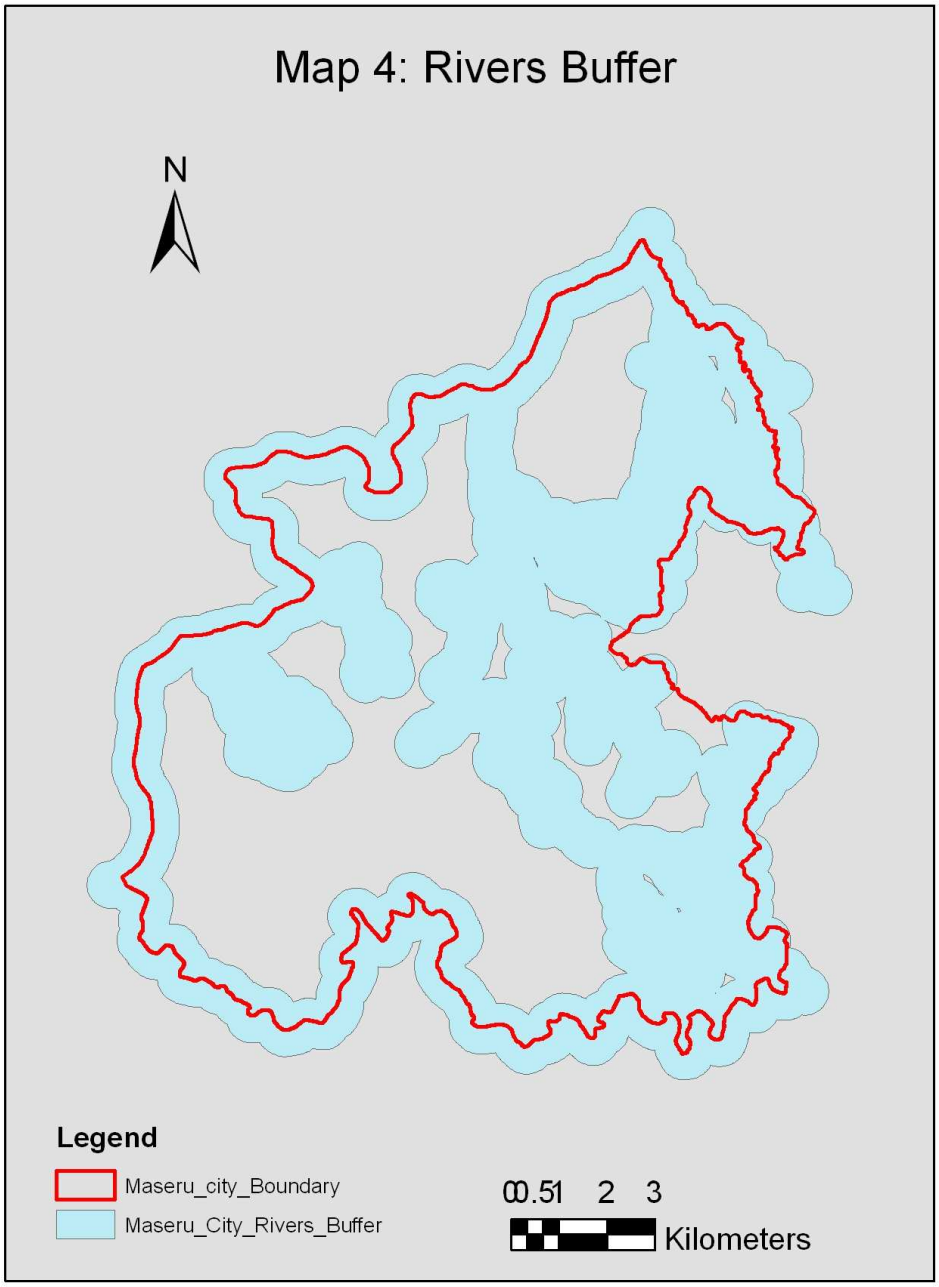


Figure 20: Map of rivers buffered at 500 m distance

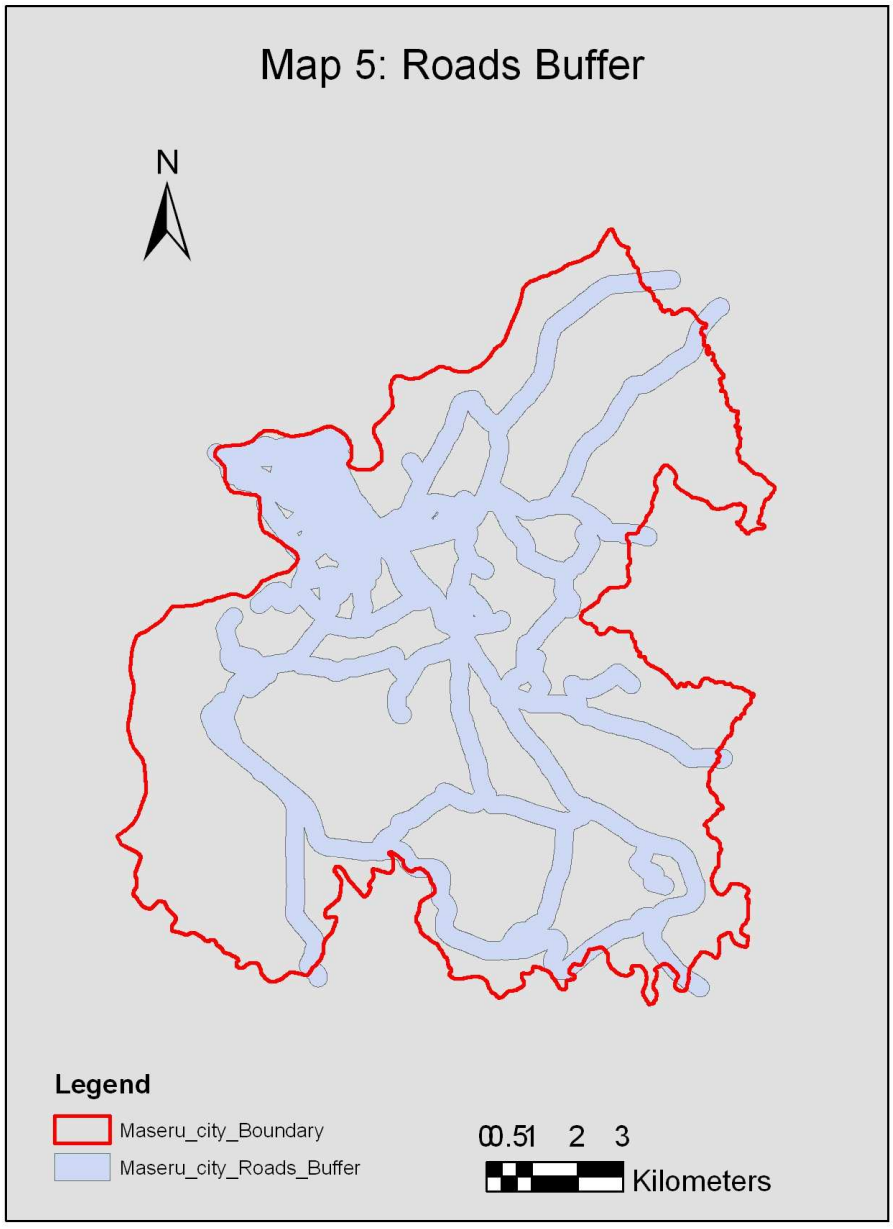


Figure 21: Map of roads buffered at 200 m distance

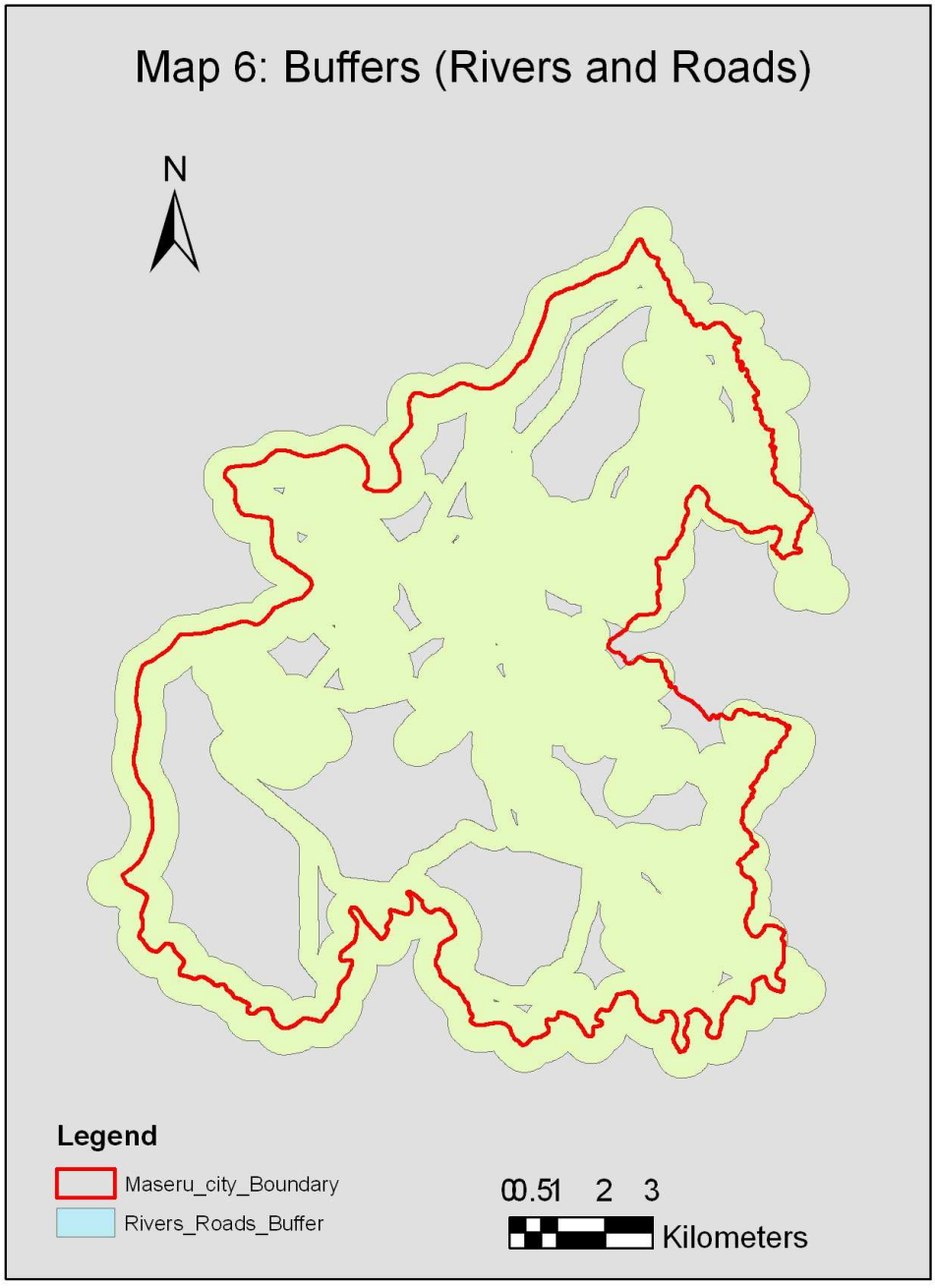


Figure 22: Map of union of rivers and roads buffers

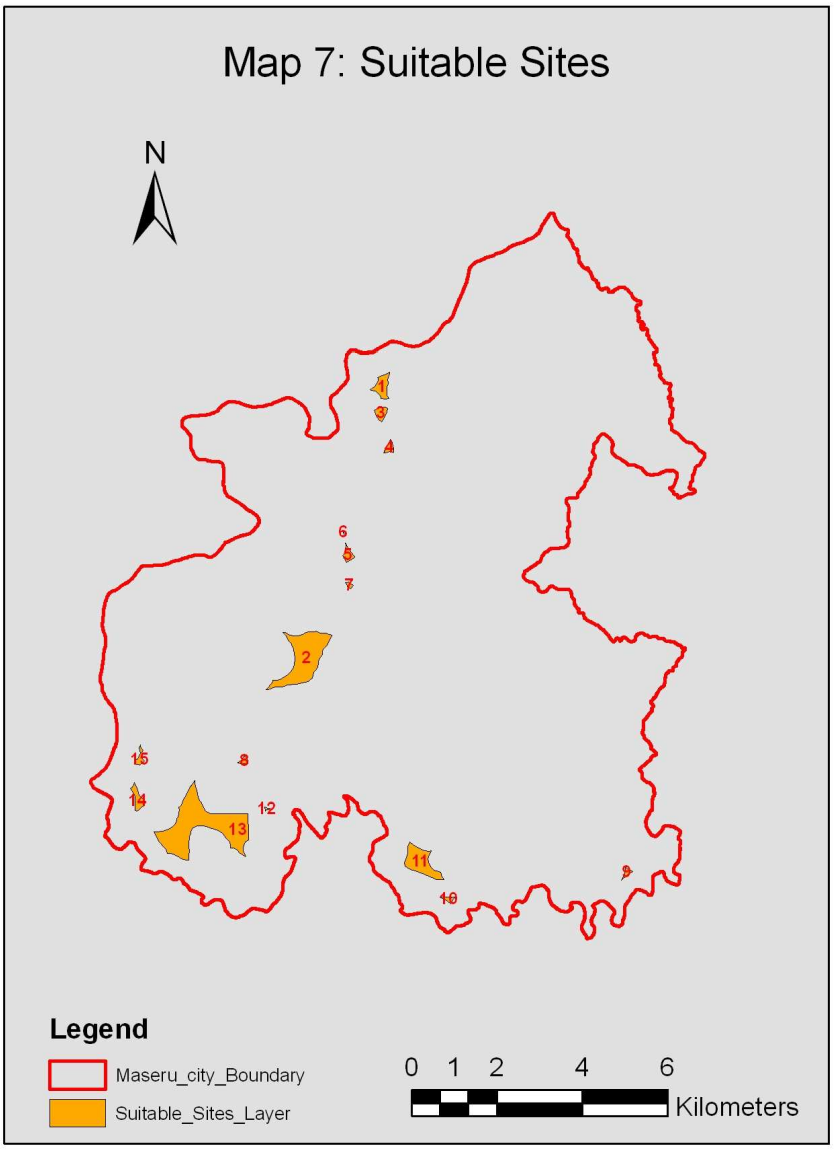


Figure 23: Map of sites suitable for transfer stations

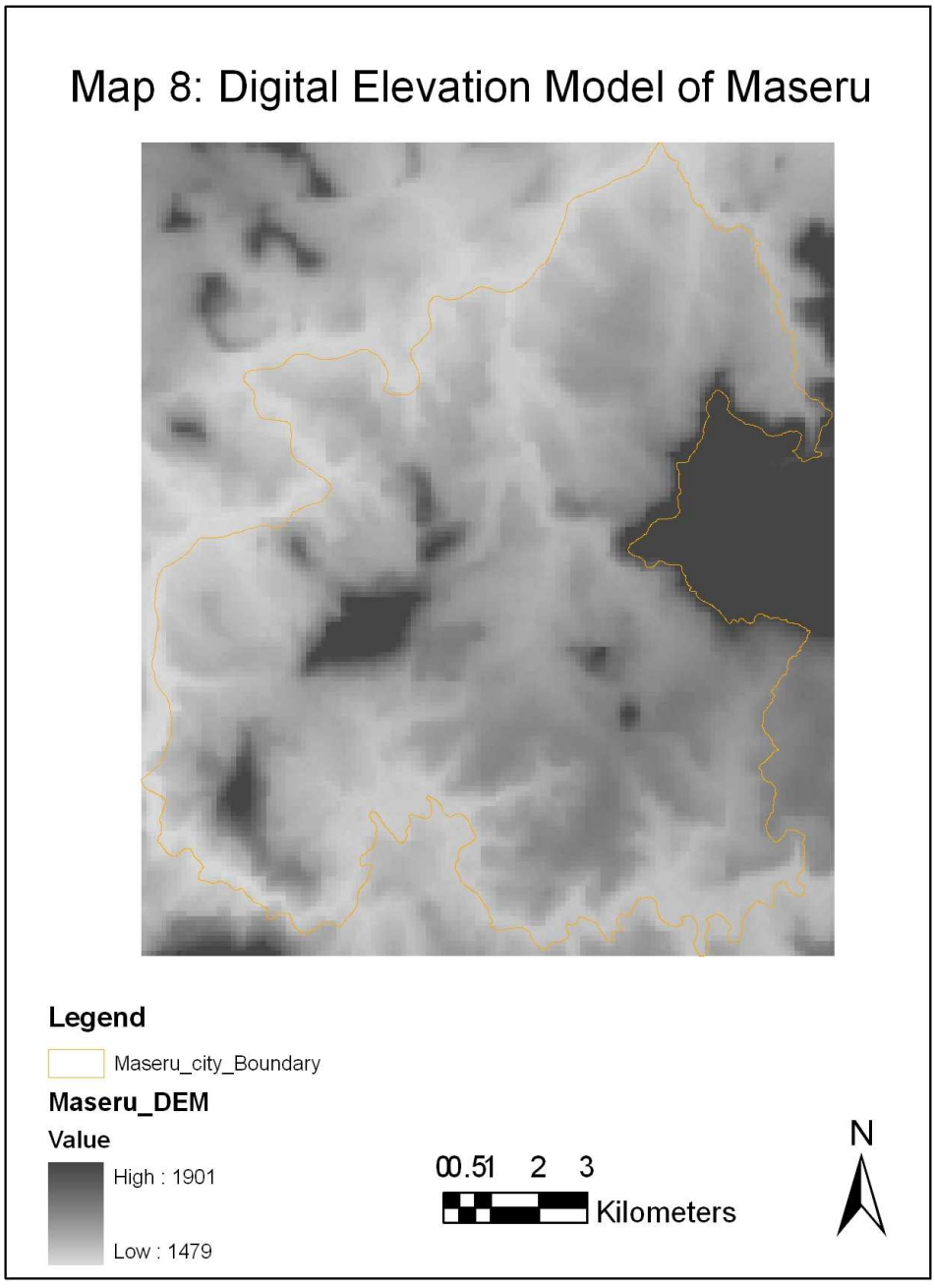


Figure 24: Map of Maseru Boundary with DEM

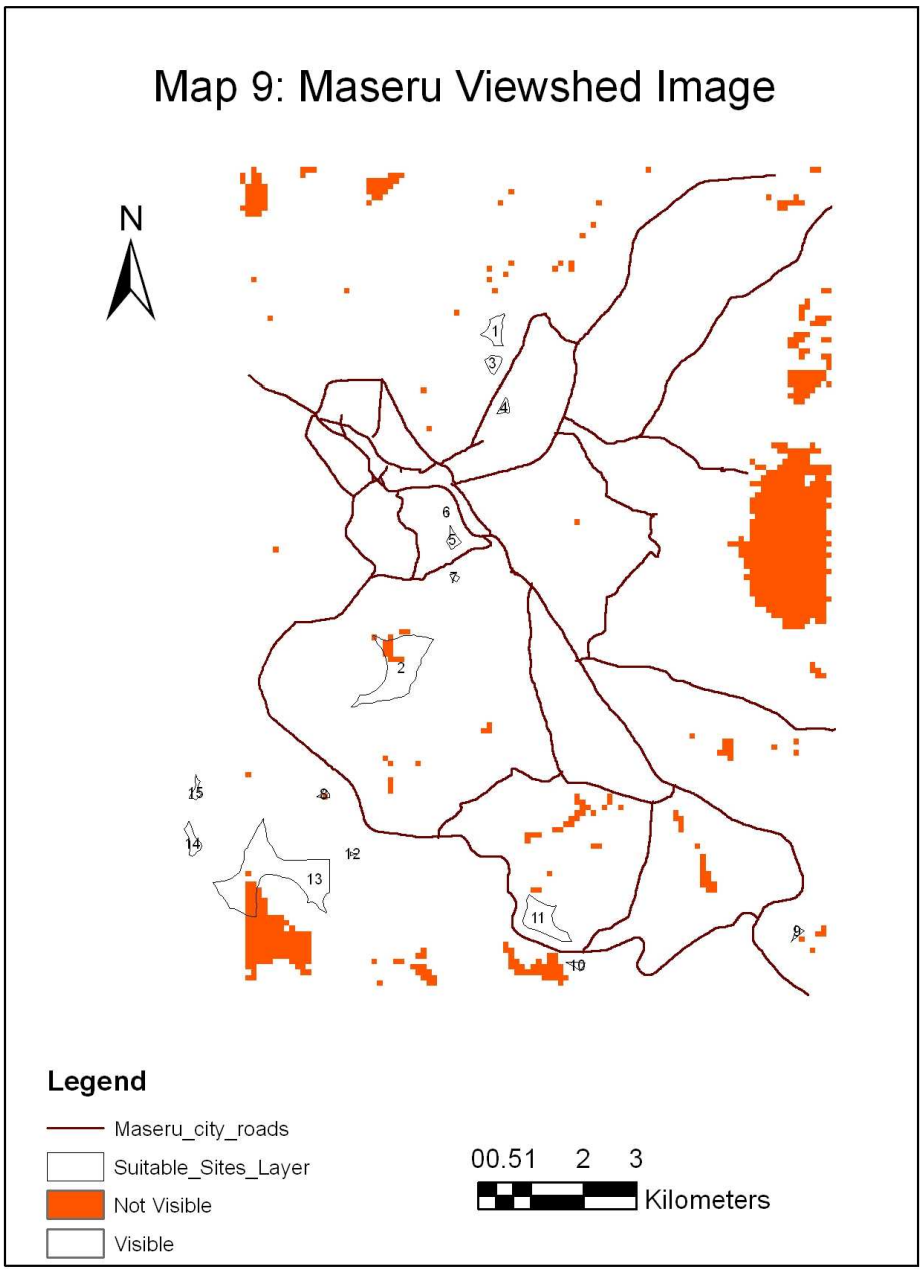


Figure 25: Maseru Viewshed Map

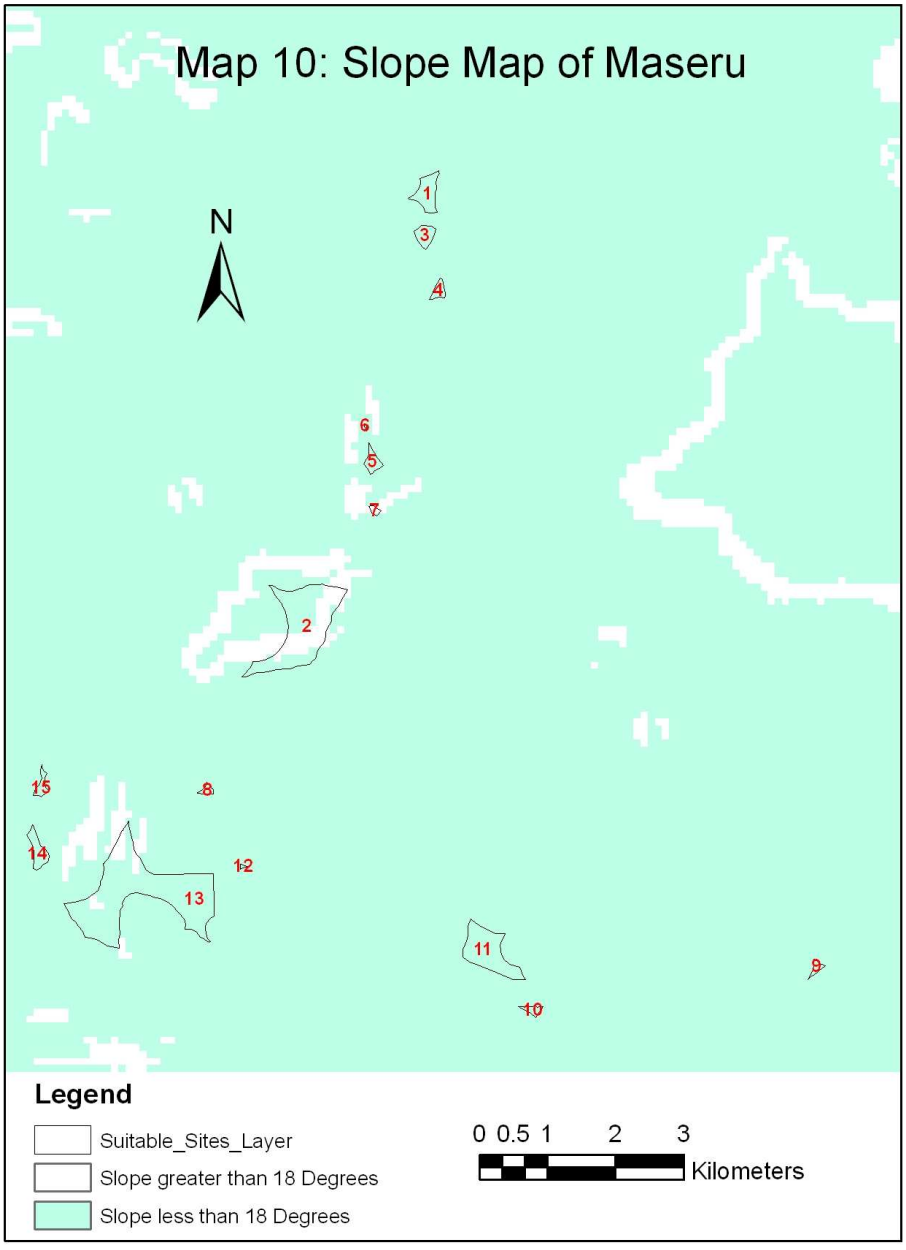


Figure 26: Slope Map of Maseru City

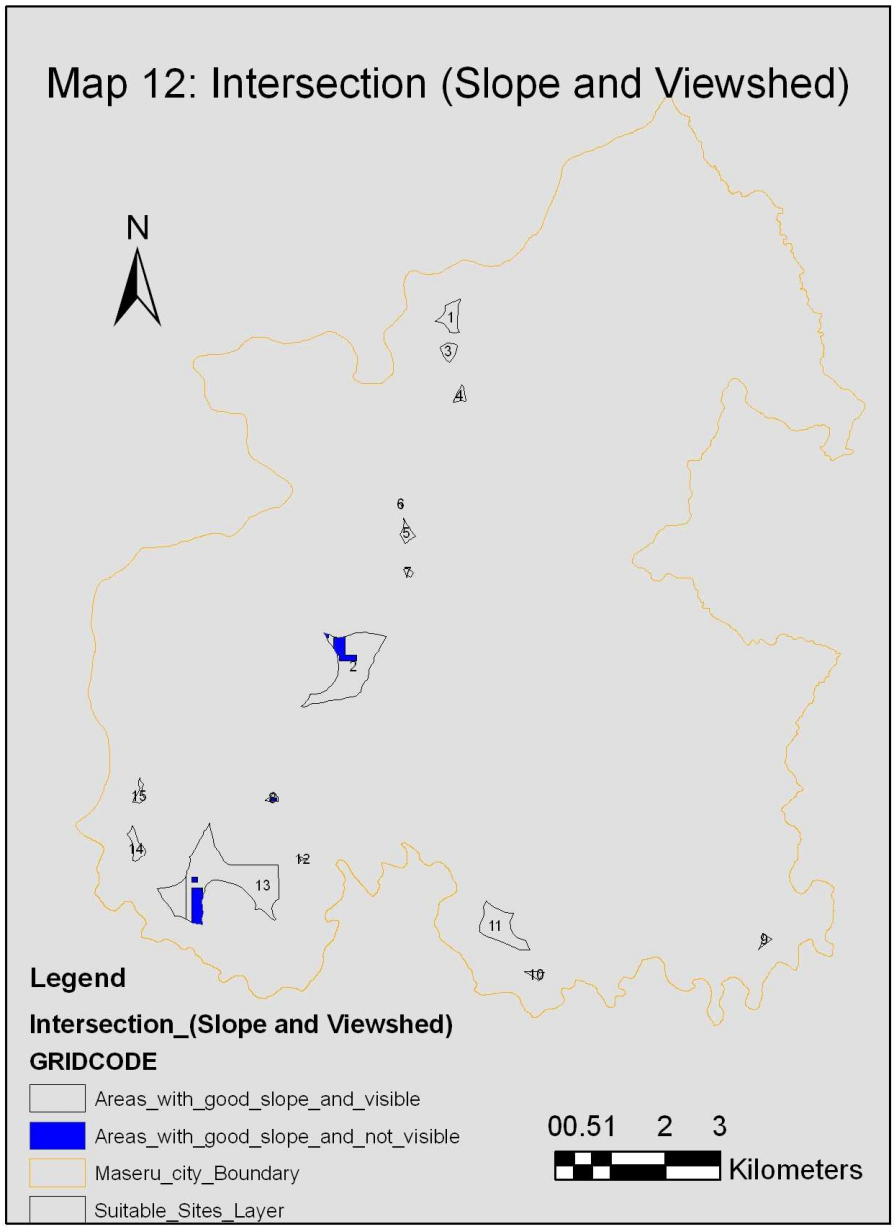


Figure 27: Areas with good slope which are not visible from the main roads

Results of areas, distance from the city center and the current land use of potentially suitable sites for construction of transfer stations are summarized in Table 3. Figure 26 shows the slopes image of potentially suitable sites for construction of transfer stations.

Table 3: Table that shows the characteristics of the potential suitable sites for construction of transfer station

Sites	Area (ha)	Current land use
1	13.96	Agric college fields
2	88.37	Plateau with tree plantation
3	7.16	Agric college Cropland area.
4	3.89	Airport Area
5	5.51	Construction of new parliament
6	0.18	Construction of new parliament
7	1.51	Plateau which has radio station towers.
8	2.24	Unused fields which are highly eroded.
9	2.26	Unused fields which are highly eroded.
10	2.70	Unused croplands and rangelands which are highly eroded
11	36.87	Croplands and rangelands which are highly eroded
12	0.43	Open space close to informal dumping site
13	150.16	Plateau
14	9.11	Croplands and rangelands
15	4.10	Unused croplands and rangelands

4.2 INTERPRETATION OF RESULTS

The results obtained from buffering for land use, rivers and roads show that 15 sites were potentially suitable for construction of transfer stations (Figure 23). One of the criteria for locating a site for a transfer station is to look for an area which can accommodate all the activities that will take place within the station. The activities that take place within a transfer station include movement, queuing, and packing of vehicles. Waste collection trucks can be more than 10 m long, while transfer trailers that move waste to disposal facility can be more than 15 m long (Environmental Protection Agency (EPA, 2002). These vehicles need wide roadways with gradual slopes and curves to maneuver efficiently and safely. Also, the site will need space for packing transfer vehicles and to allow incoming and outgoing traffic to flow smoothly without backing up onto public roads. Looking at sites **6** and **12** on Table 3, both sites are too small to allow outgoing, incoming and packing of such huge trailers.

When selecting a site for transfer facility, the potential for future increase in the daily amount of waste the facility will be required to manage, or added processing capabilities for recycling and diversion should be considered. It is usually less expensive to expand an existing transfer station than to develop a new site due to the ability to use existing operations staff, utility connections, traffic control systems, office space, and buildings. Looking at Table 3, sites **7**, **8**, **9** and **10** are big enough for a construction of a simple transfer station but they would not allow for expansion because the recommended size for a simple transfer station is about 2 hectares. As a result these areas would not be suitable for

construction of a transfer station whose services are intended to expand in the long run. Sites **3**, **5** and **15** are also big enough to allow for some expansion of the simple transfer station; however they would not be suitable for a highly technological facility as they would not allow for its expansion.

Topography factors affect the land use planning. The important factors associated with topography include aspect, elevation and slopes. Highly technological transfer stations are often multilevel buildings that need to have vehicle access at several levels. Completely flat sites need ramps or bridges constructed to allow vehicle access to upper levels (or areas excavated to allow access to lower levels). Sites with moderately sloping terrain can use the topography to their advantage, by allowing access to the upper levels from the higher parts of the natural terrain and access to lower levels from the lower parts. On the other side, sites with steep slopes might impose extra costs to the government associated with supplying the mountains area with facilities such as roads, water supply and electricity. Such sites are much more costly in comparison with the flat areas or moderately sloping terrain.

In this case, to address the criteria of topography, the use of a SRTM Digital Elevation Model (DEM) was used to determine the slopes of different sites. The results obtained show that sites **2, 5, 6, 7** and **13** would not be suitable for the construction of a transfer facility (Figure 26) as they have very steep slopes. There are no access roads to sites **2** and **13**, however they are relatively large in size. Therefore construction of transfer facilities on these sites will be expensive.

The waste can result in a serious visual pollution which could affect adjacent residential and recreational land uses. When selecting sites for a transfer station, it is very important to select sites which could not easily be seen from main roads. In this case almost all the suitable sites in Figure 23 are visible from the main roads (Figure 25). Proper maintenance of the station area is not sufficient to reduce or eliminate the problem of visual nuisance. To mitigate this problem some visual separation of the station from nearby land-uses has to be provided, such as a solid fence or wall, and planting trees around the transfer facility (Yitzhak, 1993).

The map of intersection of slope and viewshed (Figure 27) shows that sites **2** and **13** have both good slope and are not visible from the main roads. But both sites are on top of the plateau and are therefore on flat land and could not be seen from the main roads. As a result the sites could not be used for construction of transfer station.

Transfer stations generally require electricity to operate equipment, such as balers and compactors; lighting; water for facility cleaning, restrooms, and drinking; and sanitary sewer systems for waste-water disposal. Some smaller transfer stations use wells for water supply; and others especially in more rural settings, use septic systems or truck their waste water for offsite treatment. In this case all the sites selected have direct access to electricity.

The orthophoto images used were taken in 2005, since then there have been some developments. Considering current land use on the selected sites, it was found that besides sites **5** and **6** having very steep slopes, there was the construction of a new parliament

building on these sites (Table 3). Site **7** has radio and television towers, on site **12** there is the construction of a new industry. As a result all sites should be disqualified from being suitable for construction of transfer facilities.

Finally, the sites were ranked in descending order to indicate the priority of different options available to decision makers (Table 4)

Table 4: Ranking locations of suitable sites for transfer stations in descending order

	Sites
Appropriate	11 and 14
Fairly appropriate	1, 3, 8, 9, 10 and 17
Inappropriate	2, 4, 5, 6, 7, 12 and 13

CHAPTER 5

DISCUSSION AND CONCLUSION

Determining solid waste transfer stations involves many aspects, such as demography, environmental disciplines and economic policies. The combination of GIS and MCDM models has been found very useful in evaluating these aspects. The use of a MCDM model in this project provided a framework within which both quantitative and qualitative criteria were weighed and comparatively assessed. The method was less time consuming and more efficient, because all the data used were gathered from the orthophotos. Field work was significantly reduced. Combination of GIS and MCDM models were used in several studies to produce a land suitability map for different land uses. For instance, Eastman *et al*., (1993) used both GIS and MCDM to produce a land suitability map for an industry near Kathmandu using a raster GIS and AHP (Analytical Hierarchy Process) (Saaty, 1990). Pereira and Duckstein (1993) have used MCDM and raster GIS to evaluate a habitat for endangered species. In all the studies the combination of GIS and MCDM models were found to be efficient.

The list of criteria in the MCDM model used in this study could be used for other waste collection and processing facilities at the metropolitan or regional levels. In order to implement the model more effectively, the planner should possess a wide knowledge of the area under study in order to evaluate the data properly. However, there could be different

assessments of some of the criteria by decision makers because the method involves subjective judgement by the planner.

The MCDM model provides for the classification of many factors and thus makes it possible to include a large number of them in the analysis. The grading of these factors permits an evaluation of several opinions, and a counter evaluation by the public and by decision makers. In some instances it may even assist planners to link political opinions with factual information. Generally the technique can be considered to be good, and therefore useful in carrying out the exercise of selecting suitable solid waste transfer stations for Maseru city.

However, the method has some drawbacks. It is heavily based on the planner's subjectivity; as a result it could be misleadingly used by decision makers. Since Maseru is tightly constrained by its geographical position it was not very easy to find flat large open spaces which could be selected for construction of transfer stations. For instance the biggest areas obtained in the project were on top of the plateau and as a result they could not be used. The selected areas which were found to be suitable were relatively small in area.

It must be noted that the data set (orthophotos) used in this project was outdated as the photos were taken in 2005. Since then there have been some changes or developments on some of the areas. Groundtruthing was therefore done so as to overcome this challenge. The results obtained from the groundtruthing showed that in some of the areas that were selected as potential sites for transfer stations, there were some developments and the areas could no longer be considered suitable sites for transfer station.

Maseru produces a large quantity of solid waste and yet there are no proper solid waste management practices in the city. Consequently, the establishment of transfer stations at appropriate sites will improve solid waste management practices in the city. Moreover the city should consider implementing recycling programmes to supplement the solid waste management strategy. This will assist in reduction of solid waste taken to the landfill and thus prolonging its life span. Recycling may also create job opportunities. The programme of recycling has been used by other cities such as Viangchan in Laos (Dethoudom, 2004), and it has been found very useful.

The government of Lesotho should also adopt a more comprehensive educational media program to increase public awareness and stimulate their participation in solid waste management. The country should use television, posters, radio stations, and advertisements to encourage citizen participation in management of solid waste. Community leaders could also be used in their various communities as some of the people contributing in poor management of solid waste are illiterate. Public should also be made aware of the importance of recycling for human health, the economy, and the environment. The awareness campaign program should also encourage public to reuse useable materials, and promote products containing recycled materials. This could result in a significant reduction of solid waste in the streets and reduction in negative health and environmental impacts caused by poor solid waste management. The public should also be told on what type of waste should be separated and how to separate recyclables from non recyclables.

The public should also be encouraged to implement composting as good solid waste management. This would significantly reduce organic materials taken to the landfill and this can improve soil nutrients because solid waste in most of the developing countries consists of organic material. For instance, Hoornweg and Thomas, (1990), and Metin *et al*., (2003) found that the average municipal waste stream of developing countries consists of 50% of organic matter.

This study did not cover areas such as price of the land, population growth and waste generation. It is therefore recommended that other studies can look into these aspects in future.

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