The Construction of a Geographic Information Systems (GIS) Model for Landfill Site Selection

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A dissertation submitted in partial fulfilment for the requirements for the degree of

MAGISTER ARTIUM

In the

Department of Geography,

Faculty of Humanities

at the

University of the Free State

Bloemfontein

November 2007

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DECLARATION

"I declare that the dissertation/thesis hereby submitted for the degree (Masters of Arts in Geography [GIS]), at the University of the Free State in Bloemfontein, is my own original work and has not previously been submitted by me at another university/faculty. I further more cede that copyright of the dissertation/thesis in favour of the University of the Free State.

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ABSTRACT

In the past decade, locating landfill site has been recognized as a significant planning problem and has subsequently received much attention from researchers in the planning sector. In particular, the siting of landfills is becoming more of an issue due to the prevalent “not in my backyard” (NIMBY) and “not in anyone’s backyard” (NIABY) concerns from the public.

The purpose of this study, after identifying important criteria for siting landfills, was to develop a user-friendly landfill site selection model using a Geographic Information Systems (GIS) framework. Due to unavailability of electronic spatial data for Lesotho, Bloemfontein area was used as a test case. The model is tested in Bloemfontein with the intension to be applied in the city of Maseru as soon as the spatial data become available.

The three main objectives were to develop GIS criteria for locating the landfill, identify possible sites that were suitable for this type of development and evaluate the effectiveness of these GIS methods used in the study.

Production of constraint and factor maps took place. Afterwards, final suitability map was created using ArcGIS analysis tools. The optimum suitability map indicated that there were more optimal sites found within Bloemfontein city.

The results discovered in Bloemfontein city using the GIS-based study revealed that although highly suitable areas were limited, a site was still able to be chosen under the predefined parameters. The site is not located on, or near, any environmental interest areas and is located a significant distance away from streams and urban areas, which minimizes social conflict and environmental impacts.

The site is also located close enough (1-2km) to major road (N8) to Kimberley from Bloemfontein city and railroad, which ensures that economic costs of implementation are minimal. The selected region has a slope less than 12%, which are both an infrastructural advantage and a means of minimizing environmental impacts.

Furthermore, the landfill is located in an area within 22 kilometres of the Bloemfontein study area. Since the site is located in a highly suitable area, environmental, social, and economic concerns have been met.

Ultimately, the study proposes an acceptable landfill site for solid waste, taking Bloemfontein as the test study area. This research will contribute in developing Lesotho's spatial database of environmental and social information to assist in the formulation of environmental policy. It is also expected that such municipal GIS when planned and implemented efficiently with sufficient public awareness and support would be instrumental in bringing reforms at the local and national level, realizing a major improvement without much capital investment.

Keywords: Municipal solid waste, Geographic Information Systems, landfill, not in my backyard, not in anyone's backyard, site selection, lecheate, solid waste management, contamination, Multiple Criteria Evaluation, proximity, suitability.

OPSOMMING

In die afgelope dekade, is ongewensde fasiliteitsplasing erken as ’n beplanningsprobleem waarvan kennis geneem moet word. Gevolglik het dit baie aandag geniet van navorsers in die beplanningsektor. Die plasing van stortingsterreine word toenemend ‘n probleem as gevolg van die publiek se houding van “nie in my agterplaas nie” (NIMBY) en “nie in enigiemand se agterplaas nie” (NIABY).

Die doel van die studie was eerstens om belangrike kriteria vir die plasing van stortingsterreine te identifiseer en tweedens om ’n model te ontwikkel met behulp van ’n geografiese inligtingstelsel (GIS) vir die plasing van gebruikersvriendelike stortingsterreine. Te wyte aan die nie-beskikbaarheid van elektroniese ruimtelike data vir Lesotho, is die ruimtelike data van Bloemfontein gebruik vir ’n toetsstudie. Die model is getoets in Bloemfontein met die voorneme om dit in die stad Maseru toe te pas, sodra daardie ruimtelike data beskikbaar gestel word.

Die drie hoof doelwitte was om GIS kriteria te ontwikkel vir die plasing van stortingsterreine, om moontlike terreine wat geskik is vir hierdie tipe ontwikkeling te identifiseer en om die doeltreffendheid van die GIS metodes wat in hierdie studie gebruik is, te evalueer.

Beperkingskaarte en faktorkaarte is geteken. Daarna is ‘n finale geskiktheidskaart geteken deur gebruik te maak van GIS analise. Die optimale geskiktheidskaart het aangetoon dat daar meer geskikte liggings in Bloemfontein was.

Die resultate van die GIS-gebaseerde studie in Bloemfontein het aangetoon dat, alhoewel uiters geskikte areas beperk was, ’n terrein steeds gekies kon word binne die vooraf bepaalde parameters. Die terrein is nie geleë op, of naby, enige omgewingsbelangrike gebiede nie, en is geleë op ’n aansienlike afstand van strome en stedelike gebiede, wat sosiale konflik en omgewingsimpakte minimaliseer.

Die terrein is ook geleë naby genoeg (1-2 km) aan die hoofpad (N8) na Kimberley, sowel as die spoorlyn, wat verseker dat ekonomiese koste van implimentering minimaal sal wees. Die geselekteerde terrein het ’n helling minder as 12%, wat beide

’n infrastrukturele voordeel inhou, en bydra tot die verlaging van die impak op die omgewing.

Daarbenewens is die stortingsterrein geleë binne die 22 kilometer studiegebied van Bloemfontein. Aangesien die terrein geleë is in ’n uiters geskikte area, is alle omgewings-, sosiale en ekonomiese belange in ag geneem.

Laastens stel hierdie studie ‘n aanvaarbare terrein vir die storting van vaste afval voor, met Bloemfontein as proef studiegebied. Hierdie navorsing sal bydra to die ontwikkeling van Lesotho se ruimtelike databasis van omgewings- en sosiale inligting om te help met die formulering van omgewingsbeleid. Dit word ook verwag dat wanneer munisipale GIS soos hierdie effektiewelik beplan en geïmplimenteer word met voldoende publieke bewustheid en ondersteuning, instrumenteel sal wees om hervorming op plaaslike en nasionale vlak te bewerkstellig. Dit sal ’n groot verbetering teweeg bring, sonder te veel kapitale belegging.

Trefwoorde: munisipale vaste afval, geografiesie inligtingstelsel, stortingsterreine, nie in my agterplaas nie, nie in enige iemand se agterplaas nie, terreinselektering, loogwater, vaste afvalbestuur, besoedeling, veelvoudige kriteria evaluering, nabyheid, geskiktheid

DEDICATION

This work is dedicated to my late father, Teboho Eben-Ezer Thoso and my late mother Ma-Alice Naza Thoso, my wife-‘Mamoepi, my daughters - Nthomeng and ‘Mats’oloane, my sisters - Nthabeleng and Ntholelo, the Thoso Family, relatives and friends.

Without their support, I would not be where I am today.

STATEMENT OF PERMISSION TO COPY

In presenting this research study, in accordance with the requirements for the Master of Arts in Geography (GIS) degree at the University of the Free State, I agree that the Library shall make it freely available for inspection. I further agree that my supervisor/department may grant permission for extensive copying of this research study for scholarly purposes. It is understood that any copying or publication of this study for financial gain shall not be allowed without my written permission.

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ACKNOWLEDGEMENTS

Firstly, I give thanks and praise to GOD for everything that happened in my life.

Living and studying in the University of the Free State (UFS), South Africa for the last three years has been a great experience for me. Much of the work for this project as well as for my study programme could not have been completed without the help and support of many people. First of all, I would like to thank Dr Charles Barker, who is my supervisor. I am so deeply grateful to his help, support, and valuable guidance throughout this research and my study programme that I do not have enough words to express my gratitude. I also owe many thanks to Professor Peter Holmes, who is the Head of the Department of Geography without whose encouragement and support in the past years I would not have had an opportunity to complete this research.

Financial support for my study and this research from the Lesotho Government through the National Manpower Development Secretariat (NMDS) and the University of the Free State through the Faculty of Natural and Agricultural Sciences postgraduate grants is also greatly appreciated. I would also like to thank Mr Raphael Thuube (Lecturer - National University of Lesotho) and Mr Kali 'Nena (Lecturer - UFS) for their assistance and help in dealing with all research related problems and paper work.

The help and assistance of the staff of the UFS, Department of Geography, especially Mrs L Kronje for translating the abstract, course-mates, friends and my family is also gratefully acknowledged.

Lastly, many thanks are due to the Lesotho Ministry of Financial Planning and Development through the Bureau of Statistics, where I was working before joining UFS. Without their permission and support, it would have been impossible for me to study in South Africa.

TABLE OF FIGURES

ACRONYMS

BOS	Bureau of Statistics - Lesotho
CSIR	Centre for Scientific and Industrial Research
DANCED	Danish Cooperation for Environment and Development
DEA	Department of Environmental Affairs
DOE	United Kingdom Department of Environment
GIS	Geographic Information Systems
IAEG	International Association for Engineering Geology
LHDA	Lesotho Highlands Development Authority
LULU	Locally Unwanted Land-Use
MCE	Multi-criteria evaluation
MLM	Mangaung Local Municipality
MSW	Municipal Solid Waste
NES	National Environmental Secretariat - Lesotho
NIABY	Not in anyone's backyard
NIMBY	Not in my backyard
NMDS	Lesotho National Manpower Development Secretariat
PPIAF	Public Private Infrastructure Advisory Facility
SWM	Solid Waste Management
U.S.	United States of America
WASA	Lesotho Water and Sewage Authority
WB	World Bank

TABLE OF CONTENTS

CHAPTER 1

OVERVIEW OF THE STUDY

1 INTRODUCTION

This chapter presents the general idea of municipal solid waste in terms of the sources and the impacts of waste on the environment and on human health. The research problem studied, purpose of the study, hypothesis testing, and objectives of the study will be discussed. Finally, the study area will be described.

Increasing level of municipal solid waste is, nowadays, a serious problem in urban areas of the world. A high population growth rate and increasing per capita income have resulted in the generation of enormous municipal solid waste (MSW), posing a serious threat to environmental quality and human health. This is particularly relevant in the case of developing countries where large quantities of MSW are dumped haphazardly, thereby putting pressure on scarce land and water resources. At the same time, this adversely affects the health of human beings, mostly that of poor persons who have greater exposure to it (Chakrabarti, 2003).

According to Schubeler *et al*. (1996), MSW is defined as refuse from households, non-hazardous solid waste from industrial, commercial and institutional establishments (including hospitals), market waste, yard waste and street sweepings.

It has been estimated that approximately 80 percent (%) of the MSW generated throughout the world is land filled, although the figure for South Africa may be as high as 85% (Richards, 1989; DEA, 1991). Although the composition of land filled MSW varies considerably among countries of different socio-economic backgrounds, it usually includes organic material (such as paper and paperboard, wood, textiles, food residues and garden waste), as well as inorganic material (such as builders' rubble, metal, glass and plastics). Organic material consisting of cellulose, carbohydrates and proteins is readily decomposed by microbes into carbon dioxide

(CO_2) and methane (CH_4), and contributes some between 6 and 18% to global methane production (Bingemer & Crutzen, 1987).

1.1 CAUSES OF INCREASE IN THE GENERATION OF SOLID WASTE

McLain (1995) attributes the increase in solid waste generation to changes in lifestyles in the last 50 years. He observes that the increase in nuclear families (households consisting of a father, a mother and their children [siblings]) causes less bulk purchasing and more products packaged in small-serving portions. This accelerates the rate of after-consumption waste. Reliance on heavily packaged prepared foods is itself increasing due to a significant rise in women who participate in the labour force and the use of modern kitchen equipment.

Another substantial portion of the waste (particularly in developed countries) comes from non-durable paper, mainly used in copier machines and personal computers, as well as and the increasing use of junk mails.

Although MSW is thus seen primarily as coming from households, waste that comes from offices, hotels, shopping complexes, schools as well as municipal services is seen as significant. In overall, the major types of MSW are food waste, paper, plastic, rags, metal and glass, over and above hazardous household waste that includes electric light bulbs, batteries, discarded medicines and automotive parts (Lant & Sherrill, 1995).

1.2 STATEMENT OF THE PROBLEM

In today's society, finding a site to locate undesirable facilities is becoming a significant problem in the planning sector (Erkut & Moran, 1991). In particular, the siting of landfills is an issue due to prevalent "not in my backyard (NIMBY)" and "not in anyone's backyard (NIABY)" concerns from the public (Kao & Lin, 1996).

Siting of landfills is also important because of the imperative nature of landfills due to the expanding population and the corresponding volume of garbage (Or & Akgul, 1994).

1.2.1 General significance of facility siting

Facility siting is significant because it has social, spatial, economic, political, ecological and environmental significance. It is important to address these concerns associated in the siting of a landfill facility.

1.2.1.1 Social and Spatial significance

Within the social realm, services such as landfill sites are necessary as part of today's society. In this manner, their spatial location needs to be carefully planned in order to satisfy the needs and wants of the population (Duarte & Roche, 1998). Most often, social concerns such as distance from urbanized areas (residential or commercial) and distance from historical, cultural, or natural/recreational sites need to be addressed. This is owing to the common mentality of the general population, known as the NIMBY, and which also influences the selection process (Lant & Sherrill, 1995). Therefore, planners and government organizations have to place a facility where it will not result in the deterioration of the quality of human life, with long-term impact on future generations of particular concern.

Many barriers to siting landfills have existed in the past, with a vast majority proven to still pose a problem today. The greatest barrier that facility site planners face is the spatial problem itself, which comprises of finding a location for the site that satisfies everyone (Mummolo, 1995). However, the main social challenge is to deal with outraged members of the community who do not want a facility to be located in their neighbourhood. This is a common occurrence when dealing with landfills and other types of disposal sites (Kao *et al*., 1996).

1.2.1.2 Political significance

Political factors also play a role in facility sitting, especially when locating a waste disposal site. It has been observed that politicians generally have a say at some point in the planning process when locating a facility (Martin & Williams, 1992). Furthermore, political boundaries can be a cause for concern when determining where to locate a facility such as a landfill. For instance, the planner has the challenge of determining which site can best serve those within certain boundaries, usually defined by political divisions (Morrison & Abrahamse, 1996).

1.2.1.3 Economical significance

The other challenge to be considered is economic influence. It is usually difficult to find suitable land to develop a landfill that is reasonably close to the garbage source (e.g. urban area). Economic considerations can play a bigger role when the only option is to transport the garbage elsewhere (Carter, 1991). Furthermore, from an economic perspective, consideration must be given to the availability of land as well as the accessibility to the proposed location via road networks. The ideal landfill site located at an adequate distance from the waste source to maintain economic feasibility yet is far enough from the waste source (urban areas) to reduce social conflict. Developments on or too close to existing road and rail networks would hinder transportation and may have an impact on tourism in the region (Zeiss & Lefsrud, 1995).

1.2.1.4 Ecological and Environmental significance

According to Bodhankar & Chatterjee (1994), facility siting is also ecologically significant as it has a large impact on the surrounding environment. For example, landfills have been known to contaminate drinking water wells, groundwater aquifers and nearby streams. Nagar & Mizra (2002) also highlight that the ecological effects of any site proposal must be considered, as a site could have the potential to release chemicals into nearby waterways and tributaries via ground leaching, which could ultimately contaminate wetlands or fish habitat.

The final barrier in facility siting is finding a location that would have the least impact on the environment (Basagaoglu *et al*., 1997). Landfill sites have the potential of harming surrounding natural water systems such as groundwater and surface waters. Groundwater contamination could occur if the water table is in close proximity to the surface. Surface water contamination could occur as a result of runoff due to a steep sloping surface (Dikshit *et al*., 2000). These environmental factors are among many of the concerns that need to be considered in the site selection process (Kao & Lin, 1996).

1.2.2 Waste disposal problems facing Lesotho

Urban centres in Lesotho are confronted with a chronic problem of waste collection and disposal. This is due to the fact that such areas have high rates of consumption of resources and as such generate increased amounts of waste. Solid waste disposal is of particular concern with indiscriminate dumping along the major roads, gullies, forests, and any open spaces (Molapo *et al*., 2002).

1.2.2.1 The Maseru perspective

The majority of the population of Lesotho has until recently resided in rural areas, with the city of Maseru being the only urban centre in the country. (BOS, 2002) highlights that recent trends towards urbanization have resulted in increased population movements to Maseru and other large centres around the country. This trend has resulted in increased pressures on services such as waste management and disposal. Because domestic waste often lays uncollected, it forces residents to illegally dump or burn it, resulting in serious environmental pollution.

Ambrose (2006) states that the Maseru City Council (MCC) is currently using the site at Ha Tšosane just below Lancers' Gap village for waste disposal. This site is 5km east of the city centre, where a wide dolerite dyke, quarried in the past for road building material, has left a large trench into which waste can be conveniently disposed of. However, this is far from an ideal site. For a start it is in what has become a built up area, with houses located within 25 metres of the dumping area with associated health risks and offensive smells. Secondly, the dump site frequently catches fire, either as a result of deliberate action or from spontaneous combustion of decaying waste matter.

On still days, the smoke spreads slowly across neighbouring housing areas creating a health hazard, both for those with respiratory complaints and also because burning plastic materials can generate carcinogenic dioxins (Molapo *et al*., 2002). Third hazard comes from the runoff from the area, which occurs when heavy rain causes runoff from the site.

The rain water filtering through the many different discarded materials, ranging from car batteries to factory waste, becomes a toxic solution which feeds into the Maqalika Reservoir, Maseru's water supply (Ambrose, 2006).

1.3 PURPOSE

The purpose of this study, after identifying important criteria for siting landfills, will be to construct a user-friendly landfill site selection model using a Geographic Information Systems (GIS) framework. Due to unavailability of electronic spatial data for Lesotho, Bloemfontein area was used as a test case. The model is tested in Bloemfontein with the intension to apply the model in the city of Maseru as soon as spatial data become available.

1.3.1 The applicability of Bloemfontein as a study area

Bloemfontein and Maseru are both situated in the southern part of the Africa continent and lie between the Southern latitudes 28° and 30° at an altitude of roughly 1,390 and 1,500 meters, respectively. They experience continental climate with hot summer days and cold, dry winters, often with severe frost.

According to Mangaung Local Municipality [MLM] (2003), Bloemfontein is the capital of the Free State province in the Republic of South Africa. It is centrally situated roughly in the middle of the Province, as well as in South Africa. The city is also the economic hub in the Province, with an economy based mainly on services and government. It lies on a high plateau at an elevation of about 1,392 m and is spacious, sprawling over hills and hill rocks “kopjes”.

Waste has generally been regarded as an inevitable consequence of rapid growth and expansion of human activities. In this manner, waste generation in both cities can be seen as being driven by expanding populations, effects of the economy and increased production of goods.

National Environmental Secretariat – Lesotho [NES] (1997) and MLM (2003) stipulate that the volumes of waste generated cannot be accurately determined by means of current record keeping systems due to problems observed with systems. These systems calculate waste in the form of truckloads per day, and the problem is that the trucks can be empty or overloaded and one cannot determine the difference. Another limitation is that the waste sites do not have weigh-bridges and there is no access control, thus making it difficult to determine the size of the waste stream generated.

MLM (2003) also confirms the significance of the total waste stream, as it cannot be measured. Concerning estimates, the total waste generated by MLM per year, based on a 260 day working year, is approximately 295 620 tons per annum.

Maseru is the capital town of Lesotho, and has an area of 4,279km^2 and a population of approximately 477,599 (BOS, 2001). Maseru represents about 23 percent of the population of Lesotho (BOS, 2002). Lesotho generated about 143,000 tons of waste in 2001(WB & PPIAF, 2004) with Maseru contributing about 38 800 tons of solid waste. With the city contributing the bulk of total waste, it thus makes sense that Bloemfontein will be used as a case study as has been described.

1.4 OBJECTIVES

The objectives for the research project are as follows:

1.4.1 To determine important criteria for locating a landfill site

In order to identify appropriate placement for a landfill site, a diverse range of criteria must be employed in a Geographic Information Systems (GIS) analysis. It is important to take a holistic approach and incorporate criteria from the social, spatial, economic, political and ecological realms of the problem (Kao & Lin, 1996).

1.4.2 To identify possible suitable locations for a landfill site

The GIS approach is going to be utilized to determine the most suitable area for landfill sites. ArcGIS will be used due to its efficient ability to perform a land suitability analysis. The factor maps will be weighted in the analysis and then combined (overlaid) with constraint maps.

1.4.3 To evaluate the effectiveness of the model as a siting tool in landfill site selection

The use of a GIS model to find a suitable landfill site using multiple evaluation criteria has many advantages. GIS is a powerful tool that enables organized and systematic analyses of spatial data. GIS technology is also effective in handling large amounts of complex geographic data and significantly aiding the facility siting process (Dikshit *et al*., 2000). Its ease of use and comprehensive display also allows for user-friendly operational tasks.

Other advantages of applying GIS in landfill siting process include an objective zone exclusion process (according to a set of provided screening criteria), flexibility for implementing “what-if” data analysis and as such investigating different scenarios related to population growth, area development and visualization of results through graphical representation (Schubeler, 1996).

1.5 HYPOTHESIS TESTING

Setting up hypotheses is an essential part of statistical inference. In order to formulate such a test, usually some theory has to be put forward, either because it is believed to be true or because it is to be used as a basis for argument, but has not been proved. For example, claiming that this constructed GIS framework can be applied in the city of Maseru and other Lesotho districts. This postulation mainly helps to confirm or invalidate the spatial data that can be amassed for the Lesotho districts.

It is, therefore, postulated as follows in this study: if Lesotho municipalities, for example, Maseru city adopted a similar GIS model as created for Bloemfontein, then the current landfill sites selection model would be improved, thereby reducing the environmental, social, economic and political problems as presented in the problem statement.

The alternative hypothesis, H_1, is a statement of what a statistical hypothesis test is set up to establish. In Bloemfontein, the developed GIS landfill siting framework is more applicable than in the Maseru city when using the same criteria.

1.6 STUDY AREA

The study area (Bloemfontein city) of the Mangaung Local Municipality (Figure 1.1) is located mainly in the Free State Province (Figure 1.2). Bloemfontein (the Free State's capital city) is situated on dry grassland at 29°06′S 26°13′E, at an altitude of 1,395 meters above sea level. The city is home to 369,568 residents, while Mangaung Local Municipality has a population of 645,455. It is geologically found in the Karoo Sequence, falling under the subgroup with an Adelaide rock formation that has a lithology of mudstone (Van Riet *et al*., 1997). The study area (Figure 1.3) will only consider areas within the radius of 25 kilometres from Bloemfontein urban built up area.

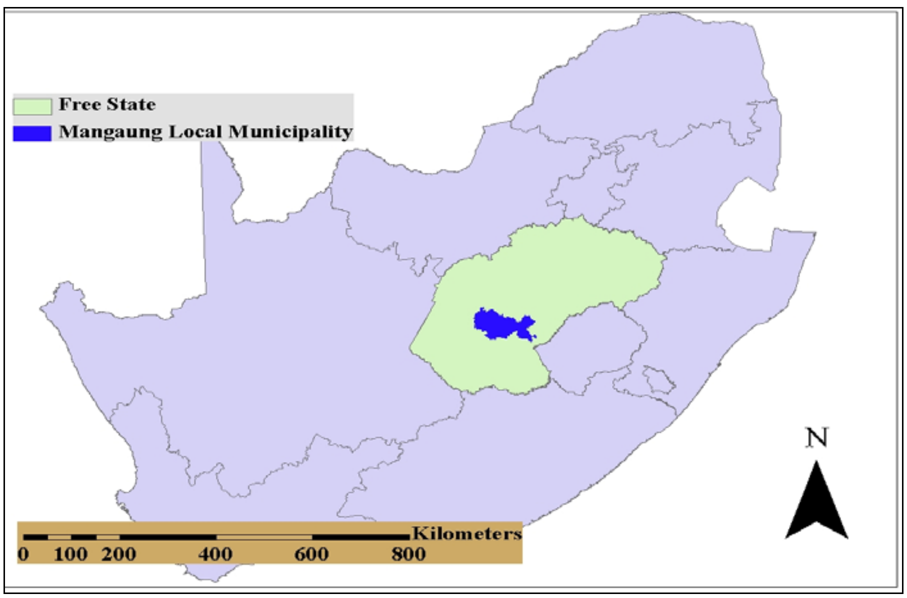


Figure 1.1: Map of South Africa depicting Mangaung Local Municipality

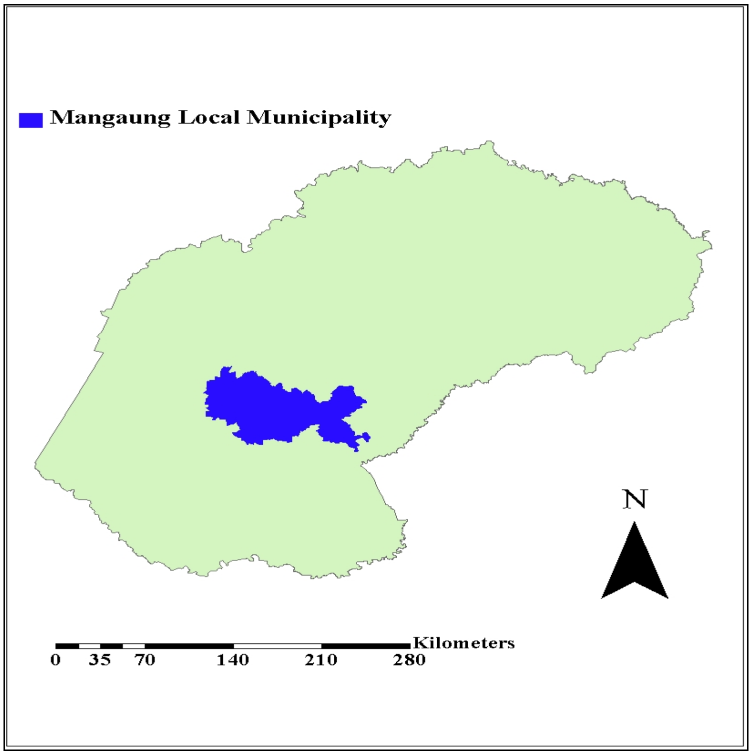


Figure 1.2: Map of Free State Province

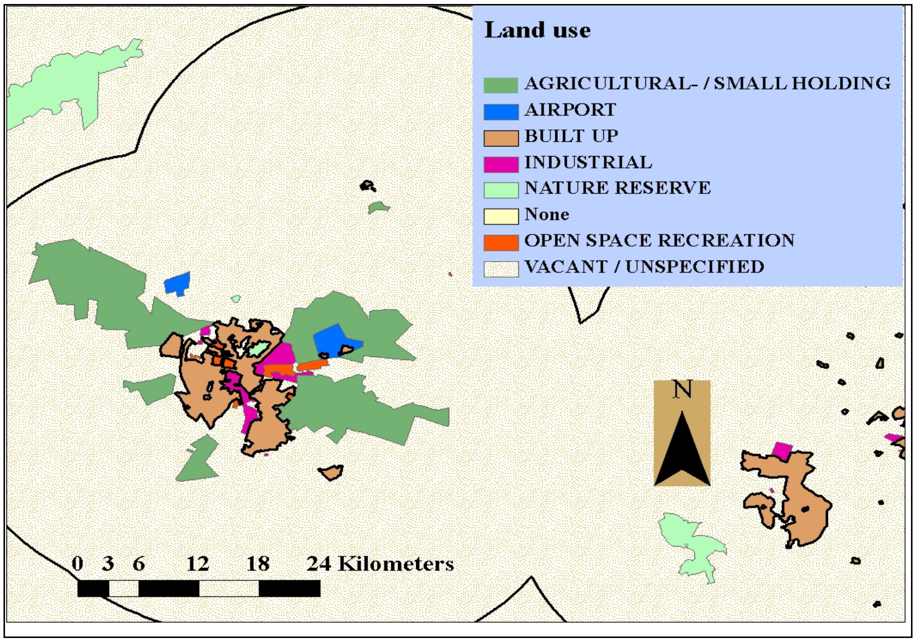


Figure 1.3: Bloemfontein Study Area Map

1.7 IMPORTANCE OF MAPS TO THE RESEARCH

Figure 1.1 depicts the Free State Province which is one of nine provinces in the Republic of South Africa and is centrally located in terms of the geographic distribution of South Africa. Figure 1.2 portrays an existence and a location of Mangaung Local Municipality within the Free State Province, while Figure 1.3 illustrates the Bloemfontein study are including the nearby towns. The importance of these maps is that they act as invaluable guides to help us interpret the spatial information gathered. Yi-Faai *et al* (1962) added that maps are the most effective means of showing spatial relationship used mainly to present conclusions drawn from the findings of completed research.

CHAPTER 2

LITERATURE REVIEW

2 INTRODUCTION

Chapter Two discusses the most relevant studies found in the literature that related to the stated problem. Problems associated with urban waste management and current waste management techniques in developing countries are discussed. Uses of GIS in waste management and the factors that are applied to determine potential landfill sites are as well showed. Furthermore, the situation of the Lesotho dump sites is looked into.

Landfill sitings are an extremely difficult task to accomplish in the world today. The lack of ability to properly site landfills has led to a great deal of controversy and negative effects. Public awareness of environmental impacts, and distrust for scientific studies to determine siting locations, might certainly leave waste managers with little room for error. With every passing year annual rates of waste disposal have increased and suitable land has decreased significantly (Mongeon & Webb, 2002).

Facility siting is by no means an original problem, nor is it one with a single approach, although one method is to use GIS which utilises two kinds of information. The first is use of spatially based data and attribute data which are linked within a GIS framework. The second is non-spatial information about the background geographical data (Bahaire & Elliott-White, 1999).

Often, projects with numerous variables are best approached in GIS using a multi-criteria evaluation (MCE) (Mondrego *et al.*, 2000). The MCE is particularly effective as it allows for designation of suitability values to portions of the study area so as to determine which sites would be best suited to meet all criteria. The main software package used for this analysis is ArcView an ESRI product, which uses various extensions to broaden both its power and applications.

Bloomfield (2000) highlights two extensions, which are particularly useful when conducting a facility siting analysis, namely, Spatial Analyst and Model Builder. These tools can be used to construct both constraint and factor maps that can in turn be combined to find suitable regions in the final analysis. The region, which contains the most advantageous combination of the requirements, is then selected in the final decision for project development

2.1 URBAN WASTE MANAGEMENT

Management of solid waste is one of the challenges facing urban areas in the world. This is because an aggregation of human settlements has the potential to produce a large amount of solid waste. Collection, transfer and disposal of such waste have been generally assumed by municipal governments in developed countries. The format varies, however, as in most urban areas, garbage is collected either by a governmental agency or private contractor, and this constitutes a basic and expected government function in such contexts. Municipal solid waste management has thus become a major issue of concern for many under-developed nations, especially as populations increase (Bartone, 2000).

The problem is compounded as many nations continue to urbanize rapidly. For instance, 30-50% of population in most developing countries is urban (Thomas-Hope, 1998) and in many African countries, the growth rate of urban areas exceeds 4% (Senkoro, 2003). Although developing nations do spend between 20% and 40% of municipal revenues on waste management (Thomas-Hope, 1998; Schubeler, 1996; Bartone, 2000), they are often unable to keep pace with the scope of the problem. Senkoro (2003) added that when the governments of African countries were asked by the World Health Organization to prioritize their environmental health concerns, results revealed that while solid waste was identified as the second most important problem (after water quality), less than 30% of urban populations have access to "proper and regular garbage removal".

2.2 CURRENT SITUATION IN DEVELOPING COUNTRIES

Municipal solid waste management is one of the major problems facing city planners all over the world. The problem is especially severe in most developing country cities where increased urbanization, poor planning, and lack of adequate resources contribute to the poor state of municipal solid waste management (Obirih-Opareh & Post, 2002; Mato, 1999; Doan, 1998; Mwanthi *et al*., 1997).

In Africa, rapid urban growth since the 1960s has put pressure on land resources within the areas surrounding cities, and has led to increased generation of waste. The problem is aggravated by the open dump nature of disposing waste especially in the slum areas of most African cities (Hammer, 2003).

Traditionally, administrations in African states permitted uncontrolled dumping in abandoned quarry sites with no provision for sanitary landfill, causing huge health problems (Mato, 1999; Hammer, 2003). A large part of the problem is inadequate financial and data resources for site selection and management (Mwanthi *et al*., 1997).

Public administration of waste collection is also inadequate for a variety of reasons which led most administrations to privatise the service, where private cost recovery seems to indicate a better solution (Obirih-Opareh & Post, 2002). These problems have resulted in serious environmental and social complications (Arinola & Arinola, 1995; Moore *et al*., 2003).

Developing countries thus have solid waste management problems that differ from those found in fully industrialized countries. Indeed, the very composition of their waste is different from that of developed nations. For instance, it has been noted that low-income countries' solid waste generation rates average only 0.4 to 0.6 kg/person/day, as opposed to 0.7 to 1.8 kg/person/day in fully industrialized countries (Blight & Mbande, 1996; Arlosoroff, 1982). Blight & Mbande (1996) and Arlosoroff (1982) also note several common elements in the composition of solid waste in developing nations. These include:

- Waste density 2-3 times greater than industrialized nations;

- Moisture content 2-3 times greater;
- Large amount of organic waste (vegetable matter, etc.);
- Large quantities of dust, dirt (street sweepings, etc);
- Smaller particle size on average than in industrialized nations.

These elements are more meaningful when contrasted with the situation in industrialized countries and, as a result, must be viewed both in terms of the additional problems they present as well as the potential opportunities which arise from their waste composition.

2.3 USES OF GIS IN WASTE MANAGEMENT

The role of GIS in solid waste management is very large as many aspects of its planning and operations are highly dependent on spatial data. In general, GIS plays a key role in maintaining account data to facilitate collection operations. In this manner, aspects such as customer service; analyzing optimal locations for transfer stations; planning routes for vehicles transporting waste from residential, commercial and industrial customers to transfer stations and from transfer stations to landfills; locating new landfills and monitoring the landfill, are important. GIS is a tool that not only reduces time and cost of site selection, but also provides a digital data bank for future monitoring programme of the site (Tomlison, 1990).

According to Barron (1995), GIS analysis of waste composition, degree of compaction and resulting density along with volumetric changes during land-filling, can ensure that the most efficient placement method is used and maximum capacity is achieved. GIS can also play an important role in the long term environmental monitoring of closed landfill sites.

The land-filling process allows many opportunities for using GIS, from displaying the outline of the void, to calculating areas of geo-membrane liners required, volumes of clay for the lining, volumes of cells to be filled, locations of lecheate pipes and gas wells, etc. (DOE, 1986).

2.4 FACTORS USED TO DETERMINE POTENTIAL LANDFILL SITES

2.4.1 Geomorphology

Since groundwater contamination issues are a major concern, geologic characteristics of a site are an important consideration. A key factor in decreasing the potential for contamination is the geomorphic characteristics or subsurface geology of the area. Earth material with low hydraulic conductivity, low effective porosity, and high retention (absorption, adsorption) of hazardous solutes are ideal for landfill locations (Atkinson *et al*., 1995; Dorhofer & Siebert, 1998).

2.4.2 Proximity to Water Sources

Landfills create noxious gases and leakage that make them unsuitable to be in proximity to surface waters (Erkut & Moran, 1991; Dorhofer & Siebert, 1998). If any landfill site were to leak waste-related chemicals into surrounding water, streams, or reservoirs, contamination would occur. The result would be the transfer of hazardous chemicals into drinking water, where reagents such as viruses and toxins could develop (Bodhankar & Chatterjee, 1994). This would pose a serious health hazard to all organisms dependant on the water, and could also bio-accumulate chemicals within the native species of the area.

2.4.3 Land-Use

The importance of minimizing the association of conflicting land-uses in landfill siting can be realized by reviewing Locally Unwanted Land-Use (LULU) areas. Public acceptance of unwanted facility sitings vary with land-use (Baban & Flannagan, 1998). Land-use of lowest value in public opinion reduces conflict over higher valued land-uses.

2.4.4 Land Value

Economic factors for landfill sitings are based in three areas, explicitly, acquisition costs, development and operation costs of each site (Erkut & Moran, 1991). Capital costs associated with the acquisition of the landfill must be matched by the capital investment put into the project in order for the landfill site to be approved.

Acquisition costs connote the consideration or compensation paid for acquisition of land, or on the expropriation of land, or the value thereof other than the value of any service or benefit that accrues to, passes to, or is provided to the persons from whom the land is acquired at the expense of the authority for which the land is required.

U.S. Department of Housing and Urban Development (2007) adds that in some cases the land and existing structures will have already been acquired. If the land and existing structures are being refinanced or reimbursed as a part of the development, then enter the relevant acquisition cost. However, if land and existing structures have already been acquired and the project is focused on renovating, demolishing, or otherwise developing the site, then it is not necessary to enter acquisition costs.

According to DWAF (2005), there are 10 considerations under economic criteria. These consist of:

- The possible incorporation of the site into the waste disposal system, either immediately or in the future.
- The economies of scale. Larger sites are economically more attractive.
- The distance of the site from the waste generation areas. This is directly proportional to transport costs.
- The size of the operation. A disposal site must cater for the disposal of the waste stream over at least the medium term to justify the capital expenditure.
  In addition to the size of the landfill proper, the anticipated extent of the ultimate buffer zone should be considered.
- Access to the landfill site. This has cost convenience and environmental implications, especially if the roads have to be considered.

- The available of on-site soil to provide low cost cover material. Importation of cover increases operating costs and cover shortage may reduce site life.
- The quality of the on-site soil. Low permeability clayey soils on site will reduce the cost of containment liners and lecheate control systems.
- Exposed or highly visible sites. High visibility results in additional costs being incurred for screening.
- Land availability and/or acquisition costs. These dependent on present or future competitive land-uses such as agriculture, residential or mining.
- Other miscellaneous economic or socio-economic issues, e.g., where the displacement of local inhabitants must be addressed.

2.4.5 Slope

It is desirable to have a topographic surface that tends to shed water to reduce pounding and incident infiltration. Erkut & Moran (1991) state that if the slope is too steep, it is difficult and costly to construct the landfill. Slope is also an important factor when siting a landfill since higher slopes would increase runoff of pollutants from the landfill, and thereby contaminate areas further away from the landfill site (Lin & Kao, 1999). As a matter of fact, Lin and Kao's study (1999) suggests that a slope less than 12% would be suitable for the prevention of contaminant runoff.

2.4.6 Soil Properties

Certain soil characteristics promote a safer and more economically feasible implementation and operation of a landfill. Permeability, effective porosity, and workability are important soil considerations (Atkinson *et al*., 1995).

Texture analysis, therefore, allows for soils to be characterized based on the above-mentioned characteristics. Soils with high silt and clay fractions provide groundwater protection and are an economically cheaper means to construct a landfill liner. Erkut & Moran (1991) and Dorhofer & Siebert (1998) emphasize that if clay is not available at a location, it must be hauled to the site or substituted with a geosynthetic system to maintain water quality levels.

2.4.7 Economic Distance Cost from Population Centres

Costs associated with economic distance relate to additional costs that come into the picture when development has to be located at a considerable distance from the source of the waste. Having close proximity to the source gives a lower long-term economic cost, since lengths of hauling the waste are decreased and are also more economically suitable (Baban & Flannagan, 1998).

2.4.8 Distance from Population Centres

Social and political opposition to landfill siting has been indicated as the single greatest impediment to successfully locating waste disposal facilities (Lober, 1995). The NIMBY phenomenon, described in greater detail by Erkut & Moran (1991), Lober (1995), and Kao & Lin (1996), is both an important consideration and restraint to landfill siting. The external cost and undesirable characteristics of landfills often cause people to perceive the hazards and risks as outweighing the long-term benefits (Baxter *et al*., 1999).

Transportation, noise and congestion, lower property values, and lessening of community or personal self- image are the high costs perceived by the public (Lober, 1995). Costs and benefits are found to be directly proportional to the extent that an increase in the distance at which one lives from an undesired facility reduces the amount of perceived costs.

2.4.9 Proximity to Recreational Areas

Sites which are located within or adjacent to important recreational or tourism-related activities are less desirable. However, landfill activities can be visually buffered and operated to minimize intrusions. This criterion also includes minimal consideration for historic resources (Guam Environmental Protection Agency, 2004).

2.5 GIS PROJECTS IN FACILITY SITING

Methods of designing spatial models for site planning were first discussed over 30 years ago before the advent of automated geographic information systems (McHarg, 1969). Recently, the process for locating a site has made extensive use of the Geographic Information System (GIS) projects. Below are local and international studies/projects conducted with respect to landfill sites selection with an aid of GIS technology.

2.5.1 Solid Waste Site Selection Criteria for Niamey, Niger

The aim of this project was to use GIS and remote sensing techniques to identify appropriate areas suitable for waste disposal at Niamey, Niger. It provides a selection of environmentally friendly disposal sites, thus supplying reasonable, convenient and administratively transparent solutions to the waste disposal problem (Twumasi *et al*., 2005).

A number of essential factors were considered in locating landfill sites. Such factors included both physical and social environments. McKechnie *et al*. (1983) documented six factors that constitute these essential factors: topography, climate, hydrology, cover material (land cover), geology, and land uses.

Due to data constraints, Twumasi *et al*. (2005) used topography, hydrology, cover materials, existing housing and land development (roads etc.) of the area as guides to site selection. Criteria were specified to assume that dumpsite would be outside the buffer zone of the hydrology, forested areas, roads and existing housing. These criteria were:

- 300 meters away from the main road;
- areas less than or equal to 230 square meters based on the contour map;
- minimal noise contamination from truck movement;
- 300 meters away from water bodies;
- located in area not crossed by major roads;
- not located in areas of active agricultural land or near land under development and
- 40 kilometres away from the nearest population centres.

Different layers relating to these criteria were used to compare maps and located areas which conform to the criteria. It was emphasized that these were the criteria used to solve the siting problem at Niamey. The nearest population centre was the city of Niamey itself. Manu *et al*. (2004) outlined that if these criteria were to be applied to other siting problems, it would be necessary to modify them in light of the new geographic and demographic constraints. Thus, for some urban areas, it may not be possible to find a site more than 40 kilometres from the nearest population centre; but siting may be possible if the critical separation is reduced to 20 kilometres.

Different layers such as water, road networks, wells, market centres and vegetation were overlaid. Two Boolean operations were performed using the topographic data. One was the area with height less than or equal to 230 meters, and the other with area greater than 230 meters. The final landfill sites also felt within the topography of 230 meters or less. It also showed buffer of 300 meters distances away from the major road network, vegetation (tiger bush) and water (Twumasi *et al*., 2005).

2.5.2 Identification of suitable landfill sites in Western Cape

The Centre for Scientific and Industrial Research (CSIR) South Africa was appointed by Spoornet South Africa to conduct the study with the aim to identify suitable areas for a regional landfill site in the Western Cape Province using Geographic

Information System (GIS) Technology. The information was required by Spoornet as part of a “pre-prefeasibility” study aimed at assessing possible options and strategies regarding the establishment of a waste-by-rail scheme in the province (Conrad, 1997)

In the first place, Frantzis (1993) states, that all areas were excluded where the establishment of a waste disposal site would not be permitted. Examples of exclusionary criteria used are close proximity to residential areas, airfields, mountainous areas, nature reserves, indigenous forests, geological faults, the coast, dams or rivers.

Once these areas had been identified, the remaining areas were then rated according to the nature of the geology, depth to groundwater, soil texture and soil depth. From the combination of these criteria favourable areas were identified (DRASTIC, 1987).

There were a number of factors that could not be included in the study, such as the location of water resources used for public water supply, the agricultural potential, land use, location of archaeological/historically important sites and areas with mineral rights. In addition, economic, social and political factors were not taken into account in this project. These factors would have to be considered in any subsequent study aimed at identifying specific sites in potentially suitable areas.

2.6 WASTE MANAGEMENT IN LESOTHO

2.6.1 Solid Waste Management

No town in Lesotho has a sanitary landfill. In addition, there are only official disposal sites, which have been selected by the district’s municipality council. Most of these are inappropriately located. All the urban waste, including medical waste, is dumped and burned at these sites without any form of cover afterwards. Apart from that, most of the disposal sites are unprotected, except only those in Butha-Buthe and Maseru, which are fenced. Therefore, the majority pose high risks of scavenging by the nearby communities (Lesotho Government, 1996).

2.6.2 Lesotho official dump sites

There are disposal sites all over the country, those that are sporadically used and those that are used in a more official and organized manner. These are the ones so-called 'official dumpsites' which were selected by default in most districts. They are just the convenient places to dump in the absence of proper landfills. There were no standard criteria used in their determination. As a result, they are all known to be highly unsuitable by all standards (DANCED, 2000).

According to Lesotho Government (1996), the sites discussed below mainly indicating their unsuitability, on the basis of simple preliminary guidelines used by the Lesotho National Environment Secretariat:

- Size of area;
- Distance to populated areas;
- Distance to sensitive water resources;
- Hydrology & Hydrogeology;
- Geology (Topsoil, Rocks etc);
- Topography;
- Distance from waste arising;
- Construction material availability (Quarry/clay pit at site);
- Current Land use;
- Local ecological conditions;
- Transportation links (main roads, access road, traffic impacts);
- Flooding occurrences;
- Public opinion, Acceptance.

2.6.2.1 Maseru

In Maseru town, there is one official dumpsite located within the village of Ha Ts'osane. It caters for all waste collected from the city centre, the industrial areas and the residential areas that get refuse removal services. This site is protected with fencing and has a guard. Scavengers collect metallic substances that are sold for recycling to make a living (Lesotho Government, 1996).

The researcher (2005) observed on his site visit that there is a continuous cloud of smoke coming from burning of waste and spontaneous combustion due to methane production. This smoke decreases visibility at Ha Ts'osane area, particularly in winter. The location of the site is critical as it is on a sloping area within a catchment of Maqalika dam which supplies domestic water in the whole of the Maseru town. It is also within the community with several houses just a few meters away. Apart from that, there are possibilities of groundwater contamination as the site itself is a cleavage that resulted from quarry mining.

Figure 2.1: Maseru (Ha Ts'osane) dump site

2.6.2.2 Teya-Teyaneng

The old dumpsite is right in the middle of a village. This was relocated without proper rehabilitation. Although the new dumpsite was in use, very little waste was observed at the place and the waste was not put in the pit. On contrary, it was dumped at the mouth of the pit. Because of this level of activity at this site, it could not be conclusive where dumping is actually done. The new site is about 2 km away from town, is adequately sited away from population, and there is enough earth material for covering waste. This only needs to be developed into a proper landfill and should be managed properly (Molapo *et al*., 2002).

2.6.2.3 Maputsoe

Lesotho Government (1996) states that, the current dumpsite of Maputsoe is a rather shallow cleavage that resulted from quarry mining. It is on a small hill about 200 m from Mokota-koti River and half a kilometre from the main North 1 road. The site for disposal is not fenced; therefore, its boundaries are not well-defined. As a result, waste is dumped not at one point, but anywhere around the cleavage. The site is always full of scavengers who select good off-cuts to use in activities that will earn them some income. About 200 m away, on the northern side of the site is a secondary school, which is also not fenced.

The community of Ha Nyenye is along main North 1 road on the east of the site. On the northeast of the site, there are numerous textile industries. On the West side, there are Water and Sanitation Authority (WASA) stabilization ponds, which are situated along the Mohokare River. The high proportion of the waste found on this site consists of off-cuts from the industries. Also found there are cans and bottles of beverages probably from the hotel. However, this site is supposed to cater for the whole town of Maputsoe including the surrounding residential areas and the nearby villages such as St. Monica’s. The business centre of Maputsoe is about 5 km and farthest residential area (Ha Nyenye) is about 7 km away (Researcher’s observation, 2005).

There have been a number of complaints lodged to the town clerk, especially for the nearby school, about the waste that is thrown around. There was no objection to make use of the site for disposal, but development is needed as it is currently unsightly.

Fencing is used to control access to the site and to reduce the dumping area to a minimal practical size whilst still allowing for convenient access and site operation. Moreover, there are dangers of not fencing the dumpsites because dumpsites attract germs and disease-carrying creatures such as rats and mice which may transfer such diseases to those who come into direct contact with the site.

2.6.2.4 Hlotse

The dumpsite in Hlotse is just an open space with no clearly defined boundaries. However, the area that is being used currently is about 3000 m^2. It is situated on a hillside about 1 km from Hlotse River. The site is about 2 km from the Sebothoane village, however, there are three households located 500 m below the site. The waste disposed at this site comes from the town of Hlotse and the surrounding residential areas (Molapo *et al*., 2002).

The farthest waste generation point (end of Mankoaneng village) is about 5km away and the nearest (Government Garage) is 500 m away. Though the site is on a hillside sloping to Hlotse River, it is located on flat narrow but long strip of land. There is no flooding occurring in this area. The site is about 1.5 km from the Nelson Mandela road and the flatness of the site allows easy access of vehicles to the site.

2.6.2.5 Butha-Buthe

This is the one dumpsite whose location is suitable since it is far from the villages and the town centre. It has been properly fenced during the Lesotho Highlands Development Authority (LHDA) operations. The fence has, however, been vandalized. The area was also a gravel quarry hence there is abundant material for landfill operation. This dumpsite only requires good management (Researcher's observation, 2005).


Figure 2.2: Butha-Buthe dump site

2.6.2.6 Mokhotlong

The dumpsite covers an area of about 2000 m^2, situated along a stream that connects to the Mokhotlong River, about 30 m downstream. It is within a soft-top soil valley, hence a high risk to both ground and surface waters. The health facility is about 1.5 km uphill, well out of town population. However, there is a public route adjacent to the site where villagers pass into town (DANCED, 2002).

Since the site is not fenced or secured as well as there being no management of any sort, scavenging is highly probable. For the site to be maintained as a dumpsite, the ground has to be well lined and a retention pond be constructed downstream. There is enough material alongside for construction and burying during operation. However the site is undesirable since it is very close to natural water source (the nearby stream and the Mokhotlong River).

2.6.2.7 Thaba-Tseka

Waste is dumped at an open space that is located above a valley whose water joins the main stream. All sorts of waste are dumped there including medical waste. This is an open space covering an area of about 2000 m^2. The top soils are loam, rich for cultivation. There is no reparation done for disposal, this is just a large area that is covered with scattered waste. There is also no coverage of dumped waste hence waste is easily blown by wind (Molapo *et al*., 2002).

2.6.2.8 Qacha's Nek

Excavated dyke (bore pit) was formerly used as an illegal dumping site, but has now been made official by the office of District manager. All sorts of waste are dumped there including medical waste. The dumpsite is too close to the houses occupied by prison warders. This, therefore, may lead to scavenging. Waste is dumped throughout the quarried dyke and not at the specific place. The site is at the high point relative to the town, which may increase the risk of ground water contamination down-stream (Ntoampe**,** 1998).

2.6.2.9 Quthing

The researcher (2005) observed that the dumpsite is properly located because it is far from the neighbourhood and is located in an unused quarry. The problem, however, is that dumping is done outside the pit, just in an open space. The dumpsite is not restricted and, as a result, it is uncontrolled. The site is located in an area that has been allocated for residential development and sites have already been allocated.

2.6.2.10 Mohale's Hoek

Ntoampe (1998) documented that in Mohale’s Hoek, there is no official disposal site. People dump waste just about anywhere. But the most adversely affected place is the stream that runs between the taxi rank and the town and it goes all the way to the Makhaleng River. The area is so close to the hospital and the public traffic into the town.

Figure 2.3: Mohale's Hoek dump site

2.6.2.11 Mafeteng

The official disposal site of Mafeteng is about 2000 m^2 located in the area commonly known as "*Sepetlele*". It is situated on a gentle slope along the Lekoantlana River that leads to the Mohokare River, and alongside Water and Sanitation Authority stabilization ponds. It is half a kilometre below the Mafeteng hospital. The nearest village, which is across the river, is about l km away. People from the neighbouring villages collect water from the same river (DANCED, 2002).

This site carries waste collected from the business community of Mafeteng, which is located at distance of 3 km from the site. It also carries waste from the residential areas, the farthest being at a distance of 5 km away. This site was selected by the district manager in collaboration with the Department of Environmental Health, the Urban Board, and representatives of the business community and also with representatives of the residential community. Thus, this site has been accepted by the whole community of Mafeteng town.

Figure 2.4: Mafeteng dump site

2.7 CONCLUSION

In concluding the chapter, the location of dumping sites in the Lesotho districts is that these dumping sites are located without any standard criteria recommended by the Lesotho National Environmental Secretariat, hence why DANCED (2002) considers them to be highly unsuitable at all standards because they are just the convenient places to dump in the absence of proper landfills. Due to lack or poor state of communal waste dump sites in the country, it is imperative to develop a GIS framework to help in finding the best locations in the Lesotho districts.

CHAPTER 3

METHODOLOGY AND MODELLING

3 INTRODUCTION

The methodology and modelling in this chapter provide evidence for model that is utilized to determine the optimal landfill sites. Data acquisition in terms of data availability is considered as it is of prime importance when using GIS. The technical approach was also employed to produce suitability maps emphasizing "suitable" geographic areas resulting from weighted and combined map layers based on established criteria. Finally, the model flow chart and justification with respect to the application of the model constructed were also confirmed.

Frantzis (1993) observes that numerous criteria must be taken into consideration when prospective sites for landfills are being studied. One of these is the need to evaluate large amounts of data as quickly as possible. GIS has thus been seen as the most reliable tool that is capable of processing and analysing all involved data and outline of results, thereby potentially saving time that would normally be spent selecting appropriate sites manually. It is certainly an ideal method for preliminary site selection studies because it efficiently stores, retrieves, analyses, and displays information according to user-defined specifications.

Relatively easy presentations of GIS siting results are also one of its many advantages. This work can be done with the aid of GIS combining a database with a cartographic output together with a data management and processing programme, as well as interfaces with other databases. GIS analysis, however, is not a substitute for field analysis even though it does identify areas that are more suitable and directs often sparse funding and efforts to these areas rather than areas that are unsuitable (Dornhofer & Siebert, 1998).

The justification of this study, after identifying important criteria for siting landfills, was to develop a user-friendly landfill site selection model using a Geographic Information Systems (GIS) framework. Due to unavailability of electronic spatial data for Lesotho, Bloemfontein area was used as a test case. The model is tested in Bloemfontein with the intension to be applied in the city of Maseru as soon as the spatial data become available.

3.1 METHODOLOGIES FOR LANDFILL SITE SELECTION APPLICATIONS

Methodologies used are normally based on a composite suitability analysis using map overlays and their extension to include statistical analysis. In this study, the approach was to utilize models that combine and integrate maps to determine an optimal landfill siting. There are a number of integration models in GIS. The study, however, selected two, Boolean Logic and Index Overlay models (Frantzis, 1993).

Probably the simplest and best-known type of GIS model is based on Boolean operation. It involves the logical combination of binary maps resulting from applicable conditional operators. If the criteria and guidelines are to be established as a set of deterministic rules (Constraints), this method is a practical and easily applied approach (Dikshit *et al*., 2000). The model consists of applying Boolean operators to a set of input maps. Each of the maps used as a condition can be thought of as a layer of evidence. The various layers of evidence are combined to support a hypothesis, or proposition. The output is a binary map, because each location is either satisfactory or is not (Bonham-Carter, 1994).

In practice, it is usually unsuitable to give equal importance to each of the criteria being combined. This is because evidence needs to be weighted depending on its relative significance. Hence, each location was evaluated according to weighted criteria, resulting in a ranking on a suitability scale. The subsequent selection process then benefits from the ability to assess suitability rankings rather than simply presence or absence.

This method is known as Index Overlay. In this method, each factor maps were assigned scores (scored maps), as well as the maps themselves receiving different weights. All scored maps were then assigned to a common scale (e.g. ranging between 1 and 10). Weights are generally assigned to these maps to express the relative importance. Determining the weights is, however, quite controversial and is basically accomplished by decision-makers through reviewing the criterion and their relative importance concerning the objective to which they contribute (Siddiqui *et al*., 1996).

Eventually, scored maps are to be combined with constraint maps to eliminate areas of absolute unacceptability. A final map will be generated that identifies regions that are most suitable for the location of a landfill site. An optimal site will be chosen based on the highest suitability values.

3.2 DATA ACQUISITION

Data availability is of prime importance when using GIS. In the current study, a comprehensive body of secondary information related to environmental (streams network and wetlands.), socio-cultural (municipal development area, historic and important conserved sites and land use), and economic factors (road network, land slope, soil cover, and geology,) was collected and produced in a digital format from Department of Environmental Affairs and Tourism through the University of the Free State, Department of Geography (GIS Section).

3.3 DEFINITION OF GIS END USERS

GIS users include:

- State and Non-Governmental Organisations,

- Government Departments,
- Local Authorities,
- Environmental and Engineering Consultants,
- Utility Groups,
- Universities and Institutes of Technology.

Langer (1995) confirms that GIS is now common place across many sectors, in marked contrast to ten years ago, when its use was limited to small groups of experts. GIS has widespread use in issues dealt with by local authorities; however, its use is often limited to simple map overlay and visualisation techniques.

The landfill GIS model (Figure 3.1) described below is designed so that non-GIS experts with a basic knowledge of GIS can run it. In this way, it will provide a user-friendly tool to aid decision-making where a broad array of complex criteria must be considered. The importance of developing a GIS model that can be used as a tool to assist local authorities and researchers in the selection of suitable sites for landfill is demonstrated by Allen *et al*. (1997).

3.4 TECHNICAL APPROACH

GIS-based analyses were conducted using ArcGIS software, Spatial Analyst. Spatial Analyst is a raster or grid based software package that provides a platform for working with gridded data sets. It was used to produce suitability maps highlighting “suitable” geographic areas derived from weighted and combined map layers based on established criteria.

3.4.1 Analysing maps

Analysing maps essentially involves setting the study area boundary, making slope map, buffer zone maps, find distance, reclassified maps and suitability maps that are presented in Chapter 4.

Raster maps as constraints maps indicating areas, which are suitable (represented by 1's) and not suitable (represented by 0's) for the siting of a landfill, will be provided. The non-suitable areas are known as buffers (Kontos *et al*., 2003). These constraints maps include the surface water, towns, rivers, roads, railroads and land-use. They will also be used as factor maps representing areas that range from low suitability to high suitability.

3.4.2 Study area boundary

Since all analyses over layers have to be limited to the extent of the study area, a boundary map (base map) is generated and has to be used for future calculations.

3.4.3 Slope map

According to the criteria, a slope map is needed due to the fact that slope is a relevant factor in siting the landfill, given that an area is an important consideration for excavation. The landfill site should have a moderate slope to assist in controlling drainage. Therefore, slopes of 4% to 12% are most suitable while slopes of 0% to 4% are less suitable but still admissible. Regions with slopes exceeding 12% are to be excluded from consideration.

3.4.4 Buffer zone

In order to make binary maps for Boolean integration method, buffer zones are to be created for maps corresponding with constraints and reclassified to two classes, namely zero (for non-suitable area) and one (for suitable area) classes.

3.4.5 Distance

Depending on the criterion, it is preferable that the landfill be built near or away from a particular source. Proximity maps are to be made using "Spatial Analyst - Distance" option for layers associated with criteria which could be ranked based on their distance from the nearest source. The source may be anything such as a city, a road, a stream, and so on. If so assumed, the scales are linear relationships. Straight line assigns values (scores) to the cells proportional to their distance from the source. Many scales, however, are not linear relationships, and yet still they are often presented in that way to save time and money or because all options are not considered.

3.4.6 Reclassified map

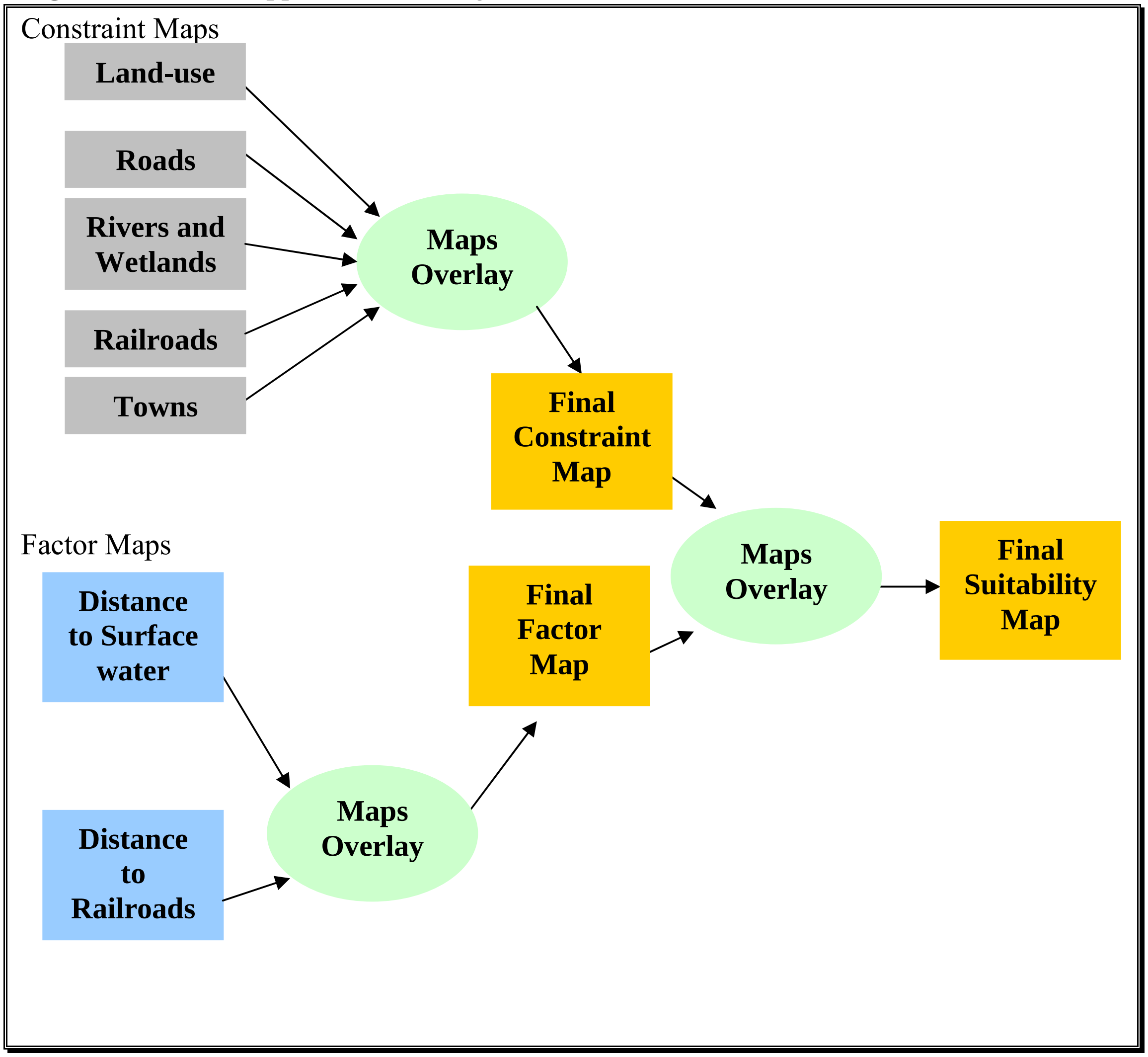
Each map layer is to be ranked by how suitable it is as a location for a new landfill. However, in order to be able to combine them, a common scale (for example, 1-10) giving higher values (scores) to more suitable attributes, is usually assigned to each class, using "Reclassify" option. The layers generated in this step, are used in Index Overlay integration method.

3.4.7 Weight and combine data sets.

The final step in suitability modelling is to determine the relative importance of each data set, weight them accordingly and then combine the data sets to produce a suitability map. Weighting the data sets define the extent to which each data set will influence the model results.

3.5 MODEL FLOW CHART

Figure 3.1: Model applied for locating suitable land for landfill



3.6 THE APPLICABILITY OF MODEL IN MASERU

The model can be applied in the city of Maseru as Mendoza (1997) elucidates that the landfill site selection model is the general model that can be applied to any region that requires strategic siting of any obnoxious facility. This model is also an excellent basis for further study as more data become available. The model can be used not only for optimal site selection, but can also be used to identify a set of possible candidate sites.

Michael (1991) also accentuates that the criteria for selecting a dumping site are almost similar all over the world with some constraints related to locality. However, some of the factors may conflict with each other; therefore, some compromises or tradeoffs between criteria will be necessary if the process is to materialize.

CHAPTER 4

ANALYSIS AND INTERPRETATION

4 INTRODUCTION

Chapter four took into account the identification of suitable criteria for landfill sites selection. The site selection model engaged three steps such as Preliminary analysis, Multi-criteria evaluation and suitability analysis. Preliminary analysis involved creation of the study area map in order to input the rasterized data layers, then Multi-criteria evaluation, which comprises production of final constraint maps and final factor maps and suitability analysis encompassing identification of the most suitable site are ultimately applied.

The advancement of knowledge in the 20th century has drawn attention to many environmental, social, economic and political concerns associated with waste facility siting. The "not in my backyard" (NIMBY) and "not in anyone's backyard" (NIABY) approaches have raised major public concerns and, thus, must be taken into consideration in facility site planning (Kao & Lin, 1996).

Landfills have created many problems in the past, but proper siting techniques and the current state of knowledge allow planners to appropriately site landfills with minimal impacts. It is worth noting that a landfill's storage capacity is directly related to the size of the site (Nagar & Mizra, 2002).

It is important that environmental, social, economic, and political concerns associated with the siting of a landfill facility are addressed. Of these, environmental impacts are perhaps the most important issues to be addressed during site selection. This is because altering the ecological balance within an area plays a significant role in ecosystems that have otherwise taken many years to develop.

Contaminations of water and soil resources are some major social concerns that have arisen in the past in response to poorly sited landfills (Nagar & Mizra, 2002). The health concerns and overall quality of life of residents who stay near a landfill have come to assume greater importance among planners.

Additionally, social concerns must be addressed before commencement of project construction to ensure that public opposition would not be a barrier during the initial phase of project construction (Hsieh *et al*., 2000). Economic concerns, on the other hand, involve the transportation of waste (Al-Yaquot *et al*., 2002), as well as the overall costs associated with implementing the landfill after an appropriate site has been selected. Finally, political boundaries and jurisdiction can also play a major role in implementation and operational functions once the landfill is in place.

The use of a GIS-based framework can be incredibly useful in locating the most appropriate site for a landfill facility. GIS can perform a number of operations to ensure the quality of the location selected, and also has the ability to manage large quantities of data at any given time (Siddiqui *et al*., 1996). Using GIS for landfill site selection is a cost-effective and time-saving tool compared to conventional methods (Dikshit *et al*., 2000).

In spite of this, many knowledge gaps exist in facility siting since it is very difficult to satisfy social, environmental, economic and political factors to the fullest extent. While the concerns of the affected population need to be addressed, in practice it has proved to be very difficult. Many social concerns deal with locating a landfill near surrounding communities which will be affected by aspects such as odour, land value and aesthetics (Tagaris *et al*., 2003). Unfortunately, not all parties involved can have their concerns satisfactorily addressed.

4.1 IDENTIFICATION OF SUITABLE CRITERIA

The site selection model involves three steps: preliminary analysis, multi-criteria evaluation, and identification of the most suitable site. The preliminary analysis stage involves creating a study area map to input the rasterized data layers, then creating constraint maps and factor maps from the downloaded Bloemfontein spatial data.

The second step involves performing an MCE, which is conducted by weighting the factor maps and combining them with the overlaid constraint map. The final step relates to finding the most suitable site using the information in the final MCE map.

A number of variables taken into consideration include land-use type, environmentally sensitive areas, distance to streams, slope, proximity to urban centres and the distance from transportation routes.

4.1.1 Constraint maps

Constraint (binary) maps are used to distinguish between lands that are suitable for landfill siting and those lands that are restricted. The constraint maps are produced by merging each individual theme with the study area. This procedure creates a constraint map for each theme containing only two classes represented by 1's (for suitable land) and 0's (for unsuitable land).

4.1.1.1 Land-use

The land-use constraint map (Figure 4.1) below is created to establish an image that represents restricted and suitable land areas in Bloemfontein for siting a landfill. The map is re-classed into 0s and 1s to indicate the restricted and suitable areas, respectively. For example, barren land is most suitable for landfill siting whereas cropland should be part of the restricted areas.

Figure 1.3 depicts the classification of land use in the study area. Parameters like nature reserves, agricultural potential, airport, industrial and built up areas have been taken into consideration. Sites with potential for higher value uses such as agriculture, residential development (built-up areas) and airport are re-classed as restricted area and hence, they are given 0 signalling unsuitable areas in the Figure 4.1.

Sites which are located within or adjacent to parks and other important recreational or tourism-related activities are less desirable. However, landfill activities can be visually buffered and operated to minimize intrusions. This criterion also includes minimal consideration for historic resources (easily observed or generally known).

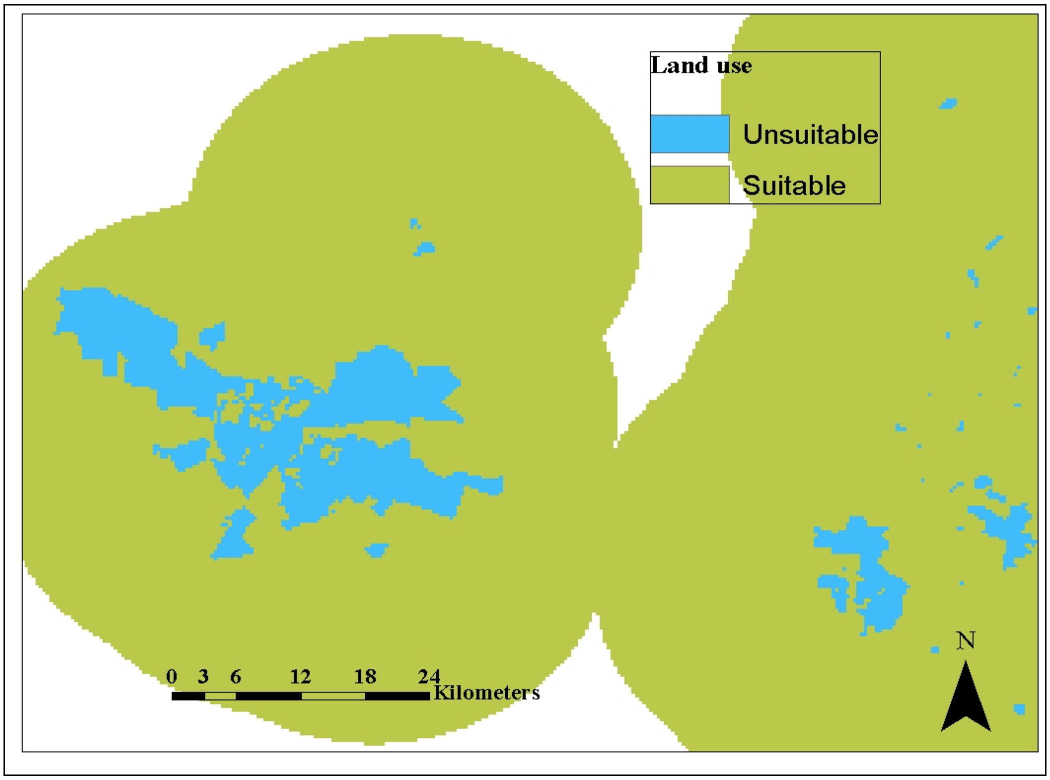


Figure 4.1: Constraint map of restricted and available land-use for Bloemfontein

4.1.1.2 Proximity to roads

Locating the landfill close to a road would help reduce costs related to transportation and new road access to the site. To accomplish this, the major roads layer (Figure 4.2) from the Bloemfontein spatial data are re-classed to make sure that the site is not located directly on a road. As a result, roads are given a 0 signifying unsuitable and all other areas were given a 1 (suitable).

The major road constraint map (Figure 4.3) is constructed in order to create a buffer zone around the major roads in Bloemfontein since roads are not a desirable site to place a landfill. However, if a site is found to be optimal where a road is situated, the cost implications of removing such a road would be enormous.

For this study, it is found that a buffer of one kilometre is sufficient for economic reasons, to avoid transportation conflicts and mainly due to aesthetic reasons. The major roads layout in Bloemfontein is extensive, and thus a medium buffer is used in order to optimize possible regions for locating a landfill site.

The buffer distance of 1 to 2km in Figure 4.3 is considered highly suitable in this regard. An upper distance boundary of greater than 2km from a road is classified as unsuitable since it would not be economically feasible to transport garbage more than 2km from a pre-existing road network.

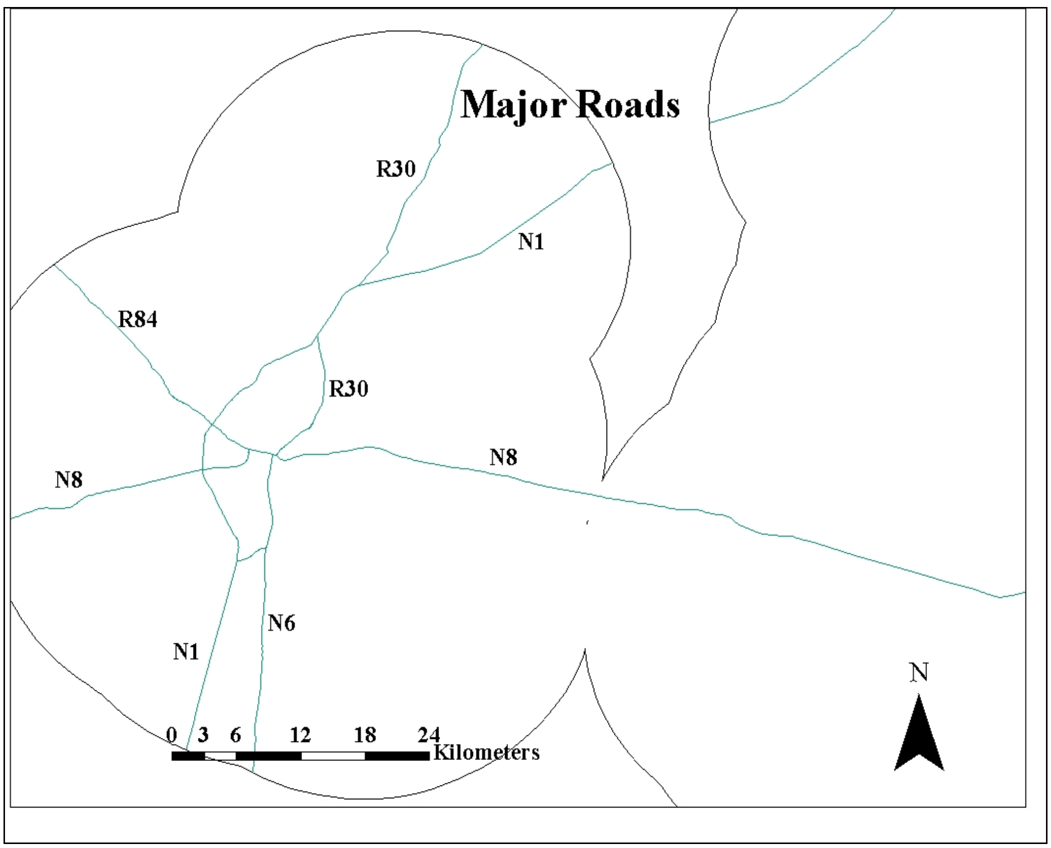


Figure 4.2: Major roads in Bloemfontein study area

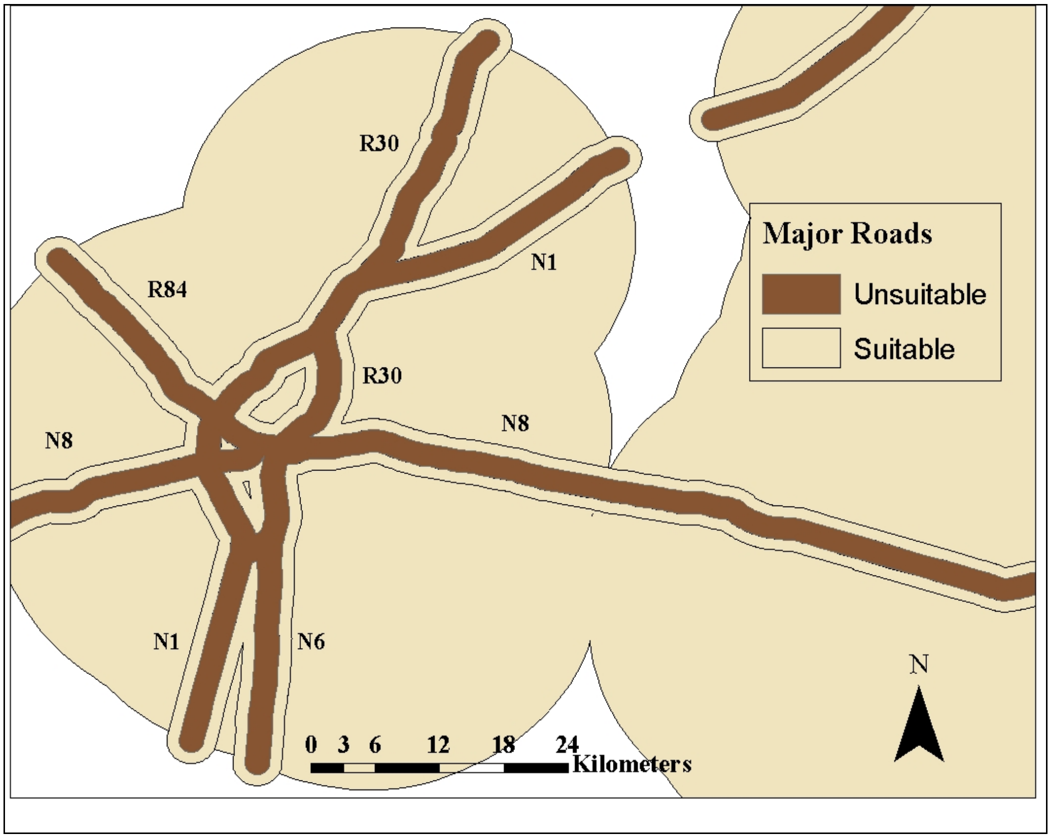


Figure 4.3: Major roads constraint map of restricted and available areas for Landfill Sites in Bloemfontein

4.1.1.3 Proximity to railroads

The railroads constraint map (Figure 4.5) is produced in order to establish buffer around. Given that building on railroads is not a desirable place to situate a landfill site, the buffer distance of 1 to 2km is employed. This direct constraint about buffered distance would avoid any conflict with transportation along the rail system and is chosen because railroads and roads have similar features on the landscape and, therefore, the same buffer distance is used.

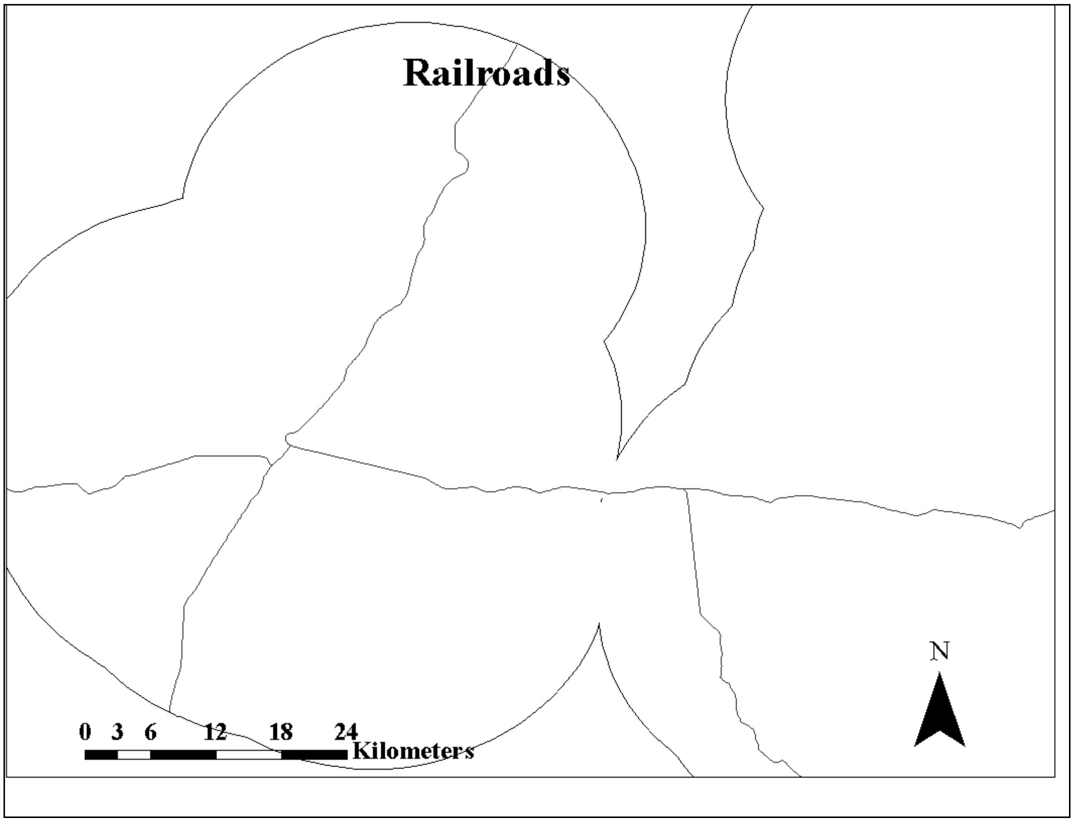


Figure 4.4: Rail roads map of Bloemfontein study area

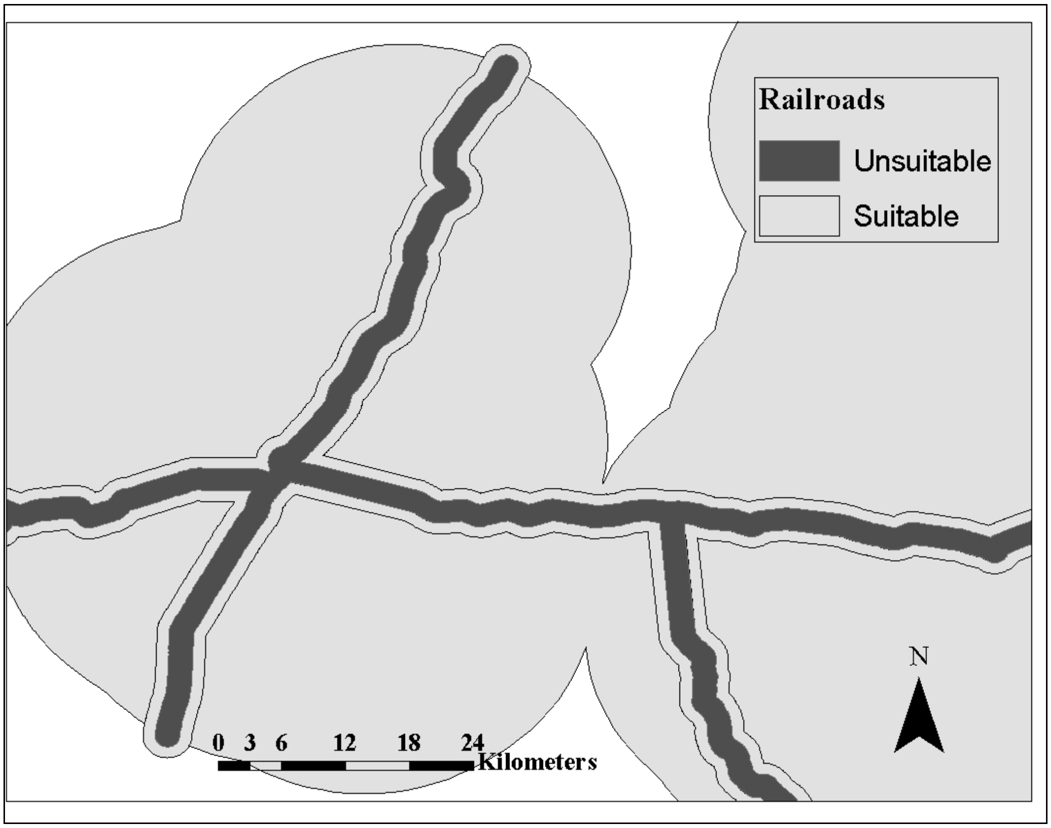


Figure 4.5: Rail roads constraint map of suitable and unsuitable areas for Landfill Sites in Bloemfontein

4.1.1.4 Proximity to surface water

The surface water (rivers and wetlands) layer (Figure 4.6) is constructed in order to create surface water constraint map (Figure 4.7) with buffer zone around since they are not desirable region to build a landfill nearby. This is due to the possibility of contaminants from a landfill leaching to the ground water and seeping into the rivers and streams. This is also primarily due to environmental concerns, where a location further away from a surface water source would be preferred. The constraint map (Figure 4.7) is then created using the buffer distance function to make 3 kilometres. All areas within buffer are given a 0 (unsuitable) and all others are given a 1(suitable).

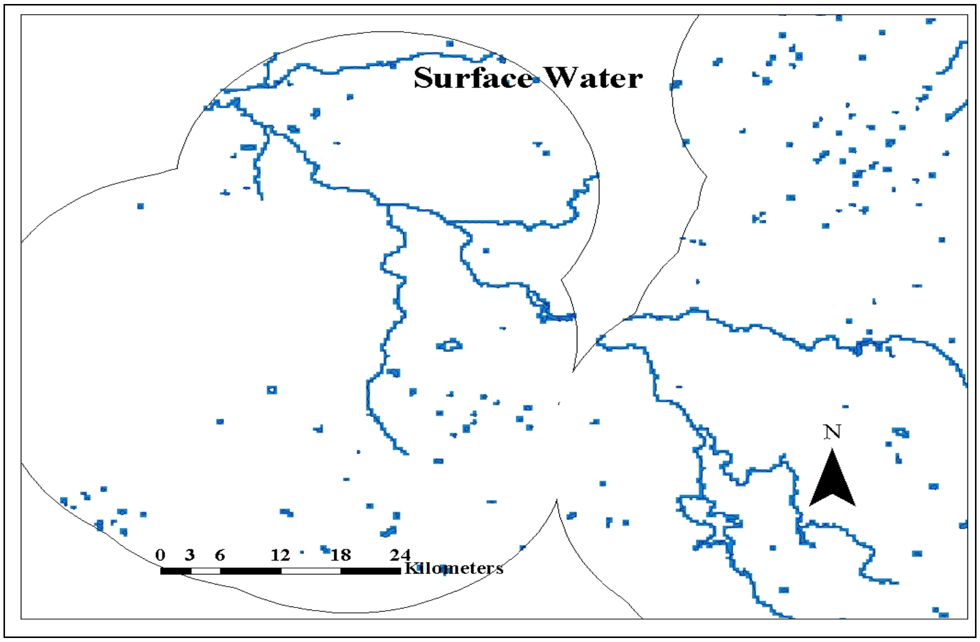


Figure 4.6: Surface Water map of Bloemfontein study area

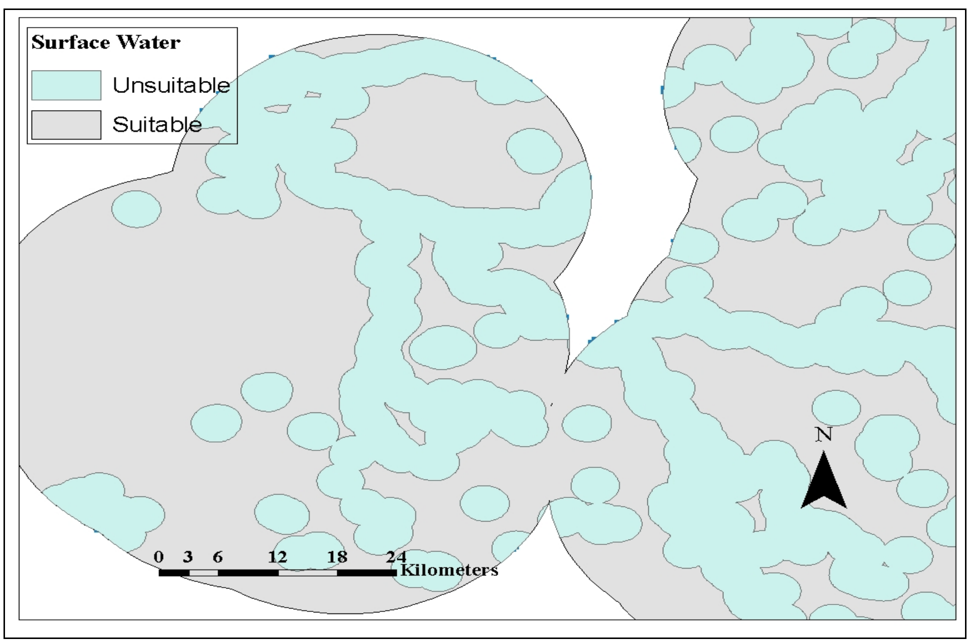


Figure 4.7: Surface Water constraint map of restricted and available land areas for landfill sites in Bloemfontein

4.1.1.5 Proximity to towns

The town constraint map is created in order to define a limit around urban areas that would protect the population from landfill hazards, such as scavenging animals and strong odour. Using the NIMBY approach, a buffer of 15km is established. Baban & Flannagan (1998) and Dikshit *et al*. (2001) state that facilitating a landfill away from urban land areas is noted for several reasons, including aesthetic and health concerns.

4.1.1.6 Slope

A low slope is required to minimize erosion and water runoff. A lower slope also facilitates the construction of the site to be much easier and with lower costs (Atkinson *et al*., 1995). The best slope chosen for the development of a landfill is between 0% and 12%. Furthermore, the slope map of Bloemfontein study area is not utilized because almost all part of the study area comprise low gradient that ranges from 9% to 15% based on the Bloemfontein contour map.

4.1.1.7 Geology

Sadek *et al*. (2001) emphasise that in the selection of a site for MSW land-filling, special care has to be given to the underlying foundation soil and bedrock characteristics: geologic structure, soil type, existing fractures, and so on. The aforementioned aspects affect the waste or leachate containment characteristics of a site.

The starting point is a geologic map of the study area showing the geologic characteristics, the chronology of a bedrock formation and lithology. Accordingly, the study area is divided into two regions: geologically suitable and non-suitable areas. The suitable areas were identified as those comprising mudstone and shale of the ecca group, shale and mudstone of the Beaufort group partially covered by wind blown sand and surface limestone as well as dolerite intrusions. Non-favourable areas are locally sandy lands.

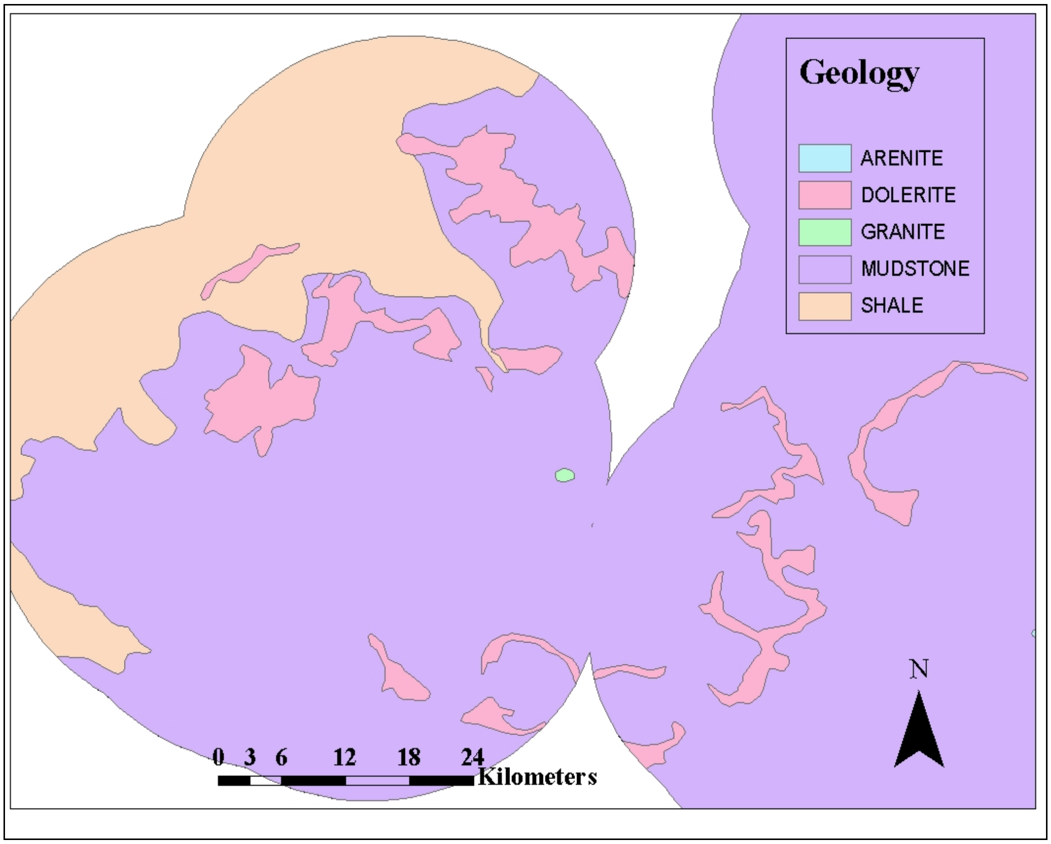


Figure 4.8: Geological map of Bloemfontein

4.2 FINAL CONSTRAINT OVERLAY MAP

The constraint maps were produced by merging each individual theme within the study area. This procedure created a constraint map for each theme containing only two classes represented by 1's (for suitable land) and 0's (for unsuitable land). The four constraint maps (layers) namely, land-use, railroads and roads, and water bodies were combined using OVERLAY function (using direct multiplication of the binary integer values) to create the final constraint map depicted below in Figure 4.9.

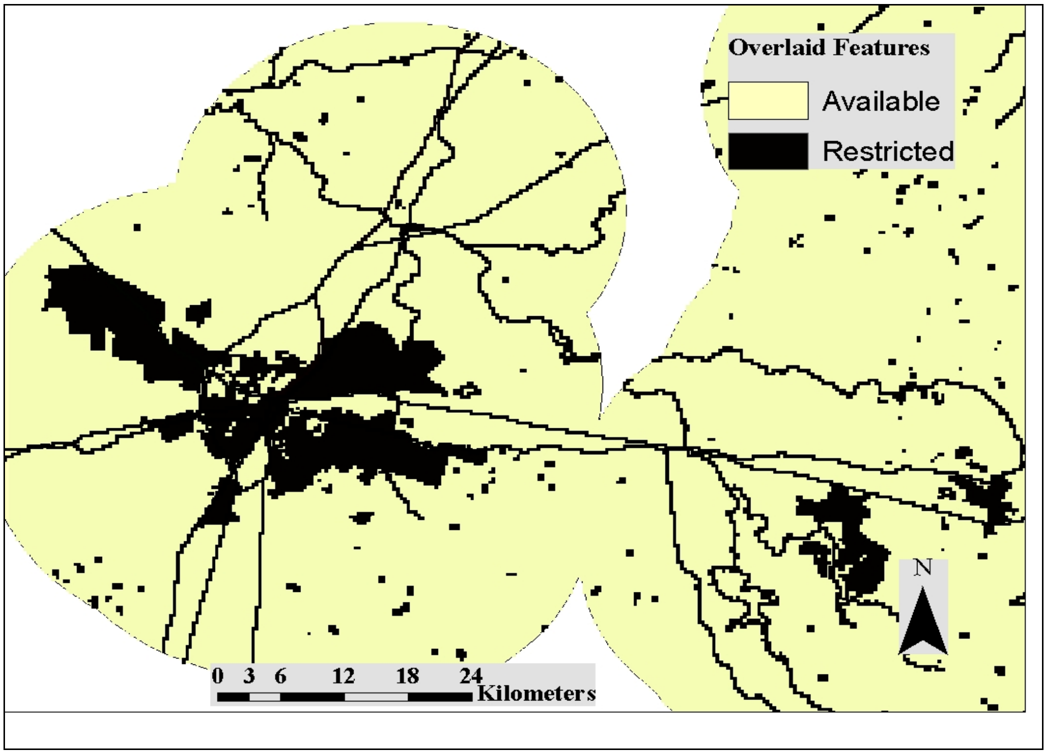


Figure 4.9: Final constraint map indicating restricted and available areas for landfill sites in Bloemfontein

4.2.1 Factor maps

Factor maps illustrate suitability of a specified feature that ranges from the least suitable locations to the most suitable locations using a range of classes. Three factor maps that are produced are surface water, roads and railroads. The surface water constraint map and the railroads constraint map were used as the input themes to create the three factor maps. Each of the four rings in the factor map is set an equal distance apart.

To create these factor image (Figures 4.9), the BUFFER zone of 3km around the grid file of surface water and Figure 4.5, the BUFFER zone of 1km is created around the grid file of roads and railroads, respectively. From there, the DISTANCE function is run on respective maps in order to find the distance from the buffer to the study area limits. The default equal interval distances were used to prevent bias and maintain a holistic approach within the study.

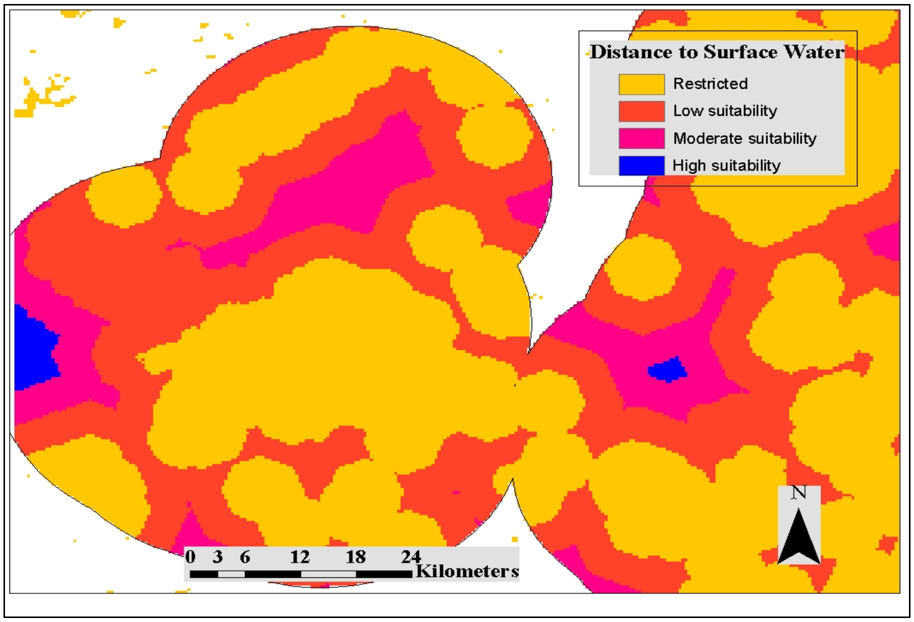


Figure 4.10: Factor map of the surface water showing the most and least suitable areas for landfill areas for landfill sites in Bloemfontein

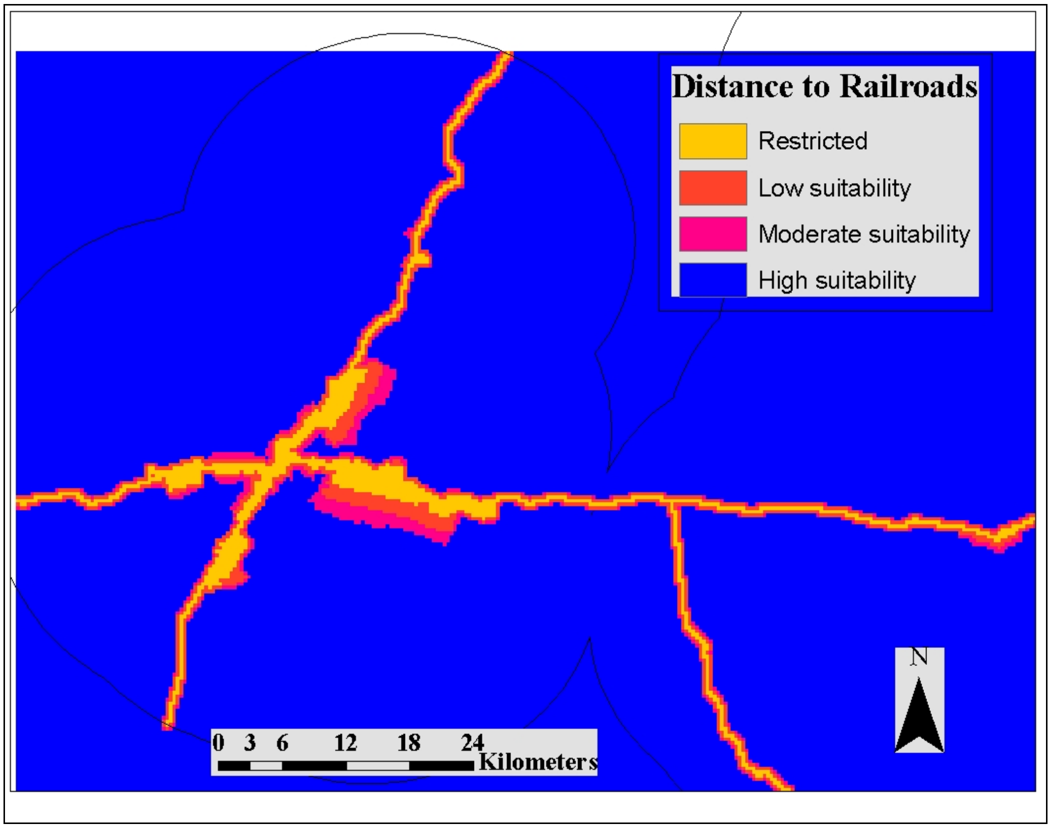


Figure 4.11: Factor map of the railroads showing the most and least suitable areas for landfill sites in Bloemfontein

4.2.2 Final Factor map

The final factor map is created using an arithmetic overlay when all factor maps are complete. WEIGHTED OVERLAY function is performed using weights of both 40 percent and 60 percent for railroads, and for surface water, respectively. A custom scale of 1 to 3 (1 – 3) is chosen for this overlay since only 3 suitability allocations are appropriate for the factor maps. Those 3 suitabilities comprise low suitability (restricted), moderate suitability and high suitability.

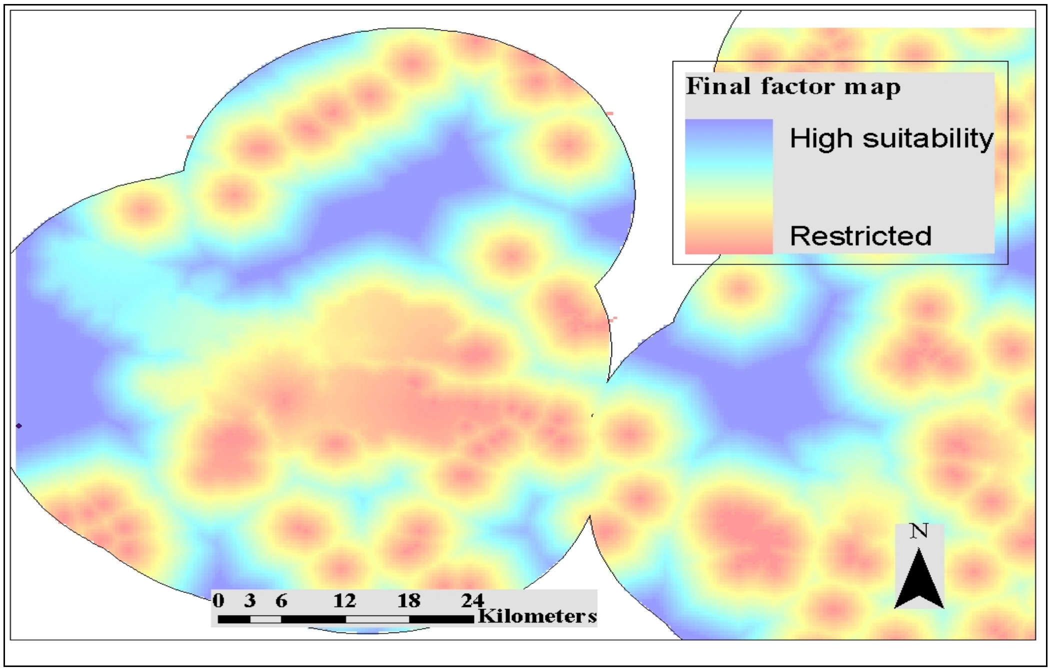


Figure 4.12: Final factor map indicating the most and least suitable areas for locating landfill sites in Bloemfontein

4.2.3 Final Suitability map

This approach consisted of the identification of locations that may present favourable conditions to the deposition of waste. The various maps analysed for environmental, socio and economic criteria were intersected to screen out unsuitable lands. Based on the available data, the final suitability map presented in Figure 4.13 is developed. The adopted criteria are applied to the spatial data using if or then queries, buffering capabilities within GIS, and map overlays and intersections to create a composite site suitability map.

The final constraint map (Figure 4.6) and the final factor map (Figure 4.12) were merged together using Map Calculator to produce final suitability map (Figure 4.13).

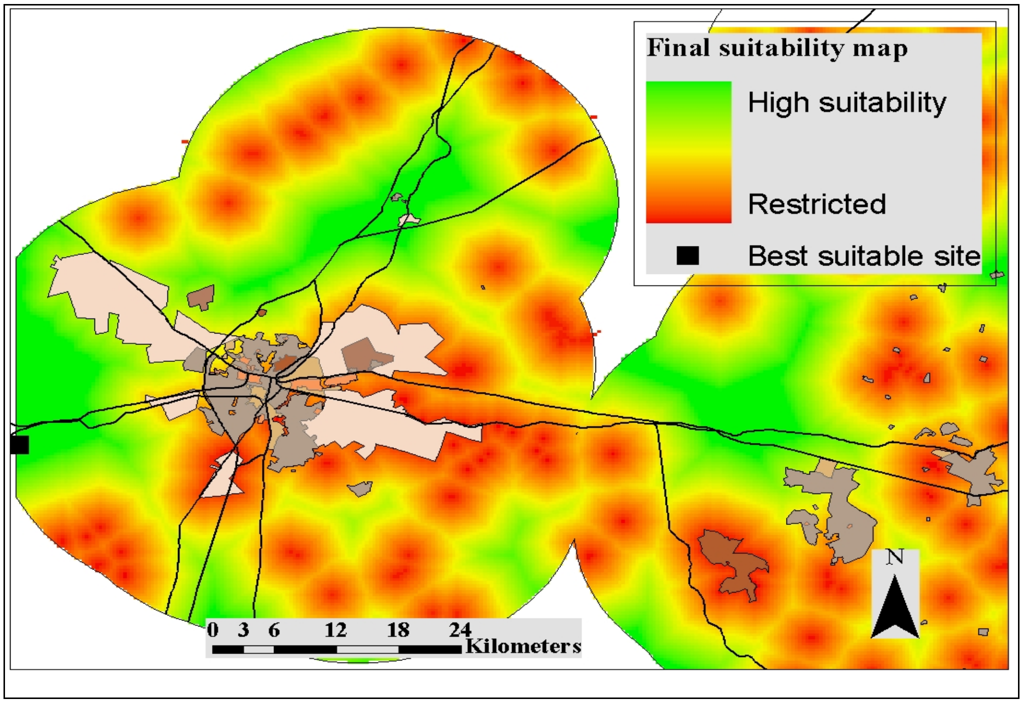


Figure 4.13: Final suitability map indicating the most and least suitable areas for locating landfill sites in Bloemfontein

CHAPTER 5

SUMMARIES, RECOMMENDATIONS AND LIMITATIONS

5 SUMMARIES

This chapter presents some salient points that have been unearthed by the study. Because these have been bearing on the direction that the study took, they then yield recommendations:

- Firstly, the study has found that the increase in the amount of garbage production is no doubt positively correlated with the increase in human population and in turn increases the pressures on siting new landfills. During this study, the utilization of GIS as a tool in siting the new landfill was employed and conclusions were drawn as to the effectiveness of its use.

- Secondly, the results of the GIS-based study showed that although highly suitable areas were limited, a site was still able to be chosen under the predefined parameters. The site is not located on, or near, any environmental interest areas and is located a significant distance away from streams, urban areas, which minimizes social conflict and environmental impacts. The site is also located close enough to major road (N8) to Kimberley from Bloemfontein city and railroad, which ensures that economic costs of implementation are minimal. The selected region has a slope less than 12%, which are both an infrastructural advantage and a means of minimizing environmental impacts. The landfill as well is located in an area within 22 kilometres of the Bloemfontein study area from the city centre. Since the site is located in a highly suitable area, environmental, social, and economic concerns have been met.

- Finally, Solid Waste Management is an obligatory function of the urban local bodies. However, if landfill sites are poorly located, they result in problems of health, sanitation and environmental degradation. With increasing annual growth in urban population and the rapid pace of urbanization in Bloemfontein and Maseru, the situation will become more and more critical within the passage of time. There are various deficiencies related to solid waste management (SWM) which are seen in these cities, such as no storage of waste at source, non-segregation at source, no system of primary collection of waste, use of inefficient tools, inadequate transportation of waste, no processing of waste, disposal of waste, lack of institutional and administrative involvement.

5.1 RECOMMENDATIONS

With the summaries in context, recommendations are made both for theoretical and practical purposes. In other words, while the study would obviously use its findings to recommend how best landfill siting can be done in other contexts, need to shed light on how future studies on the matter can be designed to achieve optimal results cannot be ruled out. The recommendations, thus, are as follows:

I. The use of a GIS model to find a suitable landfill site incorporating the evaluation of multiple criteria has many advantages. Firstly, GIS is a powerful tool that enables organized and systematic analyses of spatial data. Secondly, the results of the analysis can also be presented in the form of aesthetically-pleasing and functional output maps. Finally, the model and its operational procedures can be visually simplified and represented as a schematic diagram (flow chart) thereby increasing the comprehension of the tasks performed.

II. GIS technology has proved to be effective in handling large amounts of data and significantly aiding the facility siting process. Its ease of use and comprehensive display allows for user-friendly operational tasks. In the context of this study, the use of GIS was crucial in narrowing down the potential sites for final selection. The arithmetic overlay was performed in producing final maps that were reflective of the initial criteria and satisfied the purposes of finding potential landfill site. Therefore, the use of GIS effectively converts pre-existing data into a visual display which can be easily interpreted and assessed.

III. Additionally, this research proposes a well-judged landfill site selection methodology taking Bloemfontein as the study area. This research will contribute in developing Lesotho's spatial database of environmental and social information to assist in the formulation of available options. It is expected that such municipal GIS when planned and implemented efficiently with sufficient public awareness and support would be instrumental in bringing reforms at the local and national level, realizing a major improvement without much capital investment.

IV. Ultimately, this study can be used as a tool for facility site planners for locating landfill sites in the Maseru city and in other Lesotho districts, namely, the Lesotho National Environmental Secretariat, the Municipality Council and The Ministry of Health with its Health Care Waste Management division.

5.2 LIMITATIONS

Although it is every study's intention to meet its desired and expressed objectives, it is almost certain that limitations occur, which and apart from being a disadvantage, do provide direction for future studies. This study experienced the following limitations:

Although many factors were included in the model there were still limitations surrounding the analysis. There were layers that were not available such as depth to water table and data on the existing water wells.

For future studies it would be useful to incorporate more layers into the GIS-based model because there is no doubt that they would increase the relevancy of the final output suitability having more factors initially considered.

Concerning the Mangaung Local Municipality and the Maseru City Council, It is often seen in most of the local bodies that data lie in isolated forms. The SWM data are often not available at one place for arriving at proper decisions regarding the planning and management arrangements. Most solid waste planning efforts emphasize technology with such engineering activities as determining the number of trucks and the siting of landfills.

The existing system in the Maseru City Council, there is inadequate supervision of workers, inadequate logistics management, and spatial planning. Therefore, through continuous planning and dynamic management, these systems can be designed to have capacity that meets demand on a continuous basis.

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