

**MUNICIPAL SOLID WASTE DISPOSAL SITE SELECTION
THE CASE OF HARARE**

by

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Declaration

The candidate hereby declares that the work presented in this dissertation:- ‘Solid waste disposal site selection – the case of Harare’ for the award of the Masters in Science in Environmental Management submitted to the Centre for Environmental Management, Faculty of Natural and Agricultural Sciences, University of Free State; is that of the candidate alone and has not been submitted previously, in whole or in part, in respect of any other academic award and has not been published in any form by any person except where due reference is given.

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Approval

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Dedication

This work is dedicated to the Holy Spirit, my teacher, my helper, my counsellor, my advocate, my strengthener, my standby, my intercessor and my guide.

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Acronyms

A.H.P.....	Analytic Hierarchy Process
D.S.S.....	Decision Support System

E.I.A.....	Environmental Impact Assessment
E.M.A.....	Environmental Management Agency
E.P.A.....	Environmental Protection Authority
G.I.S.....	Geographic Information System
H.C.C.....	Harare City council
H.I.A.....	Harare International Airport
L.U.L.U.....	Locally Undesirable Land Use
N.I.M.B.Y.....	Not In My Back Yard
N.O.T.E.....	Not Over There Either
M.C.E.....	Multi Criteria Evaluation
M.C.D.A.....	Multi Criteria Decision Analysis
U.S.E.P.A.....	United States Environmental Protection Agency

Abstract

The exceptional growth in the urban population of cities in developing countries has mandated a critical analysis of urban waste management practices. In the context of

increasing urban population density, sanitary landfill solution is a lucrative means of waste disposal and attainment of an acceptable environmental quality and public health.

The location of sanitary landfill facilities in established urban developments requires careful and thoughtful consideration to create a situation which accommodates the technological, social, economic and environmental considerations associated with landfill creation alongside existing infrastructure, social fabric and environmental constraints.

This investigation contributes to the search for a suitable site for a new waste disposal facility to cater for the solid waste generated in Harare's industrial, commercial and residential areas. This research takes the form of a land use suitability assessment with a multi-criteria analysis. Factors considered include settlement pattern, industrial areas, commercial areas, wetlands, transport routes, surface and groundwater vulnerability. Weights are assigned to these factors depending on their relative importance and impact as determined through literature, local authority regulations and responses of key decision makers and stakeholders. Using Geographic Information Systems (G.I.S,) map overlay techniques; alternative landfill sites are identified and evaluated.

Multi-criteria, Land-use Suitability, Landfill, Site Selection, Analytical Hierarchy Process, Geographic Information Systems (G.I.S), Map Overlay.

Chapter 1 Introduction

1.1 Introduction

Waste is the inevitable pernicious by-product of man's developmental activities. Global urbanisation is an on-going process, the world is expected to be 67% urbanised by 2050 and Africa is expected to be 50% urbanised by 2035 (*United Nations Department of Economic and Social Affairs, 2012:1*). Urbanisation has resulted in increased per-capita waste generation. An urban resident produces twice as much waste as a rural inhabitant (*Hoonweg and Bhada-Tata, 2012:8*). These higher rates of urbanisation will result in corresponding higher rates of waste generation particularly in developing countries, where the volume of waste is expected to double between 2011 and 2035 (*Hoonweg and Bhada-Tata, 2012:ix*).

The exceptional growth in the urban population of cities in developing countries mandates a critical analysis of urban waste management practices. The city of Harare is no exception. The city of Harare is urbanising rapidly. Approximately twenty thousand (20,000) residents are added to this city each year (*Zimbabwe National Statistics Agency, 2013:12*). Furthermore, the vision for Harare to attain world class city status by 2020 calls for the establishment of an efficient waste management strategy consisting of waste minimisation, waste segregation and sanitary disposal.

Solid waste disposal in sanitary landfill facilities is an ingenious strategy to manage the enormous volumes of waste generated by urban populations. Disposal of waste in sanitary landfill facilities has the potential to attain an acceptable environmental quality and public health. Nonetheless, a judicious landfill site selection is a paramount waste management strategy, as it minimises the risks associated with waste disposal. Furthermore, introducing a new municipal waste depository into an existing urban framework requires thoughtful consideration in order to cohere with the existing infrastructure, social fabric and environmental conditions. G.I.S. is a planning tool that assists landfill site selection in the context of increasing urban population densities, competing land-uses and conflicting objectives.

1.2 Problem Statement

Harare's two principal municipal solid waste depositories, Golden Quarry and Pomona, have been in use for the past thirty years. These two landfills have now exceeded their waste handling capacities and pose environmental and health hazards. The waste management regulations enacted by the Environmental Management Agency require that each municipality have a sanitary landfill. Therefore, the City of Harare urgently needs to establish a new sanitary waste disposal facility to accommodate the waste generated by its ever-increasing population. Landfill suitability analysis is required in order to ascertain and verify the ideal location for the new municipal solid waste depository.

1.3 Research Aim

The aim of this investigation is to make use of Geographic Information Systems to guide the selection of a suitable site to accommodate a new municipal solid waste depository for the city of Harare.

1.4 Research Objectives

The primary objective of this investigation is to strategically select alternative locations for landfill development. The minor objectives of this research are:-

- i. to identify a landfill location which will safeguard Harare's streams and rivers.
- ii. to identify a landfill location which will not disrupt Harare's wetland habitats.
- iii. to elect a waste disposal site which neither disrupts the city's existing residential areas nor expose the residents to unacceptable levels of air pollution and foul odours.
- iv. to elect a waste disposal site which is a convenient distance away from the central business district.
- v. to elect a waste disposal site which is accessible from major highways and primary distributor roads.
- vi. to elect a waste disposal site which is accessible from the major industrial sites.

1.5 Research Questions

This research inquires whether there are any open spaces in the city of Harare which are ideal to function as a municipal solid waste depository. The degree of suitability is determined by the following sub-questions.

- i. How far is the site away from adjacent streams and rivers?
- ii. How far is the site away from the wetland areas?
- iii. How far is the site away from adjacent residential areas?
- iv. How far is the site away from the central business district?
- v. How far is the site away from the established primary distributor road network?
- vi. How far is the site away from the industrial sites?

1.6 Significance of Study

1.6.1 Research Justification

The decision of where to locate this new facility requires careful thought and planning in order to avoid the adverse impacts of landfill development. These impacts include inter-alia air pollution, ground water contamination, contamination of surface water bodies including streams, rivers and lakes; and degradation of sensitive areas.

When investigating the optional sites for the purposes of developing a landfill site it is important to remember the repercussions of this decision. Essentially, the short-term impacts of the landfill will be experienced during the construction of the landfill, however the contaminating lifespan consists of the long-term impacts of the landfill which may endure for centuries to come (*Rowe, 1995:3*).

The groundwater resources in Harare are finite and thus should be protected from any form of contamination. Unlike surface water resources, which are substantially replenished every rainfall season, groundwater recharge takes up only 2-5 percent of the total annual rainfall (*Rowe, 2012:6*).

The city of Harare is situated upstream of lake Chivero, therefore any pollutants in surface runoff are transported through the streams and rivers into the lake. Lake Chivero is now heavily polluted and eutrophic as a result of this phenomenon (*Nhapi, 2009:4*).

The development of a landfill in close proximity to the headwaters may intoxicate the lake to the extent that the city may be without a usable water source. It is therefore expedient to conduct a careful analysis of the optimum site for this potentially hazardous facility.

The extent of the contamination will depend on a number of factors inter alia the nature of the waste to be disposed, soils chemistry and composition, natural geology and geomorphology of the disposal site. The potential impact of the landfill may well be quite severe if it is unchecked by careful planning and design considerations. Poorly sited landfills will inevitably endanger the health of both the environment and the surrounding community groups. In such an instance, the costs of remediation of a poorly sited landfill will completely outweigh the initial marginal benefit of waste removal.

1.6.2 Research Contribution

Land-use suitability investigations direct urban planners to the most appropriate locations for elected land-use functions (*Klosterman, et al , 2000:189*). Through land suitability analysis we are able to test the planned activities against the natural intrinsic landscape characteristics and thus determine whether the planned activity would be suitable or unsuitable for that particular location (*Jafari and Zarendar, 2010:5*). The result of such an assessment is a land use planning strategy that takes advantage of the landscape's inherent characteristics and features and attains a more ideal location for land-use activities. Furthermore, the outcome of this inquiry is a selection which minimizes environmental impact and meets the social economic and environmental expectations.

The land use suitability investigations conducted in this research intend to assist the Harare City Council planning department in making a sustainable land allocation with regards to a new sanitary landfill.

Chapter 2 Background

2.1 Contextual Background

2.1.1 Waste and Landfill Site Selection

Human activity on planet earth is accompanied by the generation of waste. This derivative may be recycled, reused or reduced before it is ultimately discarded as waste. According to the Zimbabwean Waste Management Act 16 of (2005, 20:27), waste “includes domestic, commercial, or industrial material, whether in a liquid, solid, gaseous, or radioactive form, which is discharged, emitted or deposited into the environment in such volume, composition or manner as to cause pollution.”

Similarly, South Africa’s National Environmental Management Waste Act (*Republic of South Africa, 2009:16*) defines waste as, “any substance, whether or not that substance has been reduced, recycled and recovered-

- (a) That is surplus, unwanted, rejected, discarded abandoned or disposed of ;
- (b) Where the generator has no further use of for the purposes of production, reprocessing or consumption;
- (c) That must be treated or disposed of ; or
- (d) That is identified as waste by the Minister, but –
 - i. A by product is not considered waste
 - ii. Any portion of waste, once reused, recycled and recovered, ceases to be waste”

Although waste generation may be minimised and some wastes may be reused or recycled, the inevitable result is waste disposal since waste production cannot be entirely avoided. According to the Zimbabwean Waste Management Act 16 of 2005 (2005, 20:69), waste is supposed to be disposed of at designated waste disposal sites or landfills.

The American Heritage Science Dictionary (2011) defines a landfill as a depository where unwanted solid materials are discarded and sandwiched between layers of dirt in order to minimise pollution. Landfill is thus a safer and more acceptable method of waste

disposal. The development of engineered geo-membranes and linings, which prevent the passage of pollutants from the depository, has resulted in the creation of ‘sanitary landfills.’ These are acclaimed as the safer and more acceptable means of waste disposal (*Josimovic and Maric, 2012:514*).

2.1.2 The History of Waste Disposal

The origin of civilization in the form of human settlements confronted the ultimate consequence of waste generation and disposal. Consequently, waste management practices evolved and developed together with civilizations and technological advancement. The challenge of waste disposal occurs in that, once waste has been created, there is no inconsequential means to completely eradicate or eliminate it.

Every settlement in history has had to address the question of how to handle the waste that is produced by daily activities and developmental processes. There have been several approaches throughout history as mankind sought to answer this basic question.

Man’s first approach to handle waste was to simply allow it to accumulate at the point of generation. Initially, this occurred in the cities of ancient civilizations such as the Turkish city of Troy where layers of waste that accumulated over the centuries were unearthed by archaeologists (*Eblen and Eblen, 1994:9*). Although the rubbish mainly consisted of biodegradable materials, it is evident that the inhabitants periodically covered the accumulated waste with a fresh layer of clay. Historians and archaeologists have discovered that the height of accumulated waste in Troy varied between one and half meters and four meters per century. Due to the raised floor levels, the door openings and roofs also had to be subsequently raised (*Rathje and Murphey, 2001:10*).

This first approach, although convenient, had several inherent disadvantages. The accumulated biodegradable waste released a pungent odour as it degenerated. In addition, the rubbish impeded circulation in and around the dwelling. Consequently, mankind sought for ways to separate his living environment from the waste he generated. It was in this instance that mankind began to deliberate the question of the best location for waste disposal.

The Egyptian civilization, which flourished between 1200-1500BC, similarly faced the challenge of domestic solid waste accumulation. Rathje and Murphy (2001:13) unveil evidence that waste collected from the elite households was disposed in the Nile River. Due to the high demand for the finite freshwater resource, the disposal of waste in water bodies is now considered an unacceptable practice.

Mankind's second approach to handle waste was to bury the waste in pits. This was first practiced in the Cretan capital city, Knossos, where archaeologists have discovered large waste disposal pits. Their findings indicate that these refuse pits date back as far as 3000BC (Rathje and Murphey, 2001:18). Furthermore, ancient Chinese towns and cities established a system of waste collection and pit burial by 2 B.C. which was implemented by an organized workforce.

The first organized city-wide waste disposal site was created by the ancient Greeks in 500BC (Eblen and Eblen, 1994:24). Archaeologists and historians have discovered that the Greeks established a system of waste separation and segregation and put in place strict laws that administered waste management. The evidence indicates that leaders of Athens outlawed the irresponsible 'dumping' of waste in the city streets and allocated specific areas where domestic solid waste was to be discarded. The ancient Greeks elected a site a distance of two kilometres away from the city wall to act as the official waste disposal site for the entire city (Eblen and Eblen, 1994:24). Waste regulations implemented in Greece limited the extent of local waste accumulation therefore Greek cities were not buried in waste, as was the case with other ancient towns and settlements.

Mankind's third approach to waste disposal was open dumping. This practice became rampant during the Middle Ages in Europe. Waste was discarded in the streets and public squares. The piles of rubbish that accumulated attracted scavenging animals such as rodents, flies, fleas and birds. Byme (2004:7) notes that these unhealthy conditions facilitated the spread of diseases. The deadliest disease was the bubonic plague also known as, 'Black Death' which occurred between 1348 and 1351. This plague killed between seventy-five and two hundred million people (Byme, 2004:8).

Through this tragic experience, city founders and administrators realized the importance of maintaining sanitary living environments in order to safeguard human health and preserve life. To this end, Great Britain employed the strategy of waste collection. They elected a special taskforce to clean the streets and clear away the trash from the city on a weekly basis. Furthermore, in 1938, Great Britain outlawed the dumping of refuse in public streets and open waterways (*Herbert, 2007:5*).

The industrial revolution initiated the mechanization of industrial processes and the production of machine made products instead of hand crafted goods. This then marked the advent of the packaging of machine made products in paper and plastic. Although the packaging of goods assisted their handling and protection, it created a material, which needed to be disposed once the product was received, and the packaging was no longer necessary. Packaging thus magnified the volume of waste tremendously.

The fourth approach to waste handling became widely practiced between 1700 and 1900 due to the sheer volume of disposed packaging. The idea was to incinerate the waste and use the heat produced to generate electricity. Great Britain was the mastermind of this approach and constructed two hundred and fifty massive plants where waste was burnt and electricity was generated from the heat recovered. These plants identified as ‘the destructor’ were first established in Nottingham in 1874. (*Herbert, 2007:17*). The ash residues of the combustion were then transported to a selected landfill site.

The idea to retrieve energy from waste, though noble, proved impractical, uneconomical and inefficient due to the moist components of waste. These required additional coal to facilitate the burning process, which was often incomplete. Furthermore, large-scale incineration of municipal solid waste was disqualified due to air pollution and its detrimental impact on air quality (*Chadwick, 1842:349*).

2.1.3 The Challenge of Waste Generation

Solid waste is arguably the most pernicious by-product of urbanization and its associated resource intensive, consumer-based lifestyle. Urban dwellers are alleged to generate twice as much waste as their rural counterparts (*Hoonweg and Bhada-Tata, 2012:8*).

Therefore, as the world becomes increasingly urban, the corresponding volume of solid waste generated continues to rise. Today, more than fifty percent of the world's population now lives in cities, and forty-seven percent (47%) of these reside in the developing countries. Africa is expected to be fifty percent (50%) urbanized by 2035. Projections are that urban settlements will continue to grow in size in all regions of the world and attain a level of urbanization of sixty seven percent (67%) by 2050 (*United Nations Department of Economic and Social Affairs, 2012:1*).

Increased urbanization creates more affluent lifestyles characterized by consumption of more industrialized goods and services. Furthermore, commercialized technological innovations in recent years have fuelled the consumption patterns of urban dwellers. This has resulted in increased per capita waste generation. In 2001, there were an estimated 2.9 billion urban dwellers and each of these produced an average of 0.64 kilograms of municipal solid waste daily. As a result, 0.68 billion tons of waste was generated globally in 2001. However in 2011, the population of urbanites had increased to three billion and each person produced an average of 1.2 kilograms of municipal solid waste daily (*Hoonweg and Bhada-Tata, 2012:ix*). This amounted to 1.3 billion tons of waste.

Although the figures in the afore mentioned argument are averaged between developed and developing countries, they do unveil the concerning global trend of increasing per capita waste generation in recent years. In light of this progression, the 4.3 billion urban population of 2025 will probably produce 1.42 kilograms of waste per capita per day, amounting to 2.2 billion tons of waste annually (*Hoonweg and Bhada-Tata, 2012:ix*).

Rapid urbanization is anticipated in the developing world in the next two decades. Waste generated is expected to more than double between 2011 and 2031 (*Hoonweg and Bhada-Tata, 2012:ix*). The present uncontrolled disposal of waste poses a serious threat to the environmental quality of these cities, exposing the residents to pollutants and resulting in respiratory ailments, diarrhoea and dengue fever. If waste management infrastructure is not further developed within the same time interval, the impacts will be tragic. The strategic planning of waste management in developing countries, such as Zimbabwe, is therefore an urgent priority.

2.2 Waste Management Principles

2.2.1 Integrated Waste Management

The primary goal of every waste management strategy is to reduce the amount of waste generated by the residents of any given locality. Agenda 21 (1992:21.5) advocates for an environmentally sound management of waste. This approach, “*must go beyond the mere safe disposal or recovery of waste that are generated and seek to address the root cause of the problem by attempting to change unsustainable patterns of production.*” (United Nations, 1992:21.2)

Agenda 21 endorses the following objectives:-

- a. Minimising Waste
- b. Maximising environmentally sound waste reuse and recycling
- c. Promoting environmentally sound waste disposal and treatment
- d. Extending Waste Service Coverage (United Nations, 1992:21.2)

These objectives of waste management are illustrated in the Fig.1.



Fig. 1- The Integrated Waste Management Hierarchy
(EPA,1995)

Section 21.27 of Agenda 21(1992:21.5) acknowledges that even when integrated waste management principles are applied; namely avoid, reuse and recycle; these are incapable

of completely eradicating the waste. Landfills are therefore inevitable. In addition, the nature of the wastes disposed will unavoidably have an impact on the receiving environment. The magnitude of such impacts is dependent on the disposal techniques, the vulnerability of the disposal site to contamination and the management of the waste disposal facility.

2.2.2 Precautionary Principle

Waste disposal in landfills has inherent risks associated with environmental contamination of the air and soil and groundwater resources. Since human life is at risk, it is important to consider the values established by principle 15 stated at the United Nations Conference on Environment and Development (1992:1):-

“In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.” (United Nations, 1992:1). This principle advocates for the duty of care and the application of cost effective strategies to safeguard the environment from degradation.

2.2.3 Sustainable Development

The principle of ‘sustainable development’ is “development which meets the needs of the present without compromising the ability of future generations to meet their own needs.” (United Nations, 1987). Applying the principle of sustainable development to landfill development implies that the waste disposal location must not adversely affect the quality of life of future generations. In order to fulfil the mandate of sustainability, it is necessary to avoid locating landfills in areas with significant natural resource qualities including wetlands, high yielding aquifers, and protected ecological areas. In addition, adoption of landfill systems, which accelerate waste degeneration and rapid leachate collection, treatment and reuse, would ensure the minimizing the impact of the landfill for future generations.

Chapter 3 Study Area

3.1 The City of Harare

The city of Harare is the commercial and administrative capital of the Republic of Zimbabwe. The city was established by a group of British settlers named the pioneer column in 1880. They named the city ‘Fort Salisbury’ and hoisted the Union Jack at the highest pinnacle in close proximity- the Kopje. Historically, Harare was established as the central location of administrative and judicial functions; initially in the Federation of Rhodesia and Nyasaland (1953-1963) and later on in the capital city of Southern Rhodesia (1963-1969), Rhodesia (1970) and finally Zimbabwe (1980).

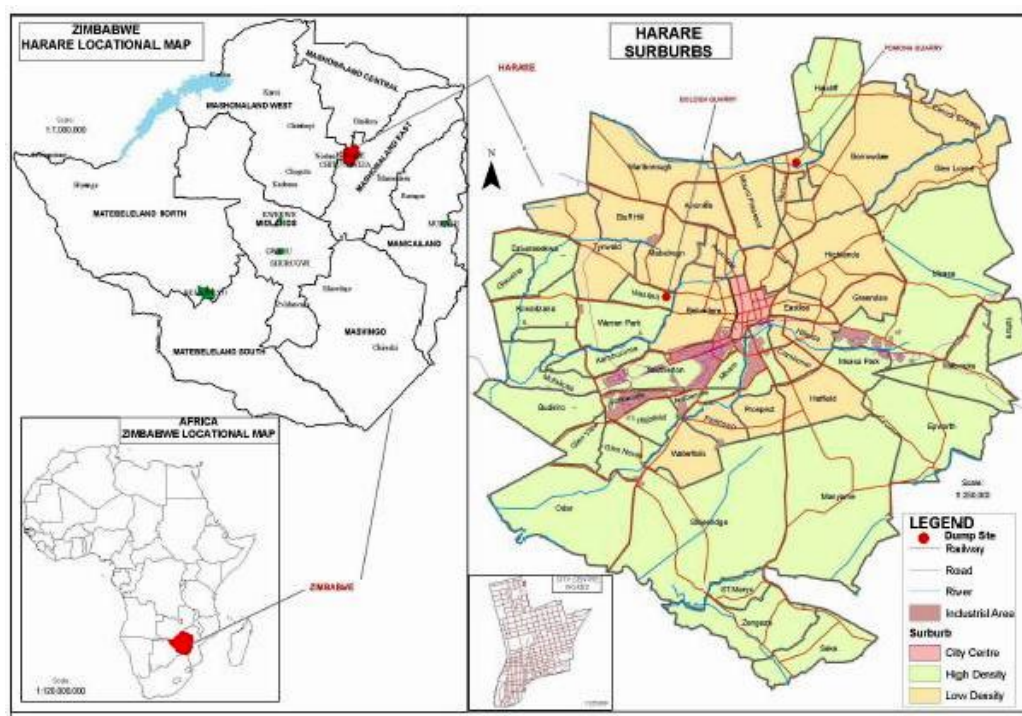


Fig. 2- The Location of the City of Harare
(Tsiko and Togarepi , 2012)

The location of the city of Harare is indicated in Fig. 2. The city of Harare consists of a central business district laid out in a grid street pattern. Residential suburbs are located on the north, east, south and west. Industrial areas fall along the railway lines and act as a buffer between the Harare North and Harare East (low density suburbs) and the Harare South and Harare West residential areas.

3.2 Waste Management in Harare

3.2.1 Waste Regulations

The desire for a healthy and hygienic environment motivated the establishment of Zimbabwe's waste management regulations and ordinances. The first regulations which influenced waste handling were contained in the public health act which was enacted in 1924 (*Magadzire and Maseva, 2006:13*)(*Muza, 2006:10*). This statute of law enforced the operations of sanitary inspectors who were responsible for ensuring that the environment in and around Harare's neighbourhoods was safe and free from refuse and litter.

The second ordinance, which legally enforced waste management regulations, was the Salisbury Sanitary and Refuse Removal Byelaws. These were instated in 1948 (*Muza, 2006:10*). The Salisbury Waste Management Byelaws Statutory Instrument 477 of 1979 outlawed the disposal of waste in public open spaces and vacant lands. In addition, the byelaws mandated that specific confined disposal sites be elected where all waste was to be disposed. Furthermore, the byelaws introduced the concept of regular waste collection. Waste was collected by designated members of the council once per week, and subsequently transported to the protected disposal site.

Lastly, the instrument placed the entire responsibility of waste collection and disposal on the local authority and their workers. These would collect the waste and subsequently transport it to the designated waste disposal site. In the exceptional case where the local authority was unable to collect the refuse; a special permit was issued which allows the owner of the waste to transport and dispose his or her own waste.

3.2.2 Waste Collection System

The waste collection policy for the city of Harare was established by the Harare City Council Waste Management Department. The frequency of refuse collection according to economic sectors is summarized in Table 1. The Harare City Council has a fleet of refuse collection trucks that are responsible for the collection of waste from the various sectors at the specified intervals. The average capacity of the waste disposal trucks is six cubic meters.

SECTOR	WASTE COLLECTION
Household	Once a week
Industrial	Once a week
Central Business District	Daily
Market Place	Daily
Hotel	Daily
Hospitals	Once a week
Schools	Once a week
Colleges	Once a week

Table 1: Waste Collection System in Harare
(Mandimutsa, 2000:8)

However, between 2001 and 2010 the frequency of waste collection reduced considerably as a result of poor maintenance of the refuse collection trucks (Tsiko and Togarepi, 2012:700).

3.2.3 Waste Volumes

The residents of Harare generate approximately 0.481 kilograms of waste daily. The waste is predominantly biodegradable waste. Gumbo (2005), (Mandimutsa, 2000:8). Research conducted by Mandimutsa (2000:8) conducted a comparative study of the waste composition of low medium and high-density suburbs in Harare. The findings of this study are summarized in Table 2. From Table 2, it may be deduced that more waste is produced in the more affluent low-density neighbourhoods, such as, Borrowdale as compared to the higher density neighbourhood of Sunningdale.

CATEGORY	Sunningdale	Mabelreign	Borrowdale
Paper and Cardboard	11.7	13.5	23.1
Glass and Ceramics	0.8	2.3	6.5
Metals	0.8	1.1	4.0
Plastics	6.8	8.0	11.7
Leather and Rubber	0.6	0.3	0.7
Wood and Bones	0.6	0.3	0.7
Organic Matter	75.9	73.6	47.7
Textiles	2.1	1.1	3.8
Miscellaneous	0.8	0.2	2.3

Table 2: Waste Volumes in Select Neighbourhoods in Harare
(Mandimutsa, 2000:8)

3.2.4 Waste Classification

The city of Harare generates waste from domestic, commercial, industrial, institutional and construction activities. A research undertaken by the International Labour Office clarifies the constituents of the waste generated by each of the aforementioned activities. This classification is outlined in Table 3.

The city of Harare is yet to establish a structured system for segregating waste. Since all the waste is customarily deposited in black polyurethane bags; waste segregation would require additional human and financial resources. There is limited data on the volumes of the different material composition of the municipal solid waste generated in Harare (Mandimutsa, 2000:8) (Kativhu, 2006:3).

SOURCE	TYPICAL WASTE GENERATORS	TYPES OF SOLID WASTE
Domestic	Single and multifamily dwellings	Food wastes, paper, cardboard, plastics, cans, yard waste, textiles, leather, wood, glass, and household hazardous waste
Commercial	Stores, markets, office buildings, restaurants, shops, bars	Packaging and container materials (cardboard and plastics), used office paper, wood shavings, food waste, hazardous waste, electronic waste
Industrial	Light and heavy manufacturing	Housekeeping waste , packaging, food waste, demolition materials, slag, mineral tailings, electronic waste, batteries, pesticides, coolants, lubricants etc
Institutional	Police camps, barracks, schools, hospitals, prisons	Food wastes, used paper and plastics, used needles, syringes, and gloves, wood, steel, concrete waste etc
Municipal Services	High Density neighborhoods	Dust /sand, leaves, paper and plastics, used needles syringes and gloves
Construction Debris	New and old building sites	Wood, brick –stones, concrete, glass and metals

Table 3: Waste Volumes Generation
(*International Labour Office, 2007:16*)

3.3 Waste Disposal Sites

3.3.1. Golden Quarry Dump Site

The city of Harare has established two official waste depositories namely the Golden Quarry Dump Site and the Pomona Dump Site. Both of these dump sites operate as open landfills. The method of disposal at each of these sites is controlled tipping for municipal solid waste. After disposal, waste is distributed until it attains the form of a thin layer. Thereafter, the waste is compacted by bulldozers or other suitable compaction machinery. Lastly, the disposed waste is covered with 200mm thick layer of soil. This sequence of waste disposal is repeated creating a multilayer waste dump.

The Golden Quarry dumpsite is located in the South West part of Harare in the direction of the National Sports Stadium. As the name suggests, the Golden Quarry dumpsite was reclaimed from an abandoned gold mine in 1985 and began to function as a waste disposal site. Initially waste was dumped in the abandoned mine's open shafts and pits. The location of Golden Quarry dumpsite is highlighted in magenta colour in Fig 3.

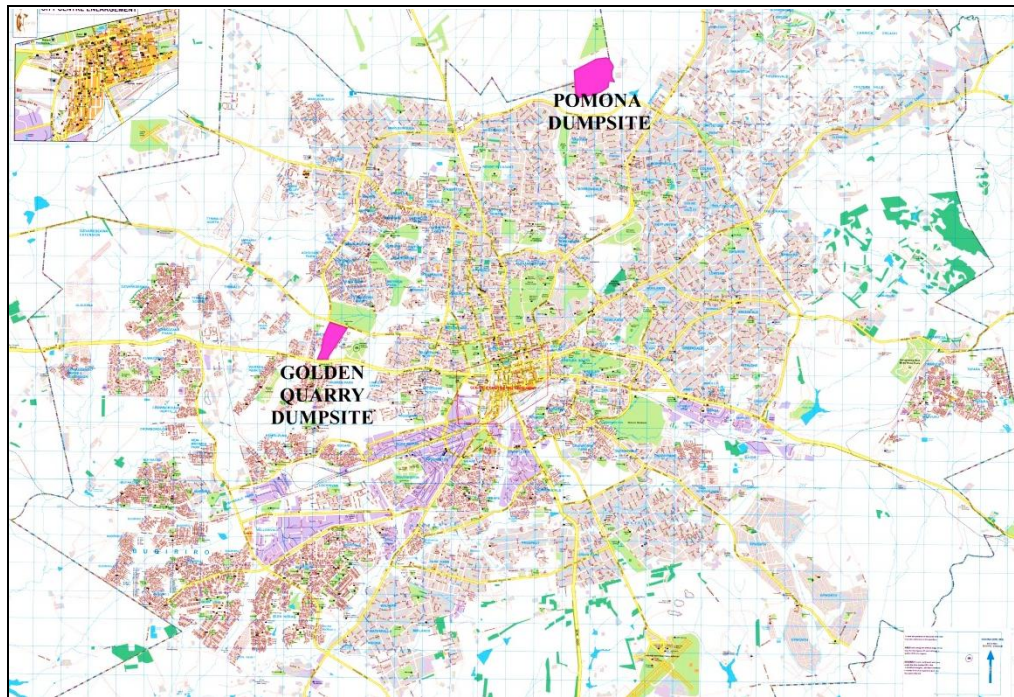


Fig. 3- Location of Golden Quarry and Pomona Waste Depositories

Golden Quarry waste depository receives waste generated in the Central Business District and the industrial areas which consist of hazardous waste, medical waste and e-waste (Tevera 1991:11) (Mandimutsa,2000:5). Furthermore, this waste disposal site assimilates domestic waste from the adjacent high density residential areas namely:- Mufakose, Dzivaresekwa, Westlea, Kuwadzana and Warren Park.

3.3.2. Pomona Dump Site

The Pomona Garbage dump site was established as a waste depository for Harare North and Harare East suburbs in 1982. The location of the Pomona dumpsite is shown in Fig. 4. This dumpsite is located twelve kilometres away from Harare's central business district (Tsiko and Togarepi, 2012:701).



Fig. 4- Pomona Municipal Solid Waste Dump Site
(*Nacquitak, 2010*)

3.4 Summary

A basic system of waste collection and waste disposal has been established in Harare. However, the city of Harare urgently needs to develop a more comprehensive waste management strategy that further incorporates aspects of waste segregation. This classification system will separate the materials which can be re-used or recycled from the waste stream, thereby minimising the volume of waste disposed and prolonging the lifespan of the of the municipal landfill sites. Furthermore the sorting of waste at the source will reduce the volume of hazardous substances included in the refuse and minimise the pollution caused by waste disposal.

Due to the continued disposal of unclassified waste at the Pomona and Golden Quarry landfills over the past thirty years, these two waste dumps have become toxic and exceeded their handling capacity of municipal solid waste. It is therefore expedient to develop a new sanitary waste depository that will accommodate the residual municipal solid waste after it has been segregated.

Chapter 4 Literature Review

4.1 Landfill Site Selection Guidelines

The judicious location of landfills is acclaimed to be the ultimate strategy to manage the potential hazards imposed by the development of municipal solid waste depositories (E.P.A., 1996:2). Consequently, a number of nations have developed guidelines and manuals to direct town planners and developers in the selection of appropriate locations for landfill development such as Germany (German Geotechnical Society, 2009:2), Malaysia (Giam, 2004:2) (Ismail and Manaf, 2012:92), Australia (D.U.A.P, 1996) and United States of America (EPA, 1998:4).

The Department of Urban Affairs and Planning regulates the selection of sites for landfill development in New South Wales, Australia. This administrative unit has published comprehensive guidelines for landfill site selection (D.U.A.P, 1996). Furthermore, this department has clearly defined environmentally sensitive areas that are inappropriate for landfill development.

Landfill site selection in Germany follows four basic phases namely:- exclusion criteria, evaluation criteria, site investigation and final decision. Table 4 summarises the activities of each stage of the landfill site selection procedure.

Condensation of Information	Steps and Criteria	Reduction of Areas
Phase 1: Exclusion Criteria	Data collection and exclusion of unsuitable areas-Negative Mapping	Total Area
Phase 2: Evaluation Criteria	Identification of possibly suitable areas-Positive Mapping	Reduction to 4-6 sites
Phase 3: Site Investigation	Site Investigation: physical technical, geological, hydro-geological and geotechnical reconnaissance, environmental assessment, comparative site rating	Reduction to 2-3 sites
Phase 4: Final Investigation	Final proposal and final decision	1 site

Table 4- Landfill Site Selection Procedures
(Oetzschner, 2009:2)

Malaysia is an example of a developing country which has devised an elaborate system for landfill site selection. The methodology used for site selection is the Constraint Mapping Technique (Giam, 2004:2) (Ismail and Manaf, 2013:92). The Constraint Mapping Technique involves eliminating the unsuitable areas and undertaking a careful

selection of possible landfill sites from the remaining area. This selection is based on critical social, economic and environmental parameters (*Giam, 2004:2*).

4.2 Landfill Site Selection Criteria

4.2.1 Criteria for Landfill Site Selection

Introducing a new waste disposal site into an existing urban matrix which has pre-defined land use systems requires careful planning and observation in order to ensure that the new facility harmonises with the existing context. The factors which influence the location of municipal solid waste depositories were identified through literature review. These include inter alia: - the existing land uses, topography, geology proximity to the C.B.D., main road, residential areas, water-bodies and wetlands, and the airports.

4.2.2 Existing Land Uses

It is important to consider the current land-use of the site, which is to be converted into a waste depository as some land-uses are more adaptable than others. Ideally, waste disposal facilities should be developed on undisturbed ground. Therefore, landfill development is more fitting on barren uncultivated pastureland as compared to cultivated agricultural land (*Josimovic and Maric, 2012:512*). Cultivated lands are less suited to the landfill function due to its high permeability as a result of frequent tillage. In Malaysia, grassland and existing forest areas are considered ideal sites for landfill development (*Gaim, 2004:3*). Nonetheless, vacant land is scarce within cities due to the high competition for land. Consequently, local authorities often resort to the adoption of defunct areas such as excavations or quarries (*Carey, et al, 2000:30*). For example, before the Golden Quarry Mine was officially elected as Harare's municipal waste depository, the Harare City Council had identified Peterborough brickfields quarry mine and Hampden brickfields quarry mine as potential landfill sites. Although such locations provide the space required for waste disposal, there is need for such sites to be rehabilitated and stabilised before they can effectively act as waste depositories.

4.2.3 Proximity to Residential Areas

Landfills are often classed as Locally Unacceptable Land Uses (L.U.L.U.) particularly by the residences who dwell in adjacent neighbourhoods. Since landfill development is associated with air, surface and groundwater pollution, the community adjoining the

waste disposal facility is most affected by these negative impacts (*International Waste and Landfill Symposium, 2005*). Land which is situated in close proximity to residential developments, educational facilities or hospital facilities will not be optimal for waste disposal as this will expose vulnerable populations to pollutants thereby endangering public health. The proximity of the landfill to residential developments is therefore a critical factor that determines the social acceptability of the facility.

Although the Environmental Protection Agency (E.P.A.) states that the minimum regulated distance of the landfill from the residential development is five hundred meters (*EPA, 2006:8*), experience proves that a distance of two thousand five hundred meters is more socially acceptable (*Josimovic and Maric, 2012:511*). Furthermore, it is recommended that a fifty meter wide vegetated buffer zone be established within this intermediate area (*Department of Environment, 2008:6*). This reduces odours, assists in the ventilation of the landfill and breaks the flow of prevailing winds which may otherwise carry odours over a large distance.

4.2.4 Proximity to Road Network

Due to the hazardous nature of waste disposal, it is recommended that landfills be positioned in secluded areas and situated at least one hundred meters away from the main road (*Giam, 2004:5*). However, vehicular accessibility to the proposed waste depository is an important consideration and imperative to the disposal function. A waste disposal site should be easily accessible from both the primary and the secondary distributor roads. Giam (*2004:5*) notes that landfill sites that are distant from the road become more expensive to operate due to the increased transport costs. Therefore, it is recommended that the distance of the waste disposal site from the primary distributor road not exceed one thousand meters (*Josimovic and Maric, 2012:512*) and the distance from the secondary distributor road must not exceed six hundred meters (*Josimovic and Maric, 2012:512*).

4.2.5 Proximity to Airports

Landfills often attract scavenger bird species in large numbers. Such bird species may easily obstruct aircraft as they attempt to alight or descend. Although the United States

Environmental Protection Agency (1993:9) stipulates that the landfill may be situated three thousand meters away from the airport runway used by turbojet aircraft and at least one thousand five hundred meters away from the airport property for piston type aircraft; any landfill situated within an eight thousand meter radius of the airport is considered to be a potential hazard and requires careful surveillance by the United States Federal Administration. Therefore, it is recommended that landfill facilities be situated at least 9500 metres away from the public airport property (*Department of Environment, 2008:4*).

4.2.6 Proximity to Water Bodies

The disposal of waste holds the inherent risk of contamination of both surface and underground water bodies. A general guiding principle is that landfills should be constructed outside of the one-hundred-year flood-line of any permanent water course (*Department of Environment, 2008:4*) (*EPA, 1993:9*). Furthermore, the location of the waste disposal facility must be such that the one-hundred-year flood-line of any adjoining lake, river or stream is not exposed to storm-water surface runoff emerging from the landfill (*EPA, 1993:9*). Where the flooding potential of the stream or river is unknown, the landfill must be at least forty meters away from the watercourse (*EPA, 2006:8*). The Australian Department of Environment (*2008:4*) maintains that the preferred distance of the landfill away from adjoining water bodies is two hundred meters. Moreover, Josimovic and Maric, (*2012:512*) further insist that the minimum acceptable distance from the river is one thousand meters and they regard five thousand meters as ideal. Whilst this may be thought of as a highly conservative position, it is important to emphasize that each situation differs according to the site hydro-geological conditions. In the absence of pollution modelling, it is difficult to estimate the pathway of the leachate pollution plume therefore the precautionary approach is advisable.

4.2.7 Proximity to Wetlands

Landfill development in wetlands is strongly opposed due to the risks of surface and groundwater contamination, the potential disruption and death of endangered species and

the adverse impact on the delicate marine habitats and ecosystems (*EPA, 2006:4*) The United States Environmental Protection Agency (*1993:10*) restricts the development of landfill facilities within wetlands since the remediation of wetlands contamination by leachate may take several decades.

4.2.8 Topography

The vertical elevation and geomorphology of a site is a significant characteristic worthy of consideration when selecting a landfill location. Landfill disposal is most appropriate on flat land or gently sloping formations as opposed to rugged, broken terrain such as khastic landforms (*Josimovic and Maric, 2012:512*). Natural depressions or undulating terrain may also be used for this purpose. Mountain peaks or areas that are raised forty or fifty meters above the mean ground level are less suitable as compared to those raised by only a few meters (*Sumathi et al, 2008:6*). Furthermore, sites that have an inclination steeper than thirty degrees are unsuitable for waste disposal, as they are more susceptible to slide and fall. The United States Environmental Protection Agency (*1993:9*) requires all landfill developers to demonstrate that the location of the waste depository is structurally stable and will not result in debris flows, sinkhole formations, rock-falls or sudden liquidation.

4.2.9 Distance from Central Business District

Although waste depositories are generally considered to be, 'Locally Unacceptable Land Uses' (LULU's), they are more functional and economically viable when they are located closer to the point of waste generation. Where practical, it is preferable for the distance of the landfill to be no further than fifteen kilometres away from the point of waste generation (*Sumathi et al, 2008:6*). Sites that are between fifteen and twenty-five kilometres away from central business district may be considered despite the fact that may be less accessible (*Sumathi et al, 2008:8*). The Australian Department of Environment, recommends that locations further than fifty kilometres from the central business district be disregarded (*Department of Environment, 2008:7*).

4.2.10 Geology and Soils

The geology and soil composition of a locality can determine its suitability to function as a waste depository (*Giam, 2004:3*). The best locations are those which have an

impermeable clay layer which is at least ten millimeters thick and low associated rates of infiltration (*Rowe et al 1994:12*). Rocks of low porosity are only ideal as long as they remain solid without cracks or crevices. Once they are fissured they are rapid transmitters of leachate and thereby extend the pollution plume. Other highly permeable geological formations include limestone, dolomites and khash formations (*Department of Environment, 2008:5*). The United States Environmental Protection Agency prohibits landfill development in faulty landscapes (*EPA, 1993:9*). In addition, a buffer distance of at least six meters is required to separate the municipal solid waste depository from any faulty terrain (*EPA, 1993:10*).

The most probable impact of landfill development is groundwater contamination. Although this cannot be avoided entirely, civil engineering has devised geo-membranes, clay layers and similar base linings to protect the subsurface from leachate infiltration and subsequent soil and groundwater pollution (*Rowe et al 1994:12*). The presence of a naturally occurring, non-porous impermeable layer of soil is highly advantageous as it acts as an aquitard to the leachate thereby preventing it from contaminating any aquifers below.

The extent of such protection will depend on the bulk hydraulic conductivity of such a clay layer which is in turn determined by its porosity, grain size distribution and mineralogy (*D'Astous et al , 1989:52*), (*Herzog et al, 1989:84*), (*Yanful et al, 1988:528*). Munawar and Feller (*2013:10*) maintain that landfills should be developed where the soil has a hydraulic conductivity less than 1×10^{-8} m/s. Where the landfill incorporates a leachate collection system, the rate of motion of the contaminant will be greatly reduced due to a lower hydraulic gradient. This will secure the groundwater still further (*Rowe et al, 1994:12*), (*Rowe, 1991:248*).

4.3 Multi-Criteria Decision Analysis

4.3.1 Definition

Multi-Criteria Decision Analysis (M.C.D.A.) is a structured system which enables the investigation of alternative solutions in the context of conflicting objectives (Voogd, 1983:21). M.C.D.A. creates a conducive problem solving environment where a clear and effective collaborative decision making process can take place. The techniques which form M.C.D.A. identify the separate choice preferences of various stakeholder groups. M.C.D.A. system makes it possible for decision makers to consider and evaluate the tradeoffs between policy objectives and thus creates a mechanism by which compromise alternatives may be explored (Jankowski et al, 1997:581) (Sage, 1991:31). Furthermore, M.C.D.A. creates a platform where decision-makers can interpret, evaluate and analyse the potential impacts of a course of action. This platform makes it easier to evaluate alternatives and select the best option which maximises the benefits whilst having the least impact (Jafari and Zarendar, 2010:5).

4.3.2 Stages of Multi-Criteria Decision Analysis

There are three stages of M.C.D.A., namely, intelligence, design and choice (Simon, 1960:273). The sequence of the decision making process is illustrated in Fig. 5.

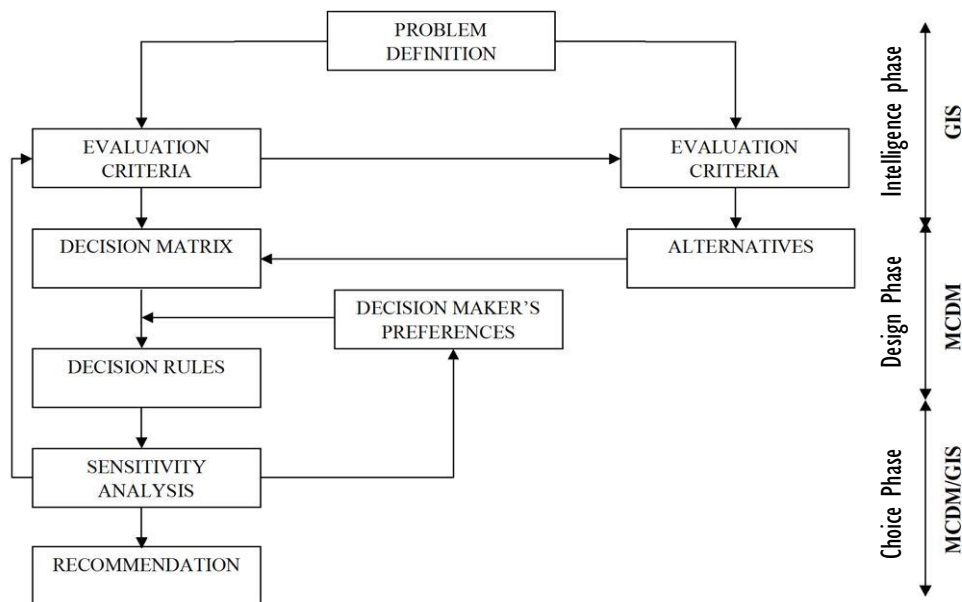


Fig. 5- Decision Flowchart for Spatial Multi-Criteria Analysis
(Malczewski, 1999)

The first phase of M.C.D.A. is the intelligence phase. During this phase the problem is analysed and evaluation criteria are identified together with the constraints. Within the G.I.S environment, the constraints are exclusionary areas, which are no longer

considered in the site selection process. The alternatives are the specific areas or domain where all the criteria are met.

The second phase of M.C.D.A. is the design phase. This is the phase where decision rules are applied after analysing the decision maker's preferences. Malczewski (1999) defines a decision rule as a procedure that guides the decision maker in the evaluation of alternatives and facilitates in the selection of a course of action. The Analytical Hierarchy process is an example of a decision rule often applied in decision-making.

The third and last phase of multi-criteria decision analysis is the choice phase. The choice becomes apparent after the application of decision rules. Sensitivity analysis is conducted to ascertain the reliability of the decision rule before the recommendations are made.

4.3.3 Land Use Suitability Analysis

Land use suitability assessment determines whether a specific location is the ideal place to conduct a particular activity (Steiner, 1991:19). Murphey (2005:80) maintains that land-use planning should be based on a comprehensive understanding of the landscape's intrinsic attributes. Conducting a land suitability assessment will unveil the entire composition of the landscape and assign activities to their best suited locations. This procedure is recognized as the best approach to land-use planning (Mc Harg, 1969:103).

Traditionally, land-use suitability analysis was performed by employing specialists of various disciplines to evaluate the decision problem and recommend the most appropriate location based on their expertise (Streinitz et al, 1976:450). However, the need to integrate the different ideas of all these various specialists into a single decision model resulted in the use of spatial data, to aid in the decision making process.

When land use suitability is being conducted, it is important to assess the compatibility of each activity with the existing landscape characteristics and site conditions. A systematic multi-factor analysis is required which integrates all the features of the landscape, biotic and abiotic, into a single model (Murphey, 2005:80). The overlaying of

translucent maps was devised in the early 20th century in order to facilitate an integrated site analysis (*Streinitz et al, 1976:450*) (*Malczeski, 2000:12*). Fig.6 is an example of a site suitability analysis where vegetation, topography, soil type, hydrology and geology maps are overlaid in order to ascertain the appropriateness for the development of either a parking lot, tennis court or access road (*Murphey, 2005:80*).

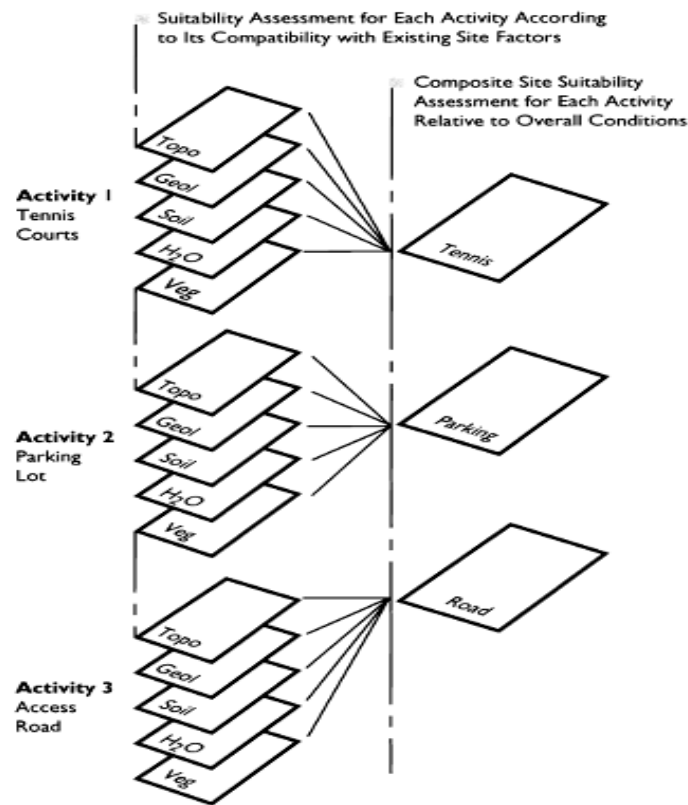


Fig. 6- Land Use Suitability Assessment – Map Overlay
(*Murphey, 2005:81*)

Map overlay techniques have evolved and developed considerably in the 20th and early 21st centuries. With the advent of computer technology, G.I.S. Software developed in recent years has enabled an automated map overlay system which not only evaluates the degree of specific locations with respect to a single factor, but also the weighted cumulative suitability of a number of predefined or set criteria.

4.4 Analytical Hierarchy Process

4.4.1 Definition

The Analytic Hierarchy Process is a method of weighting criteria developed by Professor L. Saaty in 1977. He defines it as, “ a theory of measurement through pair-wise comparisons and relies on the judgment of experts to derive priority scales” (*Saaty T.L 2008*). The Analytic Hierarchy Process is a tool that structures the decision-making process and achieves judgment consistency. This procedure enables the decision maker to prioritize the criteria which affect the decision, and thus to gain a deeper understanding of the alternatives.

The ‘priority scale’ is a scale that calibrates the alternatives according to the decision maker’s preference structure. Comparisons are made using a scale of absolute judgments that represent how much more one criteria dominates another with respect to a given attribute. This fundamental scale of absolute numbers was developed by T.L Saaty and is shown in Table 5. The methodology employed in deriving priority scales is that of ‘pair-wise comparisons.’ *Saaty T.L (1990)* emphasizes the importance of a system which captures the relative importance of various criteria and translates this into numeric ordinals along a calibrated scale.

The success of a decision support system is hinged on the structured mechanism by which it prioritises, organises or arranges ordinals and judgements. This system must possess the transparency and integrity which will prevent it from being vulnerable to bias and manipulation. In effect it simplifies the facilitation process and offers a transparent method of participatory planning.

<i>Intensity of Importance</i>	<i>Definition</i>	<i>Explanation</i>
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or Slight	---
3	Moderate Importance	Experience and judgement slightly favours one activity over another
4	Moderate Plus	---
5	Strong Importance	Experience and judgement strongly favours one activity over another
6	Strong Plus	---
7	Very Strong or Demonstrated Importance	An activity is strongly favoured over another, its dominance is demonstrated in practice
8	Very, Very Strong	---
9	Extreme Importance	The evidence of favouring one activity over another is the highest possible order of affirmation
2,4,6,8,	Intermediate Values between the two adjacent judgments.	When compromise is needed

Table 5: The Analytical Hierarchy Process Scale of Values
(Saaty, 2008:85)

4.4.2 Creating a Hierarchy

There are four basic stages to performing the Analytic Hierarchy Process. The first stage is to structure the decision problem in the form of a hierarchy. Saaty (1990:11) upholds that a hierarchy is an ordered arrangement of factors according to their level of significance. The first level of the hierarchy depicts the goal or the aim of the decision. The second level of the hierarchy depicts those criteria that will affect the achievement of the goal. The third level of the problem hierarchy consists of alternatives. The concept of the hierarchy is illustrated in Fig. 7.

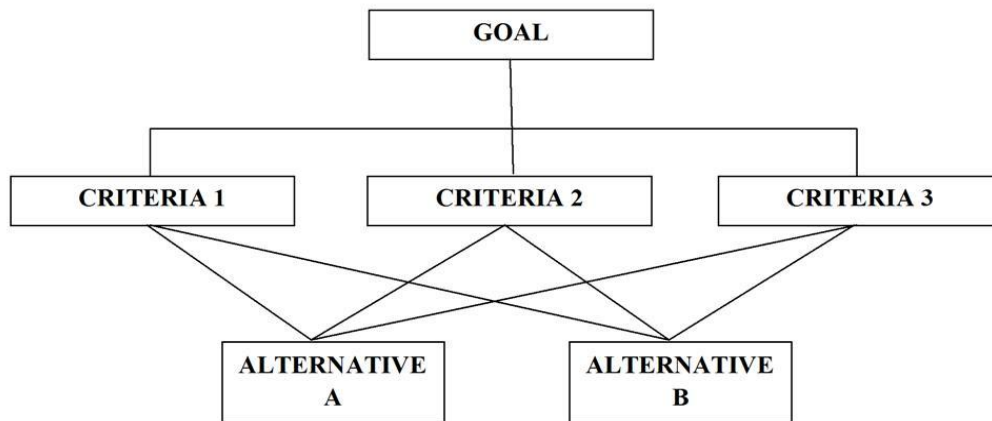


Fig. 7-Analytical Hierarchy Process:-Hierarchy

Adapted from (Saaty, 1990:11)

The first level of the hierarchy represents the goal. In the case of this research the goal is to select a suitable alternative site for waste disposal in Harare. The second level of the hierarchy relates to the criteria. The third level is that of alternatives. These are areas where all the criteria are satisfied and within these zones there are possibilities of satisfying the project requirements.

4.4.3 Pair-wise Comparisons

The second stage of the Analytical Hierarchy Process (A.H.P.) is pair-wise comparison. This is derived from the respondent's preference structure. Table 6 illustrates the pair-wise comparison based on the hierarchy illustrated in Fig 7. In undertaking pair-wise comparisons, the respondent decides upon the relative importance of one criterion over another on a scale of 1 to 9 (Saaty, 2008:85). The highlighted numbers reflect the respondent's preference structure according to the fundamental scale of absolute numbers by (Saaty, 2008:85).

4.4.4 Normalisation

Table 7 indicates the normalisation calculations performed in the Analytical Hierarchy Process. This comparison figure is compiled where the preference of the row is divided by the preference of the column. Normalisation occurs when the figures of the preference table are divided by the sum total of each column in the in comparison table. The total of each column in the normalisation table is 1.

Factor	Factor Weighting Score									Factor
	More important than			Equal	Less important than					
Criteria 1	9	7	5	3	1	-3	-5	-7	-9	Criteria 2
Criteria 1	9	7	5	3	1	-3	-5	-7	-9	Criteria 3
Criteria 2	9	7	5	3	1	-3	-5	-7	-9	Criteria 1
Criteria 2	9	7	5	3	1	-3	-5	-7	-9	Criteria 3
Criteria 3	9	7	5	3	1	-3	-5	-7	-9	Criteria 1
Criteria 3	9	7	5	3	1	-3	-5	-7	-9	Criteria 2

Table 6: A.H.P.- Pair-wise Comparison Matrix
Adapted from (Saaty, 1990:13)

FACTOR	Criteria 1	Criteria 2	Criteria 3
Criteria 1	1	5	9
Criteria 2	1/5	1	3
Criteria 3	1/9	1/3	1
TOTAL	1.3111	6.3333	13

Table 7: A.H.P. -Pair-wise Matrix Comparison Table
Adapted from (Saaty, 1990:14)

FACTOR	Criteria 1	Criteria 2	Criteria 3	TOTAL	AVERAGE
Criteria 1	0.763	0.789	0.692	2.244	0.748
Criteria 2	0.153	0.158	0.230	0.541	0.180
Criteria 3	0.085	0.053	0.076	0.214	0.071
TOTAL	1	1	1		1

Table 8: A.H.P. -Normalisation Table
Adapted from (Saaty, 1990:14)

4.4.5 Deriving Criteria Weights

The criteria weights are derived from the average of the normalised numbers from each row. These are shown in fractional form in the average column in Table 7. The resultant preference structure is 74.8% for criteria 1, 18% for criteria 2 and 0.71% for criteria 3. This weighting structure may be applied in weighted overlay techniques to account for the degree of influence of various criteria in the land use suitability assessment.

4.5 Overview

The location of municipal solid waste disposal facilities involves thoughtful consideration in order to ensure that the facility is environmentally sustainable, economically viable, and socially acceptable. Although landfills are potentially hazardous facilities, adhering to the prescribed guidelines and best practice recommendations for landfill location may greatly minimise the risk of soil, air, surface and groundwater pollution posed by municipal solid waste depositories. According to the literature reviewed the ideal site for landfill development is one which is :-

- i. Undisturbed grassland or forest.
- ii. At least two thousand five hundred meters away from adjacent residential areas.
- iii. Between two hundred and eight hundred meters away from the main road.
- iv. At least nine thousand meters away from the airport property.
- v. At least five thousand meters away from any streams, rivers or lakes.
- vi. At least one thousand meters away from wetlands.
- vii. At least six meters away from faulty terrain.
- viii. Within a fifteen thousand meter radius of commercial and industrial sites where the largest volumes of waste are generated.
- ix. Undisturbed grassland or forest areas.
- x. Consists of clay soil with a hydraulic conductivity that is less than 1×10^{-8} m/s.
- xi. Flat or gently sloping land with an inclination of between zero and thirty degrees.

Since there are a numerous factors to be considered when electing a disposal site for municipal solid waste, multi-criteria analysis is recommended in order to ensure that all factors are taken into account.

Chapter 5 Research Methodology

5.1 Research Design

5.1.1 Research Stages

The research was undertaken in several stages. Each stage involves the application of appropriate research tools and involved undertaking specific tasks, which facilitated the attainment of the stage results. Fig. 8a) and b) are flow charts which represents diagrammatically the steps taken in this investigation.

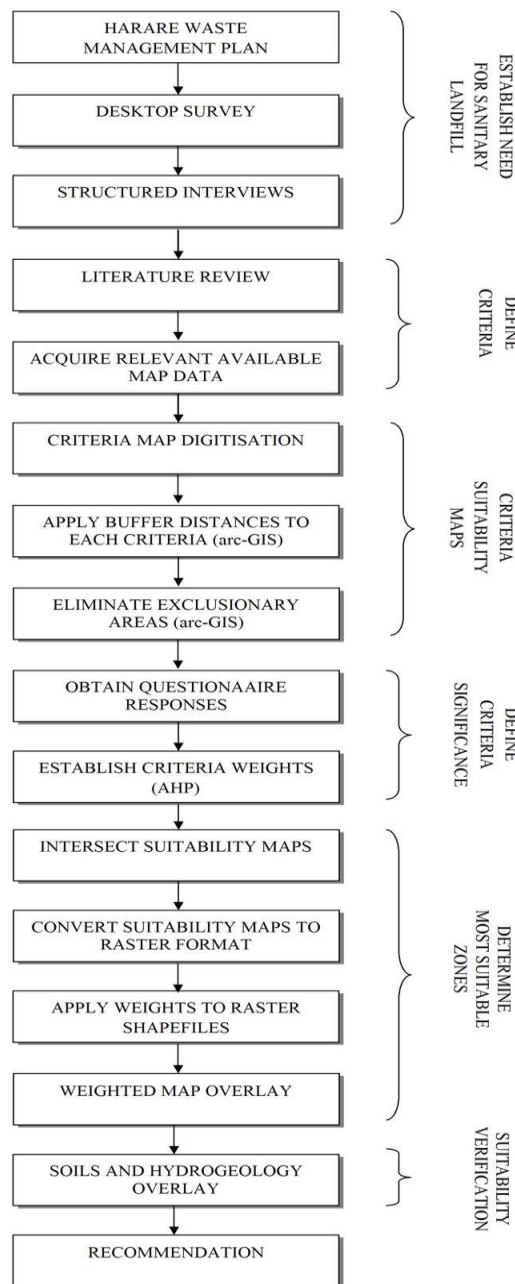


Fig. 8a)- Research Phases and Stages

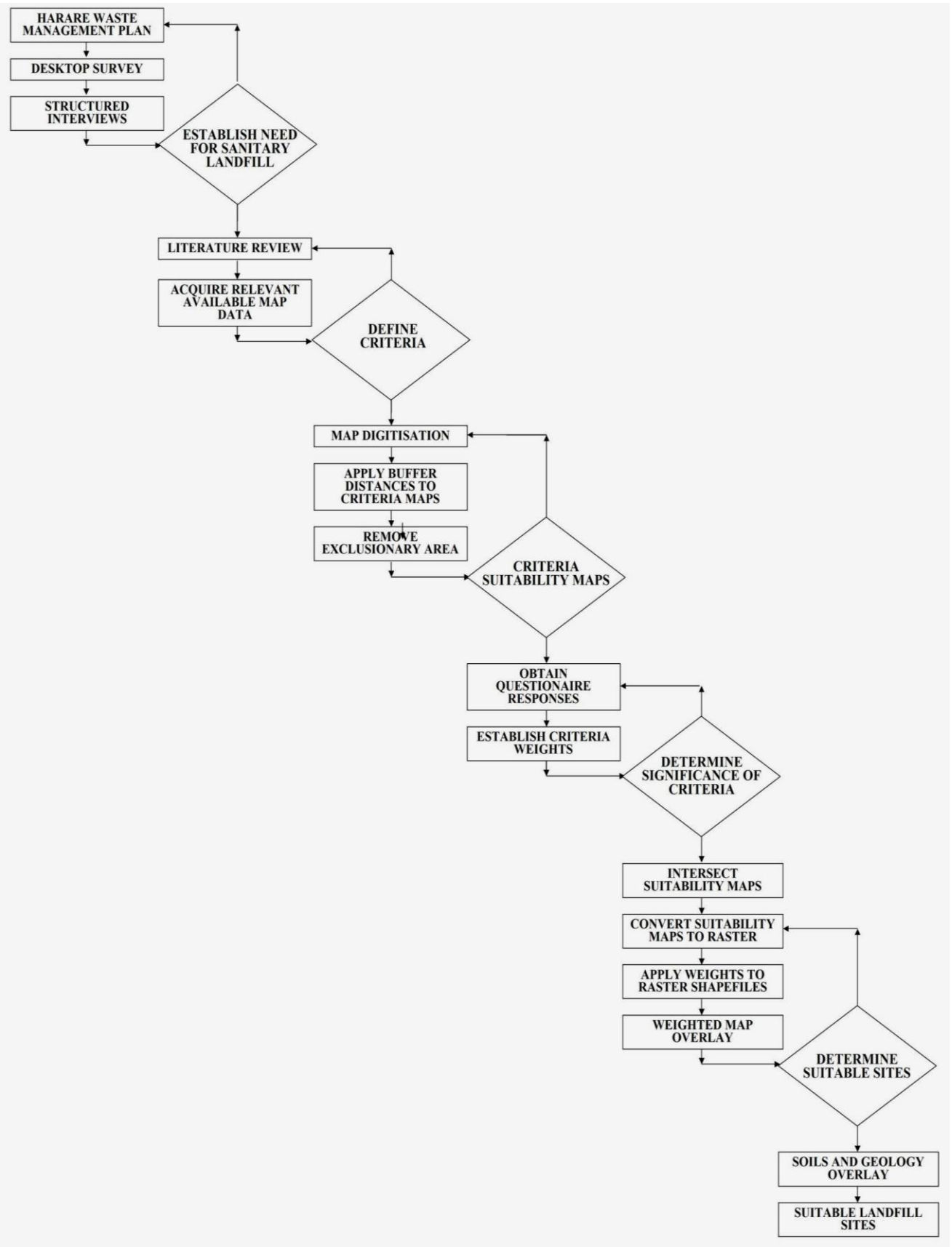


Fig. 8b)- Research Phases and Stages

5.2 Research Phases

5.2.1 Identifying the Research Problem

The first phase of the research was the identification of the research problem. This preliminary scoping was achieved by conducting a desktop survey of literature related to the topic and by conducting semi-structured interviews and discussions with representatives of the Waste Management Department of the Harare City Council and the Environmental Management Agency and with members of the town-planning department of the Harare City Council.

The desk-stop study conducted in the early stages of the research comprised a review of associated journal articles, internet articles and conference proceedings (*Tevera, 1991*) (*Nhapi, 2009*)(*Practical Action, 2006*).

The semi-structured interviews were conducted with three representatives from each of the aforementioned organisations. The answers of each of the respondents were noted. Thereafter, these answers were compared. If the response of fifty per cent of the respondents was coherent this position was accepted. However if an opinion was expressed by less than fifty per cent of the respondents, then this position was relegated.

5.2.2 Establishing Criteria

The second phase of the research involved determining the criteria which would be applied in the search for a suitable location for waste disposal sites for the city of Harare. The criteria used in this investigation were determined by the findings of the literature review and the available relevant map datasets for Harare.

Literature review was conducted by studying waste disposal guidelines developed by several countries and organisations (*E.P.A, 1993*) (*Department of Environment, 2008*) (*D.U.A.P, 1996*) in order to outline the international best practice guidelines for waste disposal site selection. This approach was taken because Harare's waste disposal guidelines were still being developed by the Environmental Management Agency at the time of the research.

From the literature review, twelve criteria were identified which determine the ideal location of landfill facilities:-

- i. Proximity to existing residential developments and community facilities.
- ii. Proximity to water bodies:- lakes, rivers and streams.
- iii. Proximity to wetlands and sensitive sites.
- iv. Proximity to cultural heritage sites and recreational areas.
- v. Proximity to industrial areas.
- vi. Proximity to transport routes and the accessibility of the site.
- vii. Proximity to commercial areas.
- viii. Distance away from airports.
- ix. Geomorphology and soil stability.
- x. Slope of the site and the elevation of the ground.
- xi. Soil type, soil composition and soil structure.
- xii. Hydro-geological conditions.

Having identified the critical factors deterministic in landfill location, the author sought for relevant map data pertaining to the aforementioned criteria. Information pertaining to the study fields was sourced from the National Surveyor General's office, the Environmental Management Agency, the Geological Survey Department, the Ministry of Agriculture and the University of Zimbabwe Survey Department. These maps are included in Appendix B.

Harare Street Map was acquired from the National Surveyor General's office. A digitised version of this map was acquired from the University of Zimbabwe, Survey Department. This map illustrates the distribution of residential built up areas, roads, rivers and streams, commercial areas, industrial sites and the location of the Harare International Airport. Fig. 9 depicts the digitised version of the Harare map.

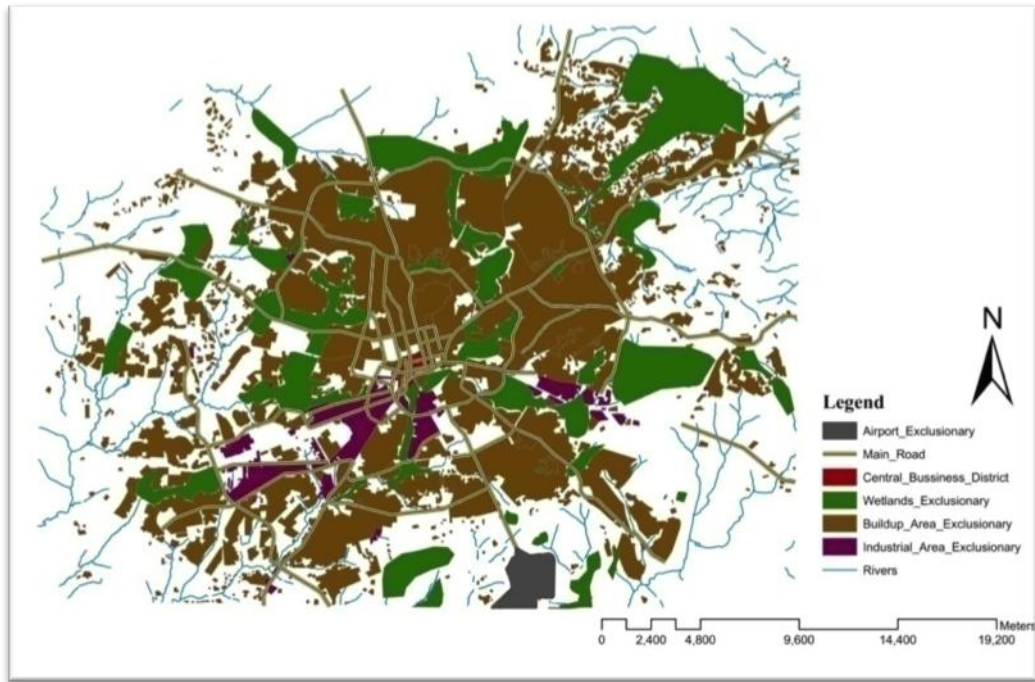


Fig. 9- City of Harare Digitised Map

Harare Wetlands Map was obtained from the Environmental Management Agency. This map illustrates the distribution of wetlands in the city of Harare. The author digitised the map and converted it into an ESRI shape-file in order to use the map in the Arc-GIS, Arc-Map interface.

Harare Geological Map was sourced from the National Geological Survey Department. This map illustrates the character of Harare's geomorphology and underlying rock formations.

The scale of the soils and topographical maps archived at the National Surveyor General's office differed significantly from the other data sets. The soils map that was available at the Ministry of Agriculture illustrated the national soils distribution. Due to the scale of the map, the distribution of soils in Harare was generalised with minimal variations. Similarly, limited map data was available on Harare's hydro-geological conditions. Despite the numerous boreholes in Harare, hydro-geological maps are yet to be developed which outline the positions of the low, medium and high-yielding aquifers.

Due to limited information availability, the final criteria considered in this investigation where:-

- i. Proximity to existing residential developments
- ii. Proximity to existing wetlands
- iii. Proximity to existing rivers
- iv. Proximity to the Central Business District
- v. Proximity to the industrial sites
- vi. Proximity to airports
- vii. Soil Type and underlying geological rock formations

5.2.3 Criteria Suitability Maps

The third phase of the research involved the generation of suitability maps for each criteria. Criteria suitability maps were created by extracting the relevant shape-files from the available map data, deciding on the appropriate buffer distances and eliminating all the exclusionary areas.

The shape files for rivers and streams, main roads, airport, industrial, residential and commercial areas were extracted from the digitised version of the Harare Street Map. The digital data sets collected from the aforementioned organisations had to be geo-referenced in order to convert all the shape files to a common co-ordinate system. The purpose of geo-referencing was to convert all the shape files of the various data sets into a universal scale and thereby depict relative position of distinct features. After geo-referencing, some of the shape files were converted from the WGS84 co-ordinate system to the GCS_WGS_1984 (Gauss) co-ordinate system. The shape-file for Harare wetlands was created by: - geo-referencing the image of the Harare wetlands map and tracing over the wetlands area using the Arc-Map editor.

The buffer distance interval for each criterion was established by considering the pattern of distribution of the field elements and the buffer distances applied in similar studies (*Josimovic and Maric, 2012*) (*Giam, 2004*) (*Sumathi et al ,2008*). The Arc-Map buffer tool was used to create the buffer zones around the shape files for each criterion. Each buffer was assigned a suitability ranking based on its buffer distance. Fig. 12a), 13a),

14a), 15a), 16a), 17a) and 18a) illustrate the outcome of the buffering procedure. The buffer tool was used to:-

- i. Map out zones of unsuitable, mid-suitable, suitable and optimum landfill locations based on their distance away from the residential areas.
- ii. Map out the zones of optimum, suitable, mid-suitable and unsuitable landfill locations based on their proximity to the wetlands in Harare.
- iii. Map out the zones of detestable, unsuitable, mid-suitable, suitable and optimum landfill locations based on their distance away from the industrial sites.
- iv. Map out the zones of optimum, suitable, mid-suitable and unsuitable landfill locations based on their proximity to the rivers in Harare.
- v. Map out the zones of detestable, unsuitable, mid-suitable, suitable and optimum landfill locations based on their distance away from the C.B.D.
- vi. Map out the zones of optimum, suitable, mid-suitable and unsuitable landfill locations based on their proximity to the primary distributor roads in Harare.
- vii. Map out the zones of optimum, suitable, mid-suitable and unsuitable landfill locations based on their proximity to the Harare International Airport.

‘Exclusionary’ areas are those places within the city of Harare where landfill establishment is not feasible. These are places where it is impossible to establish a waste depository due to the existing urban developments or site conditions. Such places include:-

- i. Areas where there are built up residential developments.
- ii. Area where industries have been established.
- iii. Areas where commercial developments have been built.
- iv. Areas that fall within a radius of 9000 meters from the airport.
- v. Wetland areas.
- vi. Areas where there are water bodies such as tributaries, rivers and streams.
- vii. Areas that fall within a distance of 250 meters away from rivers.
- viii. Areas that fall within a distance of 500 meters away from main roads.

The outcome of deleting the exclusionary areas is indicated in Fig. 13b), 14b), 15b), 16b), 17b) and 18b).

5.2.4 Determining the Significance of Criteria

The importance of each criterion was derived from the views of key decision makers and stakeholders. These views were solicited from them through a purposeful questionnaire. The structure of the questionnaire is included in Appendix A. Respondents who participated in the questionnaire were from the Environmental Management Agency, The Harare Residents Trust, the Harare Residents Association, and the Harare City Council Waste Management Department. Although ten questionnaire transcripts were distributed to each organisation there were only two respondents from the Harare City Council Town Planning Department, eight responses from the Harare Resident's Trust, six responses from the Harare Resident's Association, four responses from the Environmental Management Agency Waste Management Department, and two responses from the Confederation of Zimbabwe Industries. A summary of the questionnaire responses is included in Appendix A.

The questionnaire was used as a tool to measure the judgements of the relative importance of each criterion. The respondents were required to conduct pair-wise comparisons and compare the different factors. The respondents were required to judge whether the factors contribute equally to the location of the landfill or the one factor is more significant than another. The ranking scale that is used in this questionnaire is illustrated in Table 9.

Intensity of Importance	Importance	Degree of Preference
1	Equal Importance	Two factors contribute equally
3	Moderate Importance	I slightly favour one factor over another
5	Strong Importance	I strongly favour one factor over another
7	Very Strong Importance	I favour one factor very strongly compared to the other
9	Extreme Importance	I favour one factor extremely compared to the other

Table 9: Ranking Scale for Pair-wise Comparisons

The transparent choice software was selected to perform the integration of all the questionnaire responses through a digital application of the Analytical Hierarchy

Process. The criteria were indicated in the transparent choice software and resulted in the development of the hierarchy indicated in Fig.10.

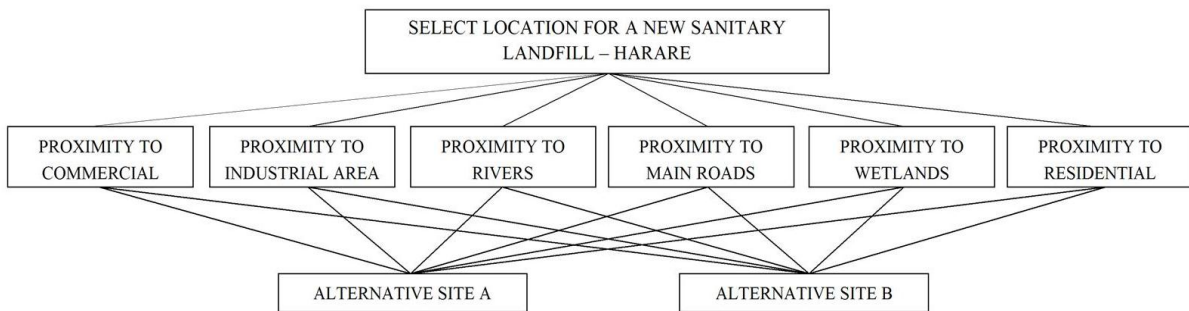


Fig. 10- Hierarchy- Harare Landfill Site Selection Criteria

5.2.5 Deriving Suitability Maps

The suitable zones for landfill development were determined using two distinct techniques in the Arc-Map spatial analyst tool set namely, 'intersect' and 'weighted overlay'. Both of these techniques apply the method of overlaying the various criteria maps in order to determine the areas that are most suitable for landfill development. This procedure is illustrated in Fig. 11.

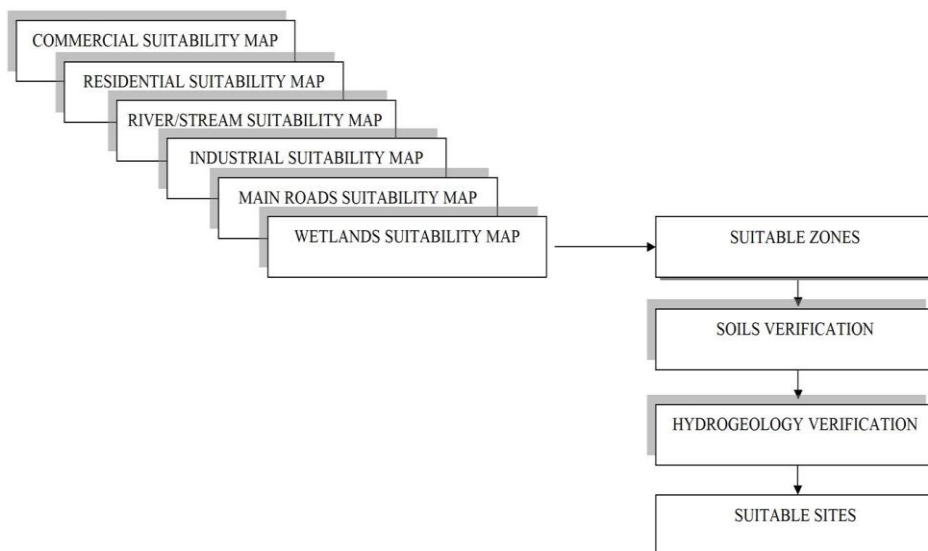


Fig. 11- Map Overlay Techniques

The map intersect tool was used to determine areas which were common suitable or optimum areas for all criteria. Table 10 illustrates the criteria buffer zones which comprise the common areas which hold potential for landfill development.

CRITERIA	BUFFER DISTANCE	CLASIFICATION
Rivers and Streams	1250-1500m	Suitable
	1500-3000m	Suitable
	3000-6000m	Optimum
Residential Areas	1000-1250m	Suitable
	1250-1500m	Suitable
	1500-3000m	Optimum
Industrial Areas	3000-4500m	Suitable
	4500-6000m	Suitable
	6000-7500m	Mid-Suitable
	7500-9000m	Mid-Suitable
Main Road	500-1000m	Suitable
	1000-1500m	Suitable
	1500-2000m	Mid-Suitable
	2000-2500m	Mid-Suitable
C.B.D.	12000-15000m	Unsuitable
	15000-18000m	Unsuitable
	18000-25000m	Detestable
Wetlands	2000-2500m	Suitable
	2500-3000m	Suitable
	3000-5000m	Optimum
	5000-10000m	Optimum

Table 10: Map Intersect Criteria Buffer Zones

Weighted overlay technique was achieved by converting each of the buffer shape files from the vector format to the raster format. Thereafter the weights were assigned of each raster layer. The weight of each raster layer is indicated in Appendix D. The weighted overlay command combines the raster suitability maps and adds the weights of each raster in the process. The result of this integration is the Landfill Suitability Map where the areas with the highest cumulative scores are classified as 'suitable' whilst those areas with lower cumulative scores are classified as 'mid-suitable'.

5.2.6 Evaluating Alternatives

A preliminary qualitative analysis of the identified suitable sites was conducted by identifying the type of soils and geological formations in the suitable areas. This was achieved by overlaying the Suitable Zones Map with the Harare Soils Map.

5.3 Conclusion on Research Methodology

The research tools used in this study enabled the author to delineate the research problem and identify possible solutions despite the time and financial constraints. Literature review and structured interviews were insightful as they established the factors which affect the location of waste disposal facilities. The G.I.S. platform played a pivotal role in this investigation. Although desktop surveys and literature review were useful in establishing the dynamics of the research problem, the G.I.S. map overlay techniques established the solution by outlining the possible landfill disposal sites.

Chapter 6 Preliminary Results Analysis

6.1 Preliminary investigations

6.1.1 Introduction

The preliminary investigations included the first three phases of the research. This chapter considers the findings of these initial investigations.

6.1.2 Structured Interviews

The interviews conducted with representatives on the Environmental Management Agency were informative and enlightening. The respondents of this regulatory body clearly expressed their disapproval of the Golden Quarry and Pomona Waste Depositories and emphasized that the current disposal to these sites is an illegal practice. The Environmental Management Agency emphasized the urgent need for a new waste depository to safeguard Harare's ground water resources and environmental quality. At the time of the interview, the waste management division of the Environmental Management Agency was in the process of developing waste disposal site selection guidelines to facilitate this development.

These insightful interviews exposed the dynamics of the waste collection and disposal challenges in Harare. Furthermore, it became apparent that although the city administrators are in the process of developing strategic plans towards the establishment of a new sanitary landfill site for the city of Harare, there has been limited analytical research to guide the site selection process.

6.1.3 Questionnaires

The respondents considered the proximity of the landfill to residential areas as the most important criteria. The average weight for this criterion was 0.24. The proximity of the new waste depository to wetlands and rivers was also considered significant. This criterion had an average weighting of 0.20. The proximity of the landfill to the industrial sites attained a significance weight of 0.16. The proximity of the proposed landfill to the commercial areas and industrial sites were judged as the least significant factors and they were rated with average criteria ratings of 0.12 and 0.8 respectively.

6.2 Criteria Suitability Assessment

6.2.1. Residential Proximity Suitability Assessment

The City of Harare's built up residential areas account for approximately 60% of the urban land use. Fig. 12 a) illustrates the distribution of built up residential areas in the city of Harare and classifies the surrounding areas according to their degree of suitability for landfill development in relation to their proximity to residential developments. Table 12 summarises the ranking structure used in the creation of the Residential Suitability Map indicated in Fig.12. In Fig 12b), the 'exclusionary areas' have been eliminated from the Residential Suitability Map indicated in Fig. 12a).

RESIDENTIAL PROXIMITY		
<i>Buffer Distance</i>	<i>Suitability</i>	<i>Ranking</i>
0-250m	Unsuitable	3
250-500m	Unsuitable	3
500-750m	Mid-Suitable	5
750-1000m	Mid-Suitable	5
1000-1250m	Suitable	7
1250-1500m	Suitable	7
1500-3000m	Optimum	9
3000-6000m	Optimum	9

Table 12: Residential Proximity Suitability Ranking Structure

According to Table 12 and Fig. 12a) and b), areas which are situated closer to residential developments are less suited to landfill development than those which are further away. Most of the suitable areas for landfill development are situated in Harare's peripheral areas that are least developed. Their marginal location therefore poses the least impact on the existing residential and community facilities.

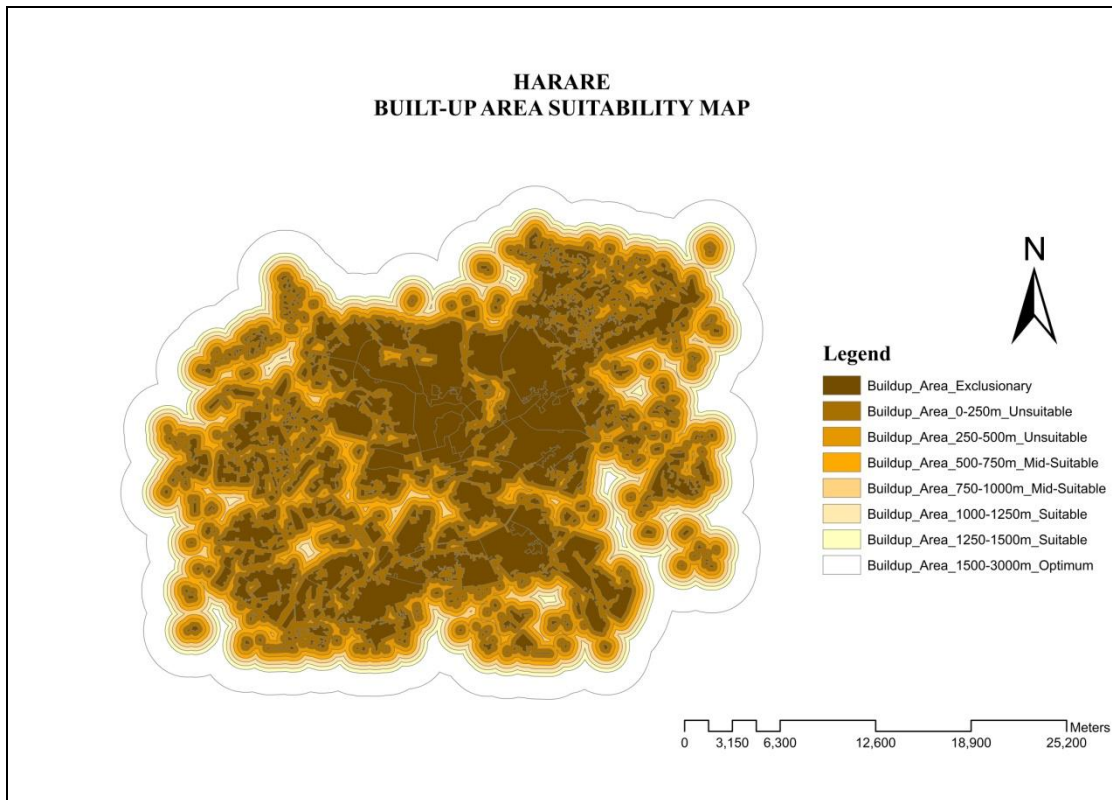


Fig. 12a)- Residential Proximity Suitability Map

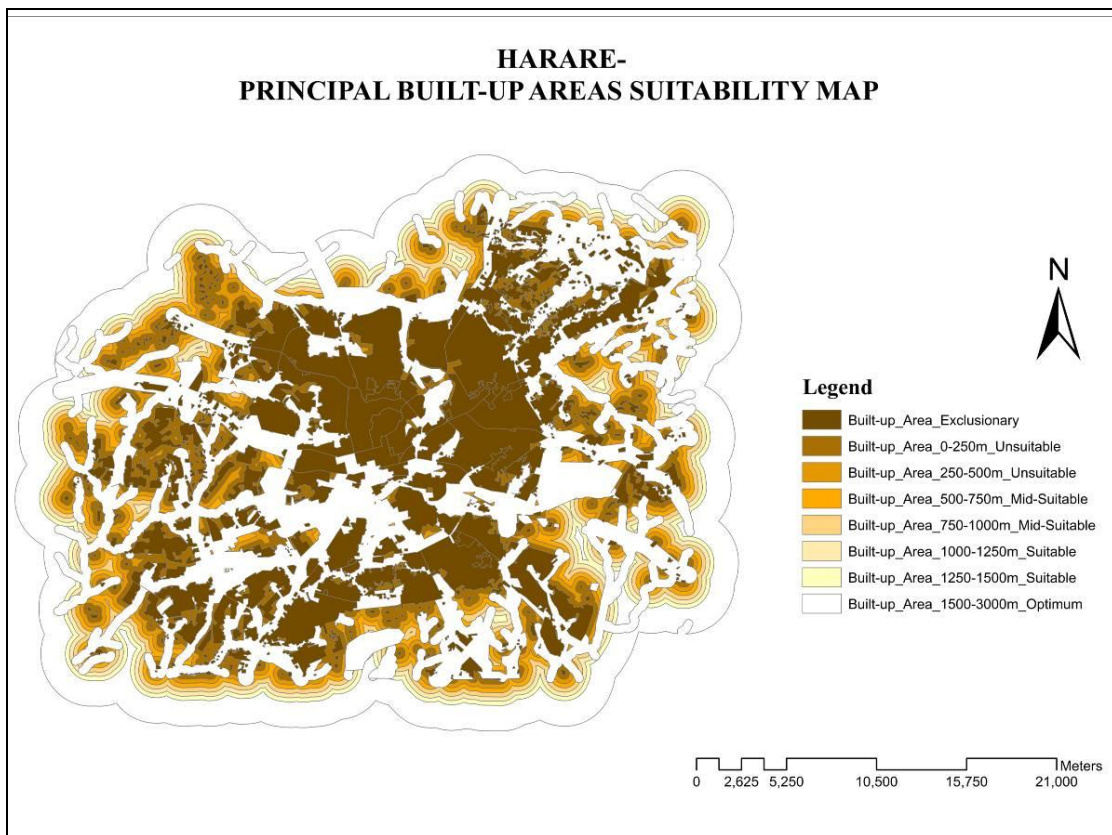


Fig. 12b)- Residential Proximity Suitability Map

6.2.2. Wetlands Proximity Suitability Assessment

The City of Harare's has several wetlands containing habitats worthy of protection from environmental degradation. Although wetlands are distributed in various parts of the city, a larger proportion of the wetlands are located in the Harare northern suburbs.

Fig. 13a) illustrates the distribution of wetlands in the city of Harare and the zones of suitability for locating a new landfill with respect to the spatial distribution of wetlands in Harare. Table 13 summarises the ranking structure used in the creation of the Wetlands Suitability Map. Fig. 13b) illustrates the same parameters where the aforementioned 'exclusionary areas' have been eliminated from the analysis.

WETLANDS PROXIMITY		
<i>Buffer Distance</i>	<i>Suitability</i>	<i>Ranking</i>
0-500m	Unsuitable	3
500-1000m	Unsuitable	3
1000-1500m	Mid-Suitable	5
1500-2000m	Mid-Suitable	5
2000-2500m	Suitable	7
2500-3000m	Suitable	7
3000-6000m	Optimum	9
6000-9000m	Optimum	9

Table 13: Wetlands Proximity Suitability Ranking Structure

A larger proportion of suitable areas for landfill development, in relation to their proximity to wetlands, are located on the outskirts of the city, with more suitable localities in Harare North and Harare East as compared to Harare South and West.

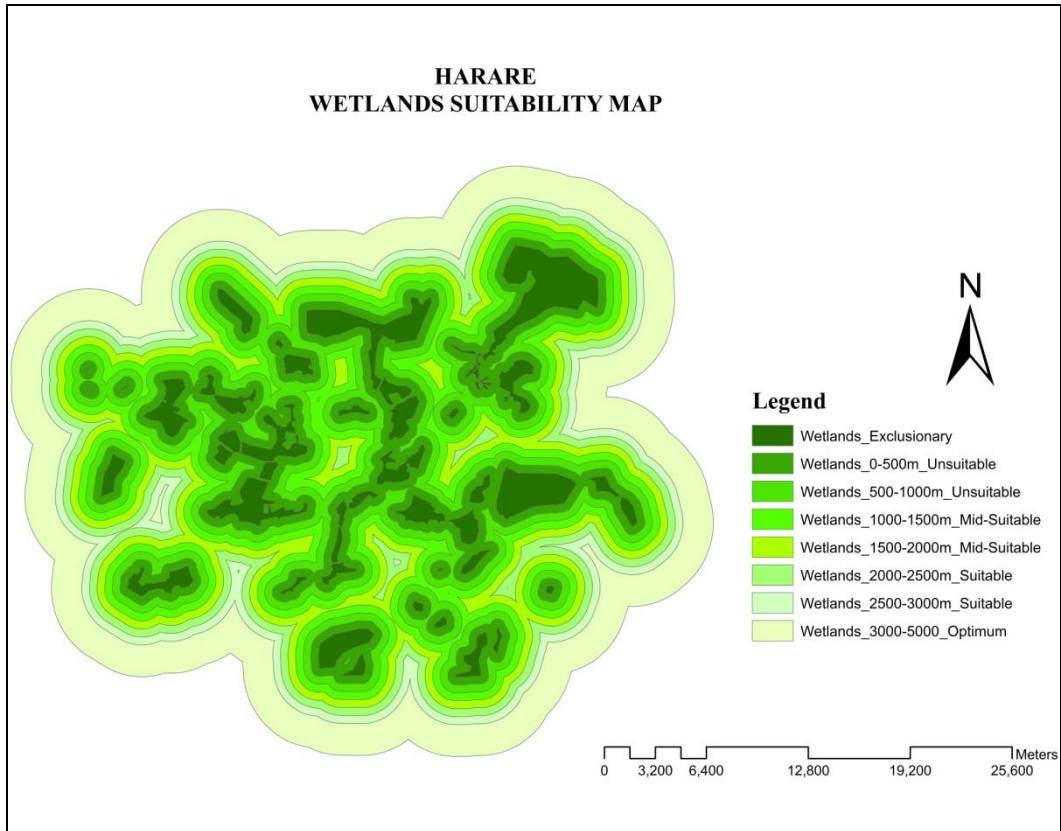


Fig. 13a)- Wetlands Suitability Map

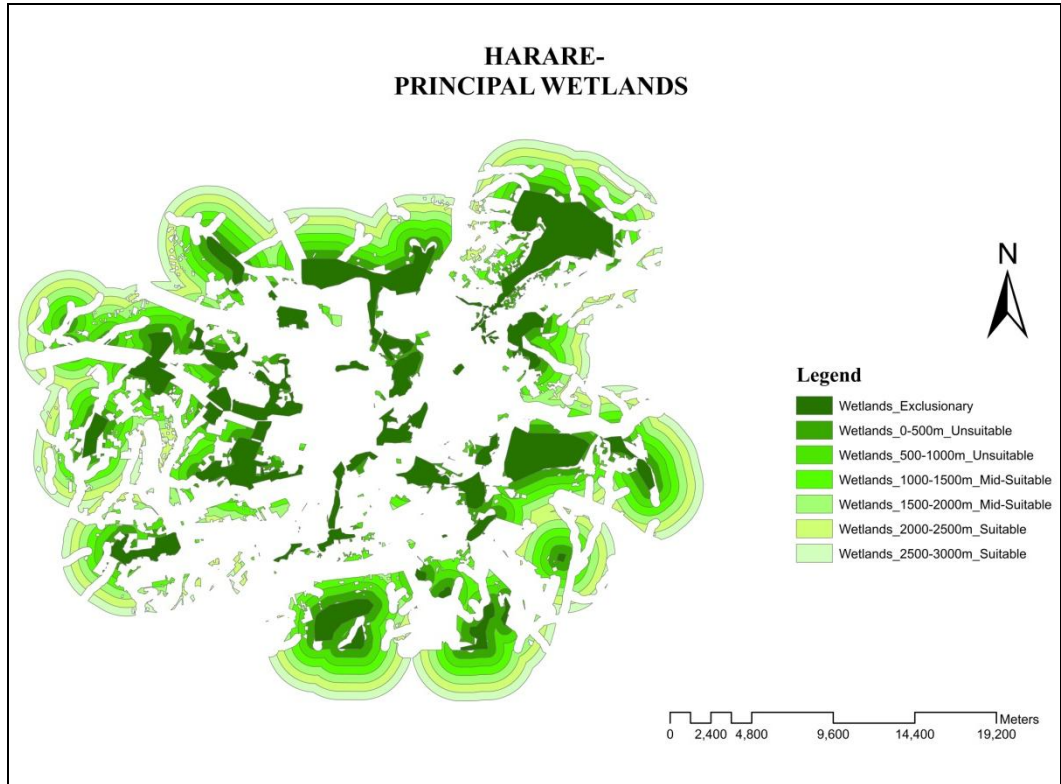


Fig. 13b)- Wetlands Suitability Map

6.2.3. Water Courses Proximity Suitability Assessment

The City of Harare is set in the midst of three river catchments namely the Manyame River catchment in northeast, the Gwebi River in the northwest and the Mukuvusi river catchment in the south (Broderick, 2012). Fig 14b) illustrates the same parameters where the exclusionary areas are omitted. Areas that are within a distance of 250 meters from the river channel are to be as ‘exclusionary’.

Fig. 14a) illustrates the distribution of rivers and streams in Harare and goes on to rank the adjacent territory according to its degree of suitability for landfill development. Table 14 summarises the ranking structure used in the creation of the Rivers Suitability Map. Fig. 14b) illustrates the same parameters where the exclusionary areas are omitted. Although Fig. 14b) indicates that a significant proportion of the residual suitable and optimal areas are situated in the periphery of the city, this may also be attributed to the limited map data which does not indicate the remainder of the river catchment outside of the boundary of the city.

RIVERS PROXIMITY		
<i>Buffer Distance</i>	<i>Suitability</i>	<i>Ranking</i>
250-500m	Unsuitable	3
500-750m	Unsuitable	3
750-1000m	Mid-Suitable	5
1000-1250m	Mid-Suitable	5
1250-1500m	Suitable	7
1500-1750m	Suitable	7
1750-3000m	Optimum	9
3000-6000m	Optimum	9

Table 14: Rivers Proximity Suitability Ranking Structure

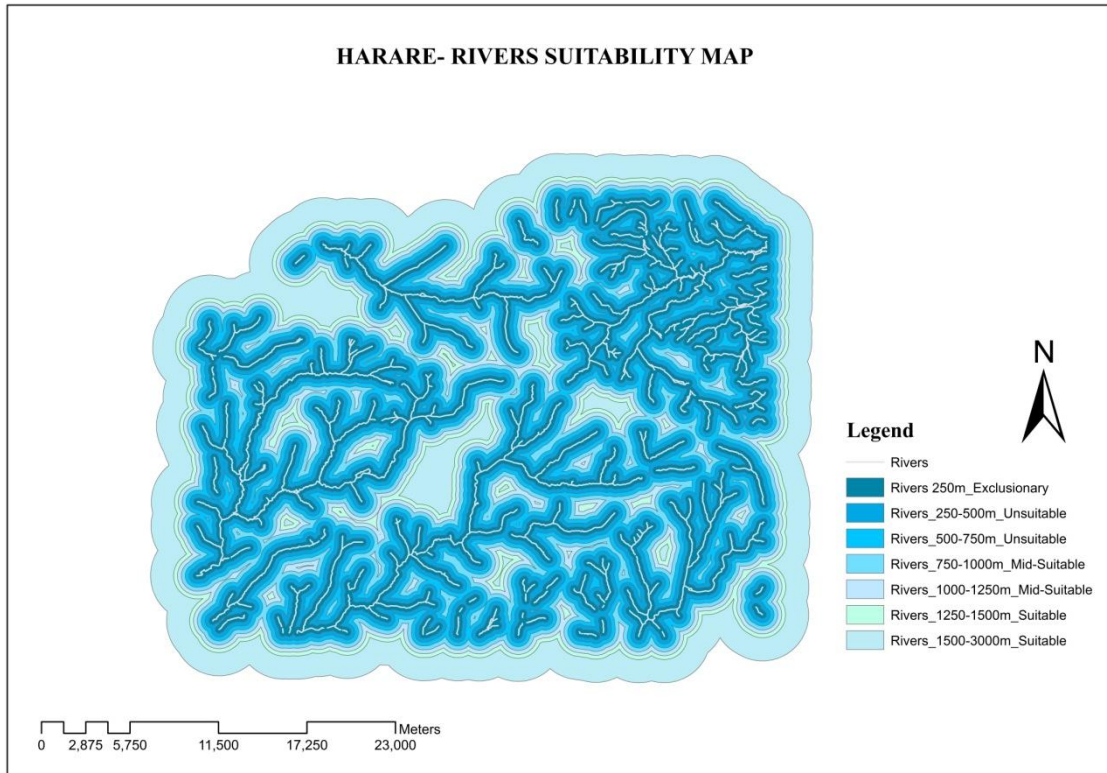


Fig. 14a)- Rivers Proximity Suitability Map

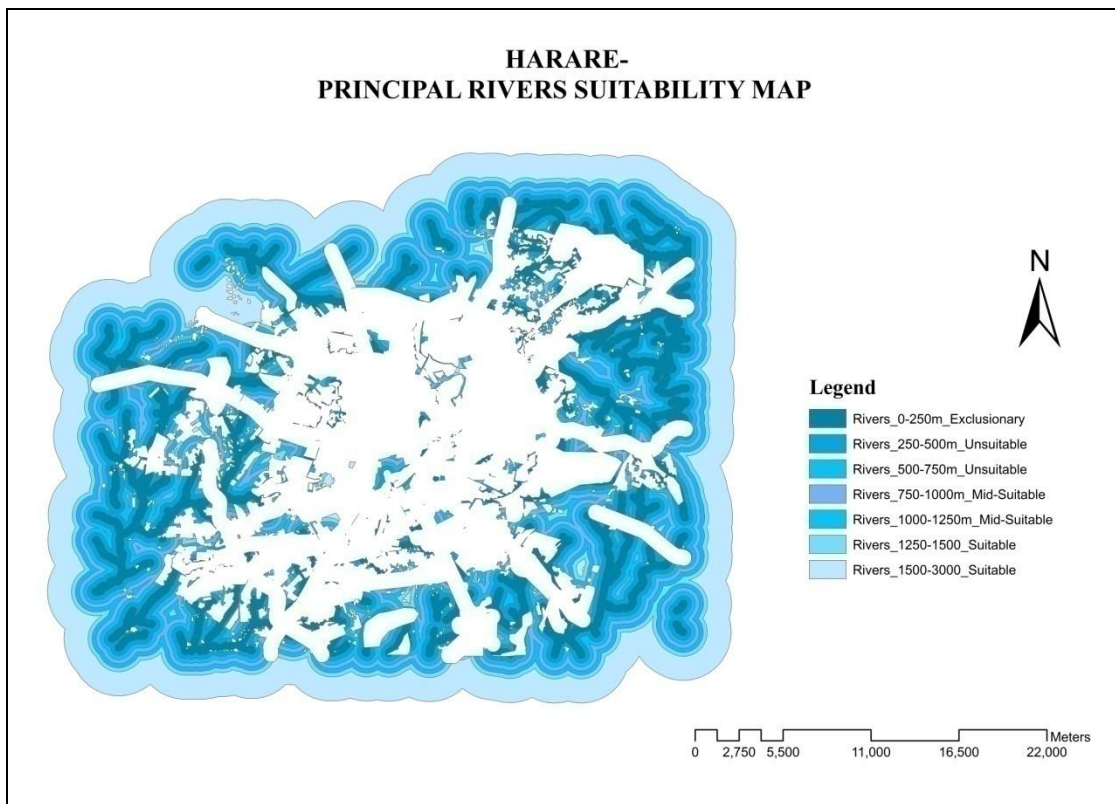


Fig. 14b)- Rivers Proximity Suitability Map

6.2.4. Roads Proximity Suitability Assessment

The primary distributor roads in the city of Harare connect in a radial pattern to regional and national destinations (Refer to Appendix B). Fig. 15a) depicts the classification of spaces in the city according to their degree of vehicular accessibility and consequent suitability for waste disposal. Fig. 15b) illustrates the same principle where the exclusionary areas have been extracted.

Locations, which fall within an offset distance of 500 meters from the primary distributor roads, are eliminated on the basis of their visibility to the public eye. They are thus assumed to be part of the roadside and classified as 'exclusionary'. Spaces that are more proximate to the main roads are classified as 'optimum' as they are relatively more accessible than those that are further away. Table 15 summarises the ranking structure used in the creation of the Road's Suitability Map.

According to Fig 15b) there are several small parcels of open spaces which are located closer to the central business district which are relatively more accessible and thereby classified as 'optimum' or 'suitable' for landfill development.

MAIN ROADS PROXIMITY		
<i>Buffer Distance</i>	<i>Suitability</i>	<i>Ranking</i>
500-1000	Optimum	9
1000-1500	Optimum	9
1500-2000	Suitable	7
2000-2500	Suitable	7
2500-3000	Mid-Suitable	5
2500-3000	Mid-Suitable	5
3500-5000	Unsuitable	3

Table 15: Main Roads Proximity Suitability Ranking Structure

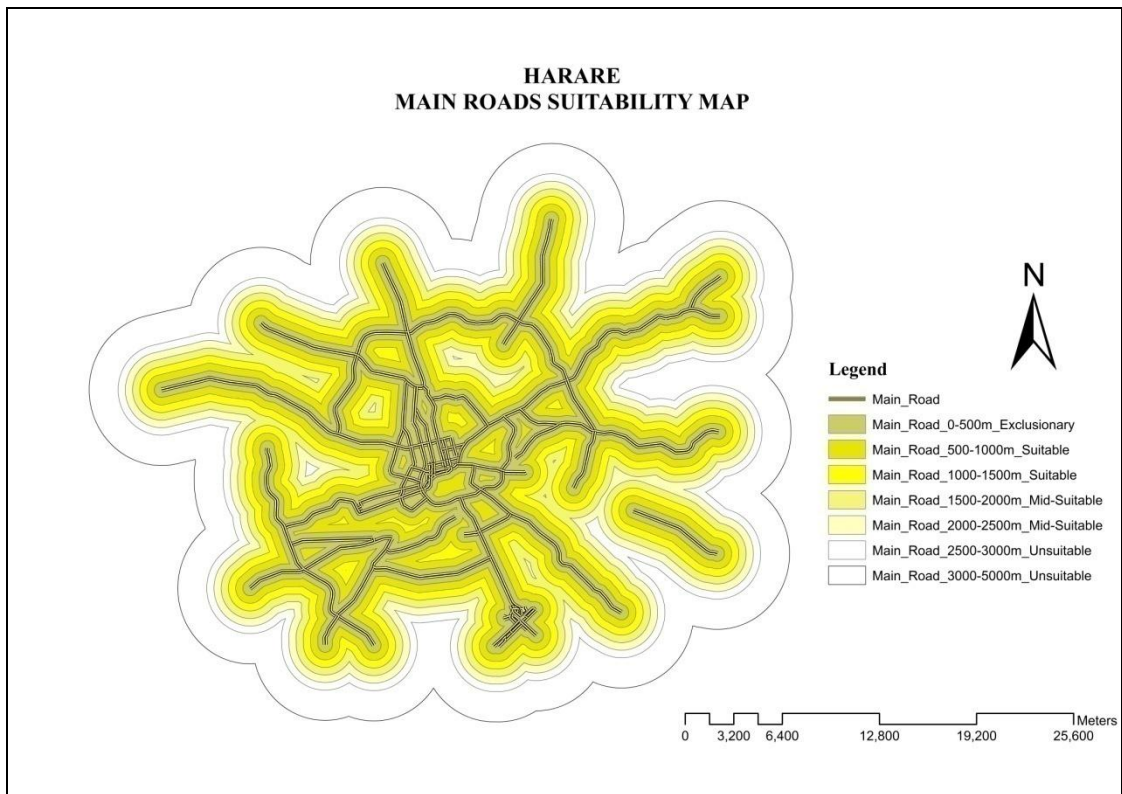


Fig. 15a)- Main Roads Proximity Suitability Map

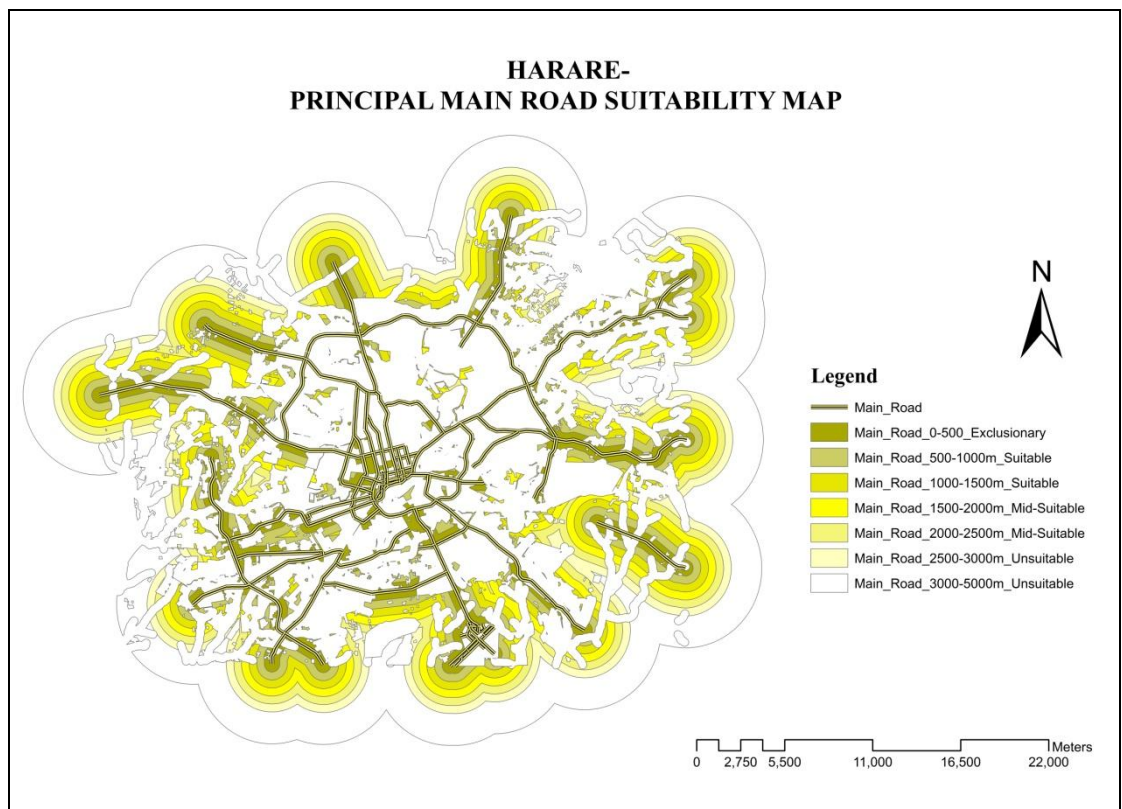


Fig. 15b)- Main Roads Proximity Suitability Map

6.2.5. Industrial Area Proximity Suitability Assessment

Harare's industrial areas are located on the southeast and the southwest of the central business district. Fig. 16a) illustrates the distribution of industrial sites in the city of Harare. Fig. 16a) depicts the most ideal locations for a new municipal solid waste depository relative to the location of the industrial sites. It is anticipated that the new waste disposal site will be proximate to the industrial sites in order to facilitate waste disposal from the industrial sites. Table 16 shows the ranking structure used to demarcate the spaces shown in the Industrial Areas Suitability Map (Fig. 16).

INDUSTRIAL PROXIMITY		
<i>Buffer Distance</i>	<i>Suitability</i>	<i>Ranking</i>
0-1500m	Optimum	9
1500-3000m	Optimum	9
3000-4500m	Suitable	7
4500-6000m	Suitable	7
6000-7500m	Mid-Suitable	5
7500-9000m	Mid-Suitable	5
9000-12000m	Unsuitable	3
12000-15000m	Unsuitable	3

Table 16: Industrial Areas Proximity Suitability Ranking Structure

In Fig. 16b) the aforementioned 'exclusionary' areas have been omitted resulting in a clearer picture of the domains of suitability. Evidently, there are several open spaces within Harare that are classified as optimum or suitable due to their proximity to the industrial sites. As depicted in Fig. 16b) the residual open spaces closer to the city centre are more accessible to the industrial sites and more suited for waste disposal than those which are a considerable distance away from the city centre.

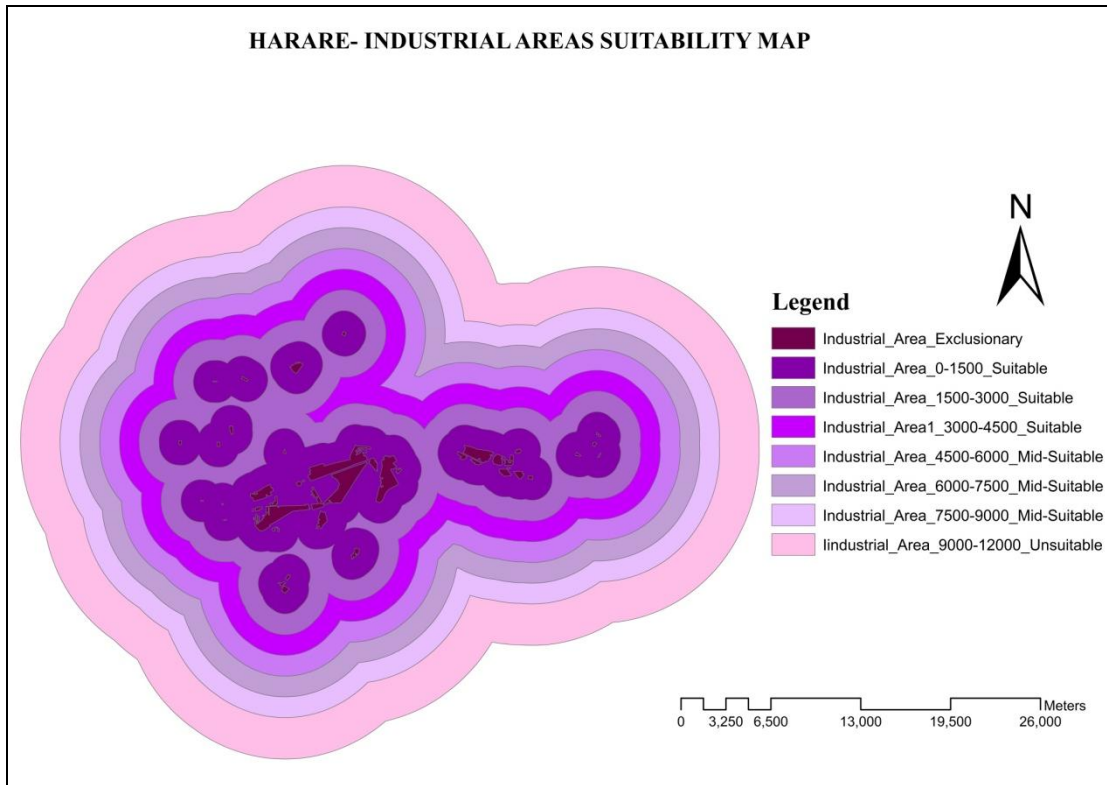


Fig. 16a)- Industrial Areas Proximity Suitability Map

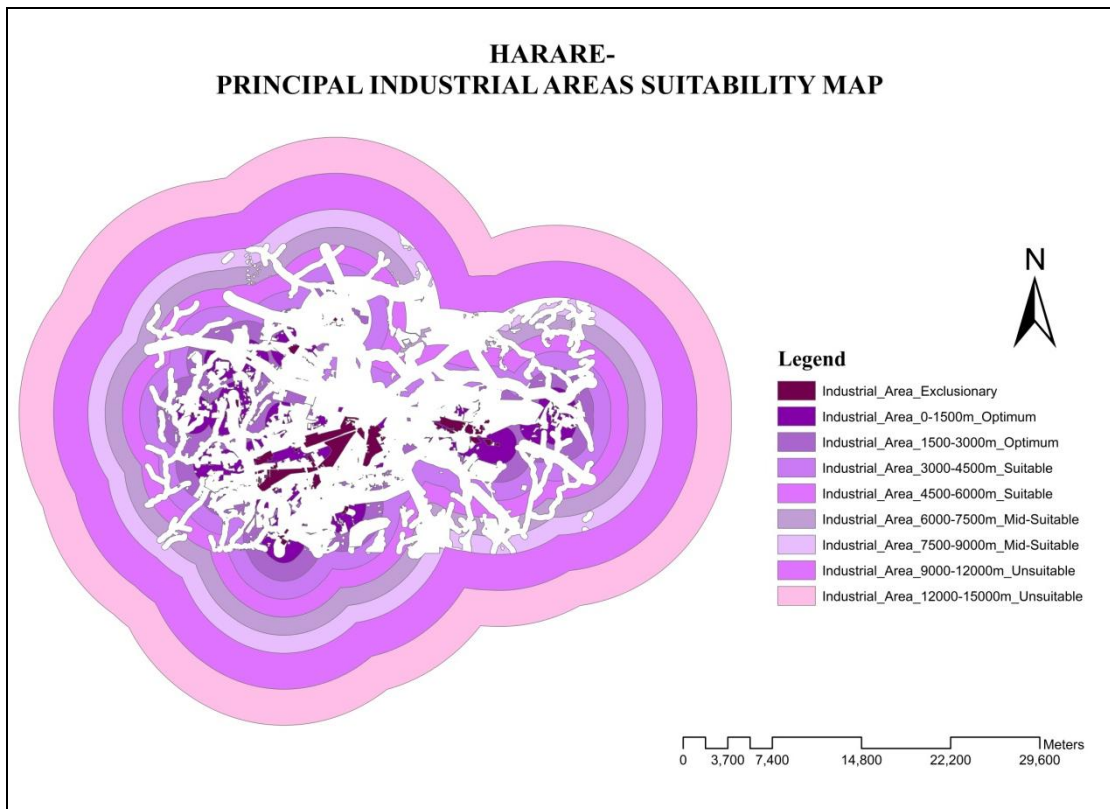


Fig. 16b)- Industrial Areas Proximity Suitability Map

6.2.6. Central Business District Suitability Assessment

Despite the decentralisation of commercial activity to adjacent district shopping centres, Harare's central business district remains the focal point with the highest intensity of commercial activity accompanied by the largest generation of commercial waste (*Mandimutsa, 2000:8*). The relative distance of the proposed sanitary landfill site from the C.B.D. is therefore a significant consideration as it affects its operational cost and viability (*Sumathi, et al 2000:8*).

Fig. 17 indicates the degree of landfill suitability with respect to the Commercial Business District. The radii indicated in Fig 16a) and b) are set according to the ranking structure outlined in Table 17.

CENTRAL BUSINESS DISTRICT PROXIMITY		
<i>Buffer Distance</i>	<i>Suitability</i>	<i>Ranking</i>
0-3000m	Optimum	9
3000-6000m	Optimum	9
6000-9000m	Suitable	7
9000-12000m	Suitable	7
12000-15000m	Mid-Suitable	5
15000-18000m	Mid-Suitable	5
18000-21000m	Unsuitable	3
21000-24000m	Unsuitable	3

Table 17: C.B.D. Proximity Suitability Ranking Structure

Fig. 17 indicates the degree of landfill suitability with respect to the commercial business district. The radii indicated in Fig 17a) and b) are set according to the ranking structure outlined in Table 17. Accordingly, areas closer to the commercial centre are more suitable for landfill development than those that are a significant distance away from the city centre.

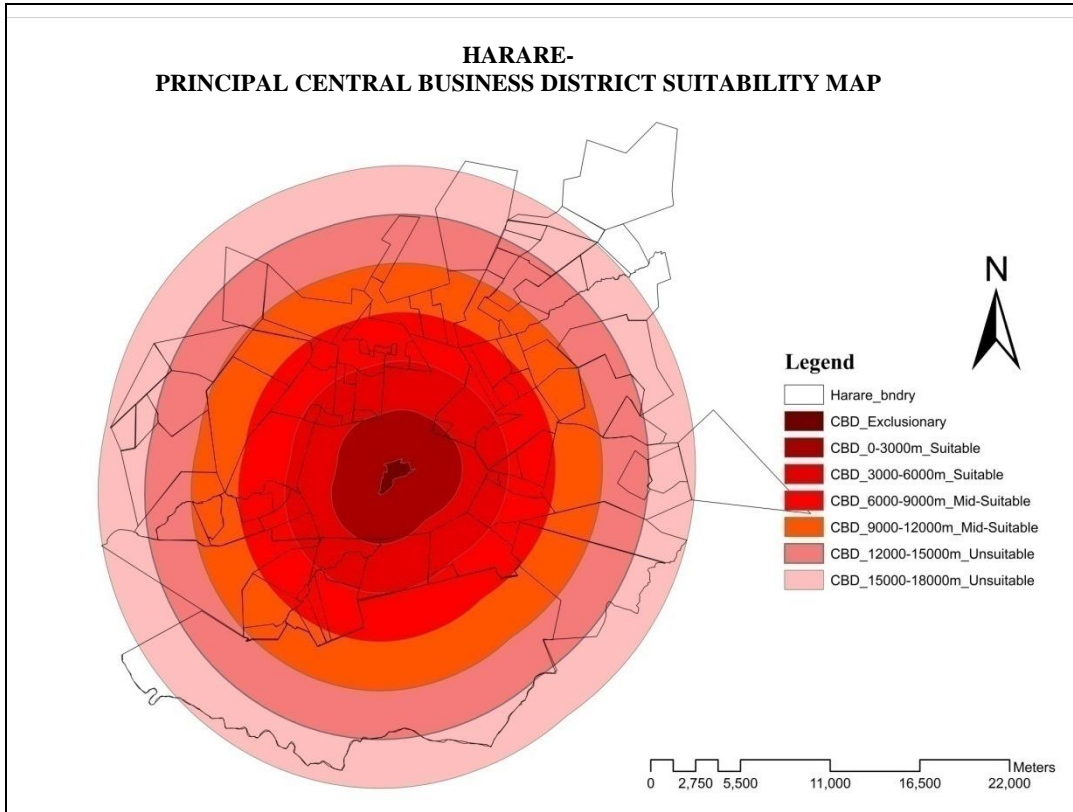


Fig. 17a)- Central Business District Suitability Map

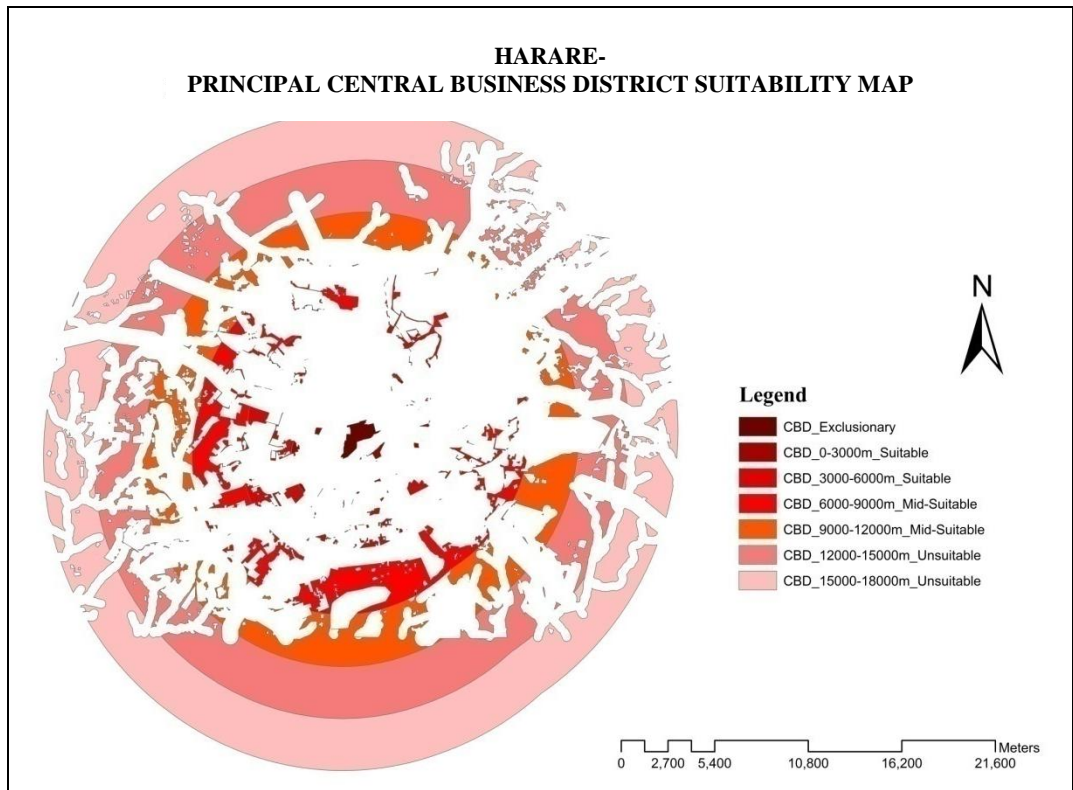


Fig. 17 -Central Business District Proximity Suitability Map

6.2.7. Airport Proximity Suitability Assessment

Harare International Airport (H.I.A.) is located approximately 12,000 meters away from the central business district and is situated in the south-eastern part of the city of Harare. Fig. 18a) is a landfill suitability map whereby suitability is ranked according to the locality's proximity to H.I.A. The ranking structure used to synthesize the Airport Suitability Map is indicated in Table 18. Fig. 18b) is a similar landfill suitability map where the exclusionary areas have been removed from the presentation.

AIRPORT PROXIMITY		
<i>Buffer Distance</i>	<i>Suitability</i>	<i>Ranking</i>
0-3000m	Unsuitable	3
3000-6000m	Unsuitable	3
6000-9000m	Mid-Suitable	5
9000-12000m	Mid-Suitable	5
12000-15000m	Suitable	7
15000-18000m	Suitable	7
18000-21000m	Optimum	9
21000-24000m	Optimum	9

Table 18: Airport Proximity Suitability Ranking Structure

Fig. 18b) indicates that a greater proportion of the residual open spaces in Harare South and Harare East are less suited for landfill development due to their proximity to H.I.A. The suitable and optimum residual spaces are situated in the northern and northeastern parts of the city.

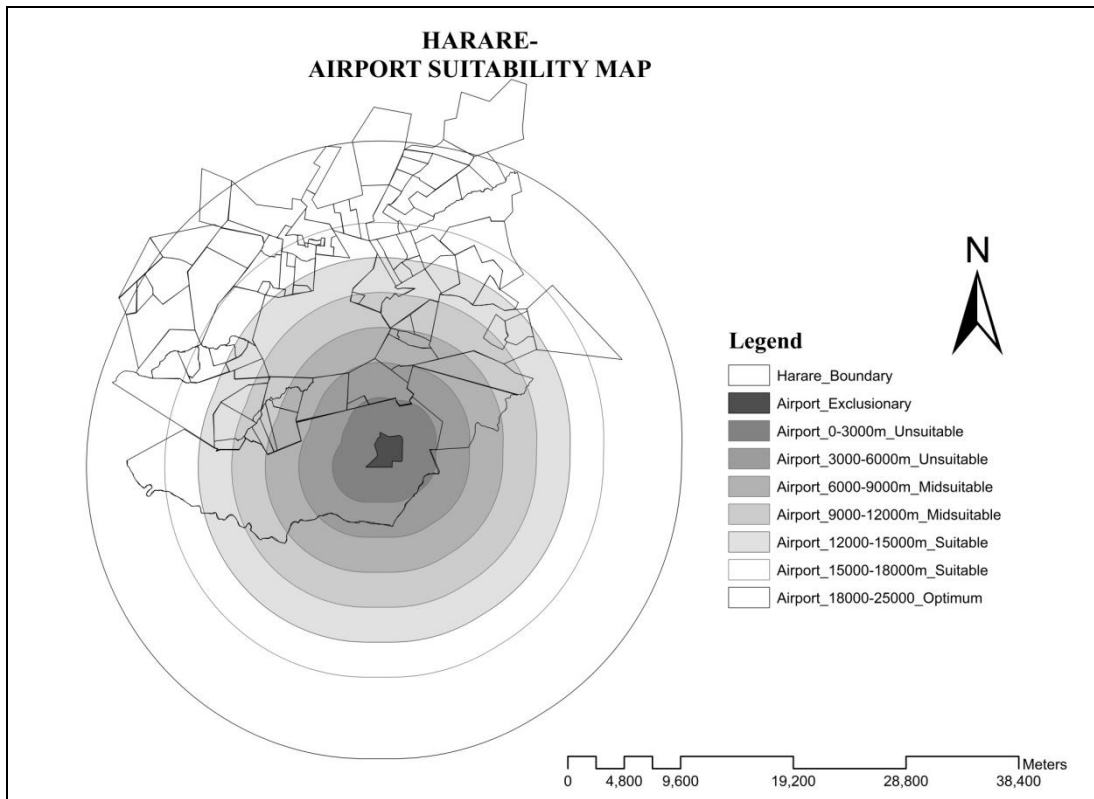


Fig. 18a) –Airport Proximity Suitability Map

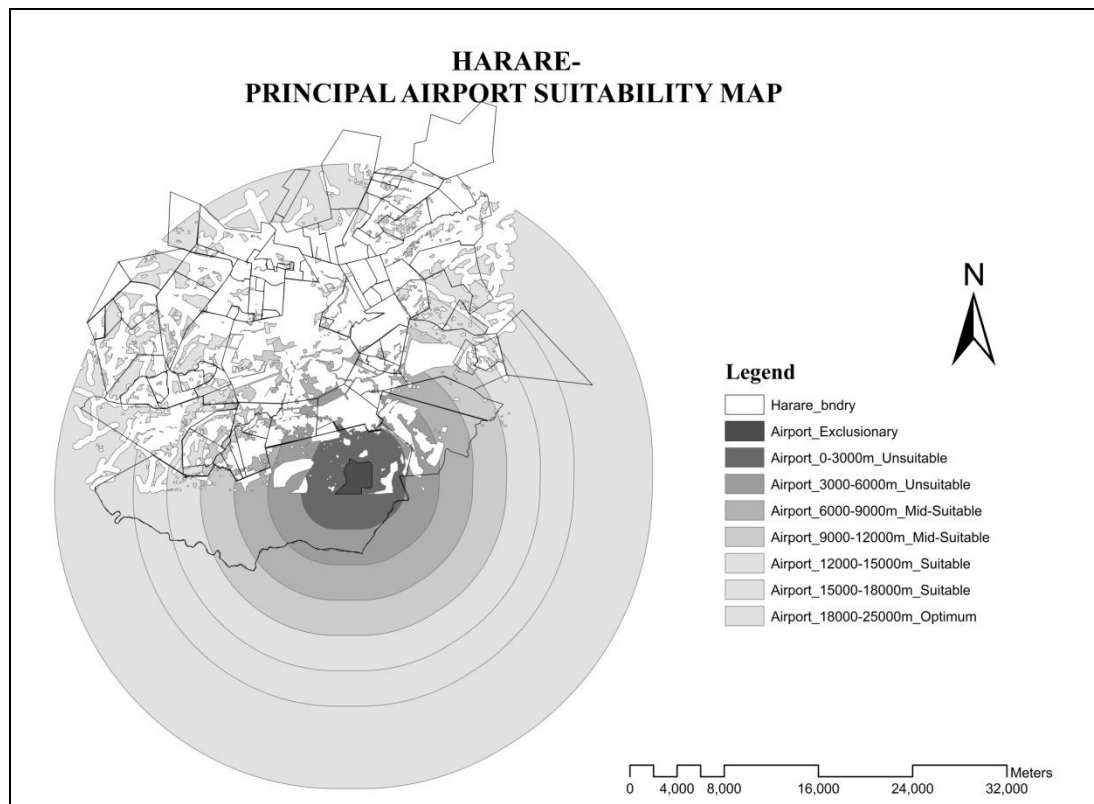


Fig. 18b) –Airport Proximity Suitability Map

6.3 Deductions from Preliminary Investigations

6.3.1. Feasible Landfill Locations

The previous discussion highlights the dynamics inherent in this multi-factorial research. The conflicting objectives of the criteria under consideration are an obvious challenge. For instance, while the most suitable areas for landfill development with respect to the 'proximity to main roads', 'proximity to the industrial sites' and 'proximity to commercial' criteria are closer to the central business district; the suitable areas for 'proximity to rivers and streams', 'proximity to wetlands' and 'proximity to residential built up areas' criteria are situated in open spaces which are further away from the central business district. It is therefore impossible to satisfy the mandates of suitability for all the criteria under consideration. However, strategic trade-offs will allow sites to be identified that satisfy the more important (higher weighted) criteria albeit at the expense of some less important (lower weighted) criteria.

Chapter 7 Results and Discussion

7.1 Alternative Suitable Sites

7.1.1. Map Intersect Preliminary Scoping

In the preliminary map overlay investigations, the map overlay intersect technique was used to identify if there were any zones of suitability where the optimum layers for each criteria intersected. Fig. 19 shows the potential landfill development zones identified in the preliminary scoping which was undertaken using the Arc-Map intersect tool. The attempt to identify a common area that is classified as ‘suitable’ or ‘optimum’ for all criteria was futile. However, this procedure isolated common areas which exist in the suitable to optimum category for the following criteria:- distance from built-up residential areas, distance from wetlands and distance from rivers and streams.

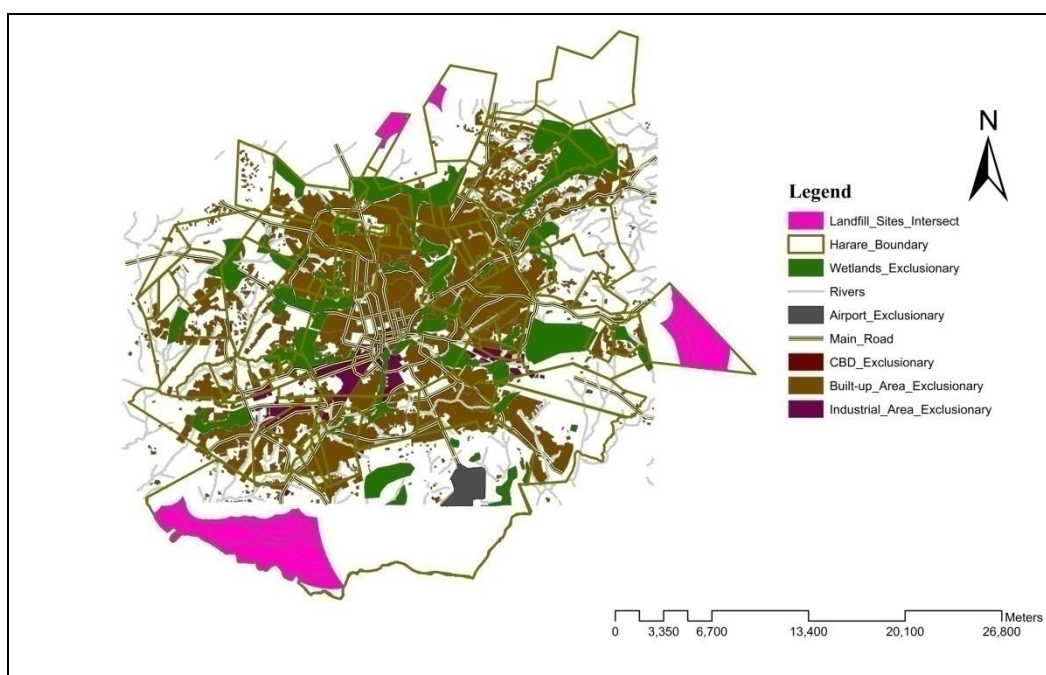


Fig. 19- Zones of Suitability for Landfill Location

Although there are common regions of suitability where layers classified as ‘optimum’ intersected for residential, rivers and wetlands criterion; these areas are sited in areas classified as ‘mid-suitable’, and ‘unsuitable’ in relation to their proximity to the central business district, main roads, and industrial sites.

7.1.2. Weighted Overlay

Subsequent investigations were carried out through the Arc-GIS, Arc-Map weighted overlay techniques that quantified the degree of suitability based on the established criteria weighting system. The weighted suitability maps were combined and the numbers allocated to each raster were added in the process.

The outcome of the integration of the weighted suitability maps for the various criteria is shown in Fig. 20a) and Fig. 20b). These maps show the sites with the highest cumulative scores (classified as 'suitable'), those with the lower cumulative scores (classified as 'mid-suitable') and exclusionary areas (classified as 'unsuitable'). According to Fig. 20a) there are suitable sites which exist outside Harare. Fig. 20b) shows only the suitable areas which fall within the confines of the city of Harare.

7.1.3. Suitable Sites

Fig. 20b) indicates three major alternative sites, within the confines of the city of Harare, which are classified as suitable for landfill development.

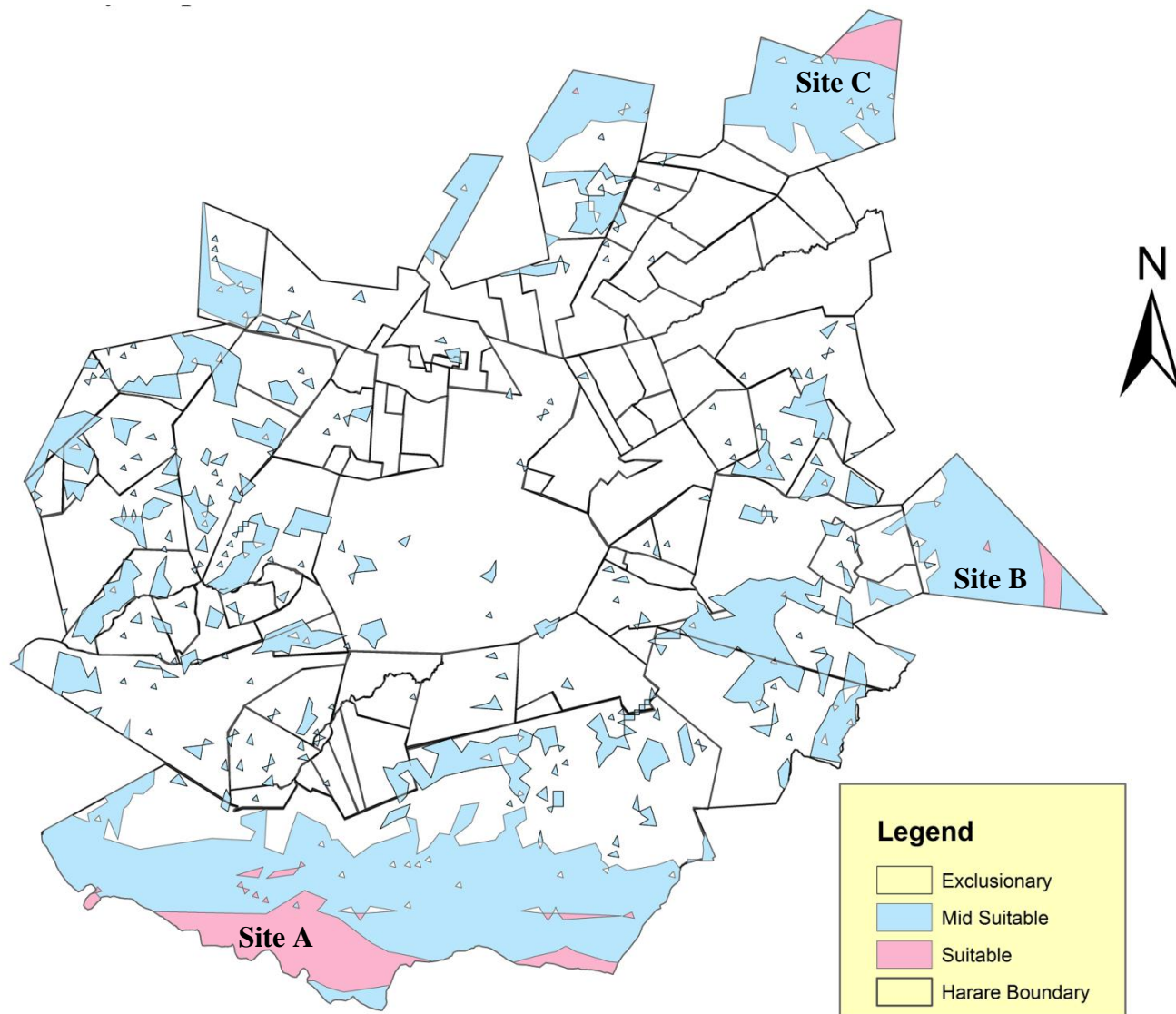
'Site A' is situated in the south-western periphery of the city and consists of 11,698,673 square meters. This site is located approximately 10,000 meters away from the Harare International Airport. Landfill development at 'Site A' will therefore, not create disturbances for aircraft.

'Site B' is situated in the eastern periphery of the city and comprises 103,080 square meters of open undeveloped land. This site is located approximately 15,000 meters away from the Harare International Airport.

'Site C' is situated in the north-eastern periphery of the city. The area of the site consists of 230,928 square meters of undeveloped land. This site is approximately 25,000 meters away from the Harare International Airport.



Fig. 20a)- Harare Landfill Suitability Map



Scale 1: 220 000

Fig. 20b)- Harare Landfill Suitability Map

7.2 Criteria Suitability of Alternative Landfill Sites

7.3.1 Suitability with Regards to Wetlands

Harare's wetlands are sensitive areas that are protected by the Environmental Management Agency due to their unique environmental function. It would be ideal for the new municipal solid waste depository to be located at least 2,000 meters away from Harare's existing wetlands in order to preserve and protect their fragile ecosystems and habitats.

Fig. 21 illustrates that sites A, B, and C are located in areas which are classified as optimum for landfill development in relation to wetlands preservation. 'Site A' and 'Site C' are positioned between 5,000 and 10,000 meters away from the adjacent wetlands. Sites A and C are therefore more suitable for landfill development. 'Site B', however, is less suitable because it is situated between 2,000 and 5,000 meters away from the adjacent wetlands.

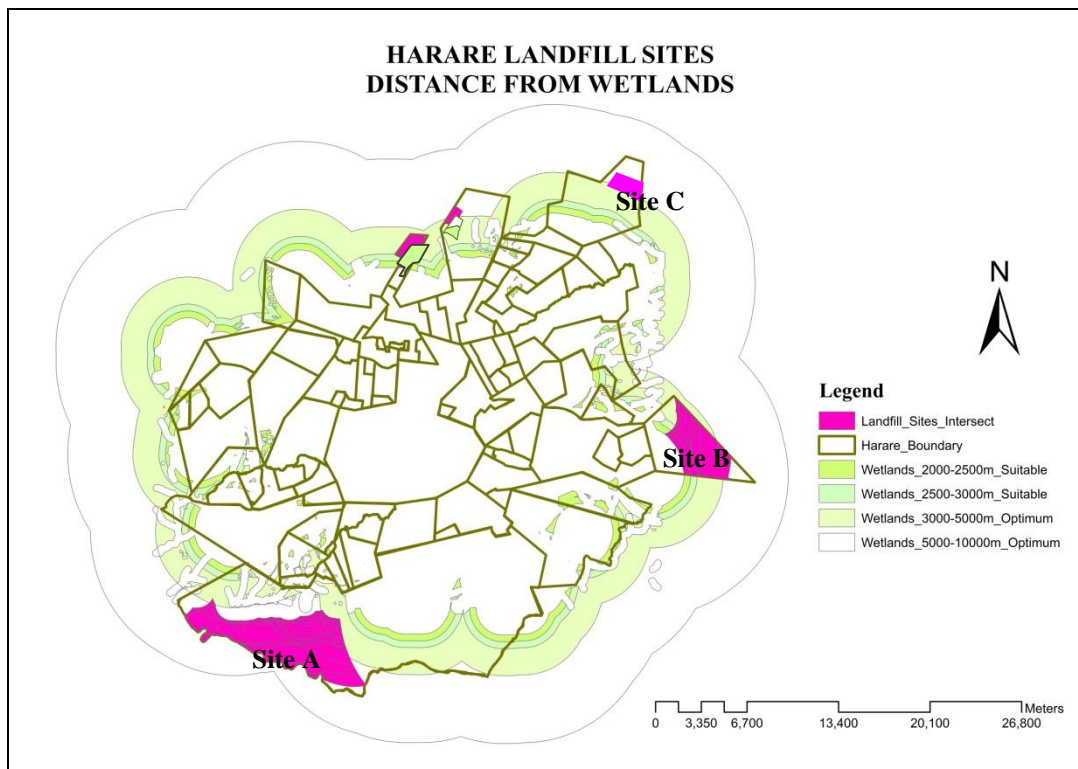


Fig. 21- Suitable Zones: Wetlands

7.3.2 Suitability in Relation to Rivers

The proximity of the proposed waste depository to adjacent rivers and streams will determine the vulnerability of these surface water bodies to leachate pollution. The ideal landfill site should be located at least 1,500 meters away from any rivers, tributaries or streams. Fig. 22 shows the relative location of Sites A, B, and C to the adjacent surface water bodies.

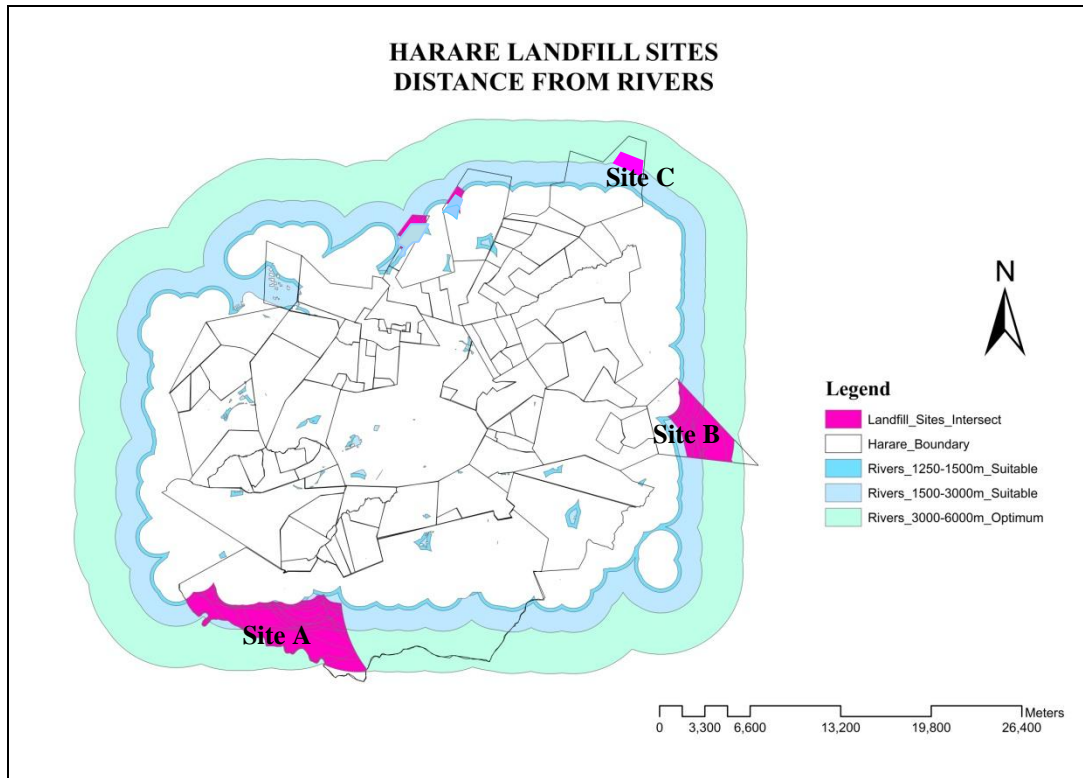


Fig. 22- Suitable Zones: Rivers

'Site C' is located between 3,000 and 5,000 meters away from the adjacent rivers and streams. Hence, the entire area accommodated by this site is classified as 'optimum' for landfill development. Considering the distance away from Harare's surface water bodies, 'Site C' is more suitable. Hence, the entire area accommodated by this site is classified as 'optimum' for landfill development. 'Site A' and 'Site B' are situated between 1,500 and 6,000 meters away from their adjacent rivers and streams. These two aforementioned sites are therefore classified as partially 'suitable' and partially 'optimum' for landfill development in terms of their relative proximity to adjacent surface water bodies.

7.3.3 Suitability in Relation to Residential Areas

The introduction of a new municipal landfill facility will inevitably affect the environment of the surrounding residential developments. It is therefore the desire of all the residents of Harare that this new facility be situated as far as possible from the existing built-up residential areas. Fig. 23 illustrates the location of sites A, B, and C relative to their adjacent built-up residential areas.

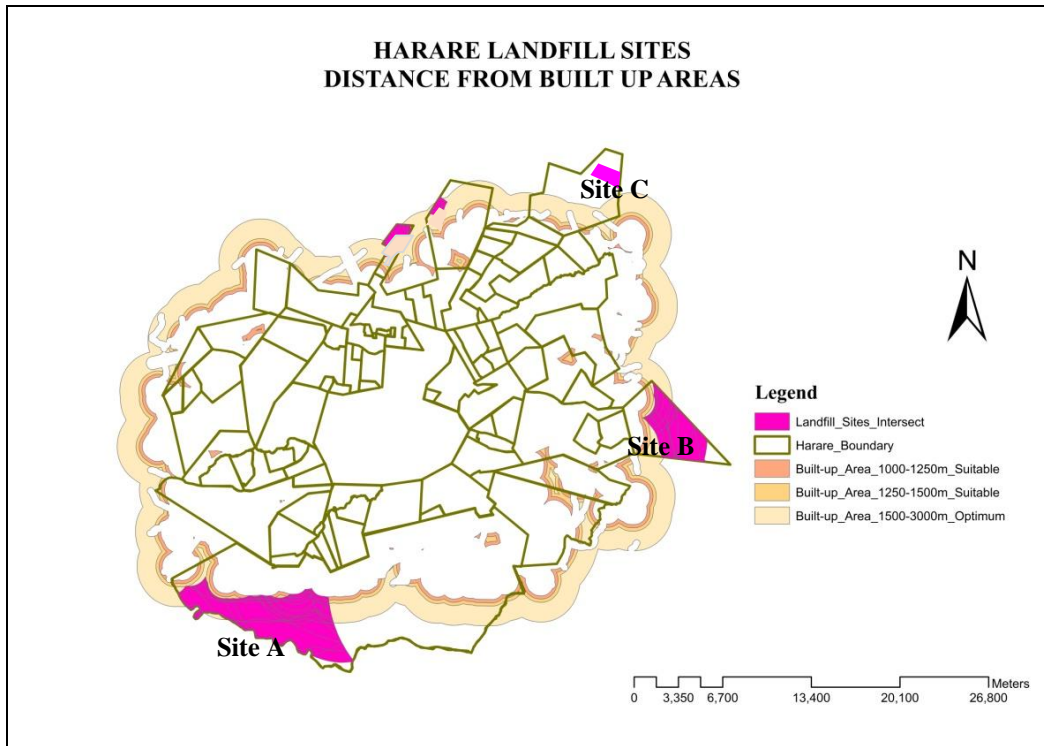


Fig. 23- Suitable Zones: Residential

Site A, B and C differ in terms of their distance away from adjoining built-up residential areas. 'Site C' is situated between 6,000 and 10,000 meters away from the nearest built-up residential areas. It is the most suitable site for landfill development taking into consideration its distance away from adjacent residential developments. 'Site A' and 'Site B', though suitable, are partially more proximate to the neighbouring residential areas as they have portions which fall within a distance of between 1,500 and 3,000 meters away from the existing built-up areas.

7.3.4 Suitability in Relation to Industrial Areas

It is anticipated that the new waste depository will absorb non-hazardous waste generated in Harare's manufacturing areas. A landfill site that is relatively more proximate to the industrial sites would therefore be more ideal. Fig. 24 depicts the location of Sites A, B and C and indicates their relative proximity to the industrial areas.

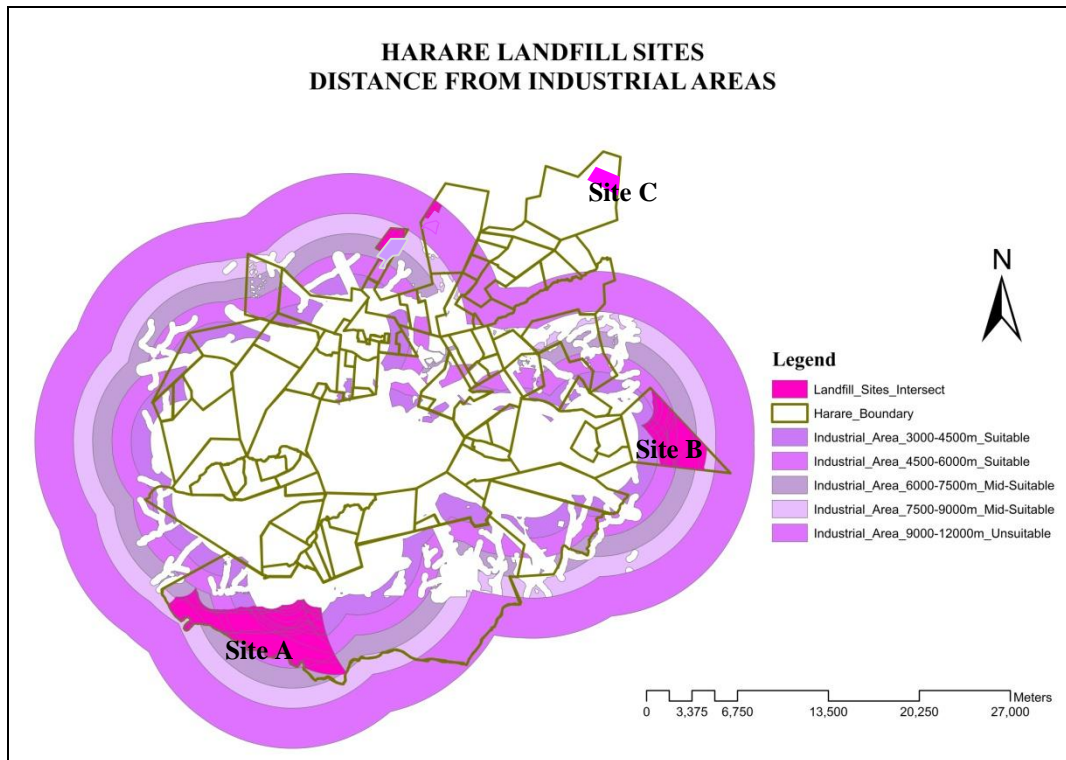


Fig. 24- Suitable Zones: Industrial

Sites A, B and C have varying degrees of suitability considering their distance away from the industrial areas. 'Site A' is the most suitable site. A large proportion of 'Site A's' area is situated between 3,000 and 6,000 meters away from the industrial areas. Therefore, 'Site A' is classified as 'suitable' for landfill development. Conversely, 'Site C' is located between 15,000 and 18,000 meters away from the industrial areas. Accordingly, 'Site C' is categorised as 'unsuitable' as it is the least proximate site to the industrial areas. However, 'Site B' is positioned between 4,500 and 7,500 meters away from the adjacent industrial areas. Hence, 'Site B' is classified as mid-suitable for landfill development.

7.3.5 Suitability in Relation to the Location of Main Roads

The accessibility of the new waste depository has significant bearings on its functionality and viability. Should the landfill be situated in a location that is distant from the primary distributor road and waste generation centres it may not be fully utilised due to its inaccessibility and the high transport associated with waste disposal. Ideally, a waste disposal facility should be situated between 500 and 2,500 meters away from the primary distributor road. This interval distance includes areas classified as 'suitable' and 'mid-suitable'. Fig. 25 indicates the location of the proposed landfill sites A, B, and C; and their classification in terms of their proximity relative to the primary distributor roads.

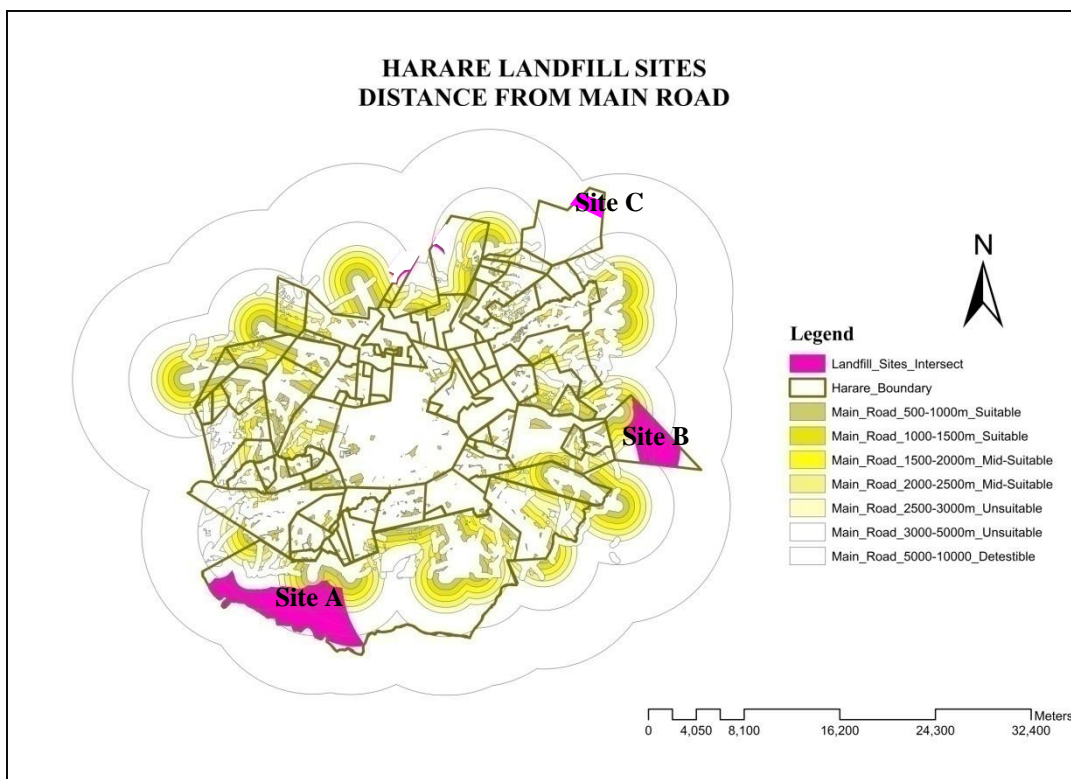


Fig. 25- Suitable Zones: Main Road

None of the sites are located in areas that are accessible and therefore classified as 'suitable'. However, approximately 10% of 'Site A's area is in an area categorised as 'mid-suitable' for landfill development. 'Site C' is located between 6,000 and 10,000 meters away from the nearest highway and may therefore be regarded as the least suitable site for landfill development considering its degree of inaccessibility.

7.3.6 Suitability in relation to the Commercial Centre

The proximity of the proposed municipal solid waste depository to Harare's Central Business District is a further indication of the facility's accessibility and consequent viability. Fig. 26 illustrates the relative location of the elected landfill sites, A, B, and C, to the Harare's Central Business District.

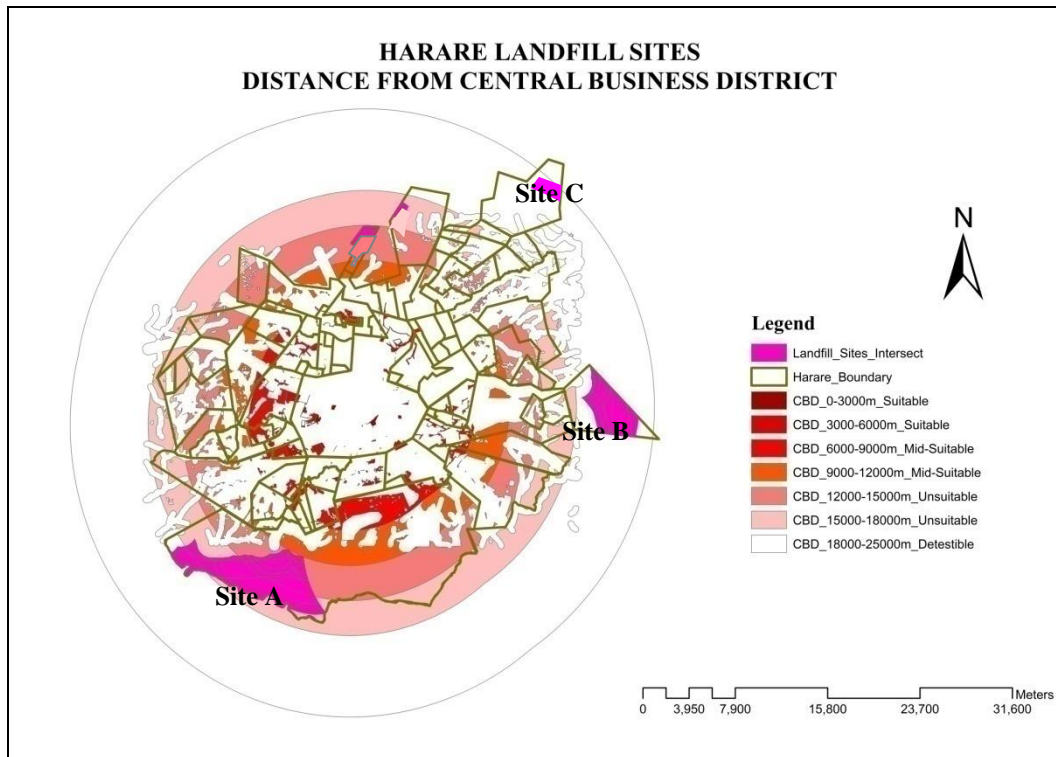


Fig. 26- Suitable Zones: C.B.D.

The site that is nearest to the C.B.D. is 'Site A'. Approximately one third of 'Site A's area is located between 12,000 and 15,000 meters away from the C.B.D. and classified as 'mid-suitable'. The remaining two thirds of 'Site A's area is situated between 15,000 and 18,000 meters away from the C.B.D. and classified as 'unsuitable'. Nonetheless, 'Site A' is the most proximate waste depository for commercial waste. 'Site B' is positioned between 15,000 and 18,000 meters away from the C.B.D. It falls into the 'unsuitable' category. 'Site C' is situated between 25,000 and 28,000 meters away from the C.B.D. 'Site C' is the furthest site from the C.B.D. and the least accessible landfill site for the disposal of commercial waste.

7.3 Verification

7.3.1 Soils and Geology

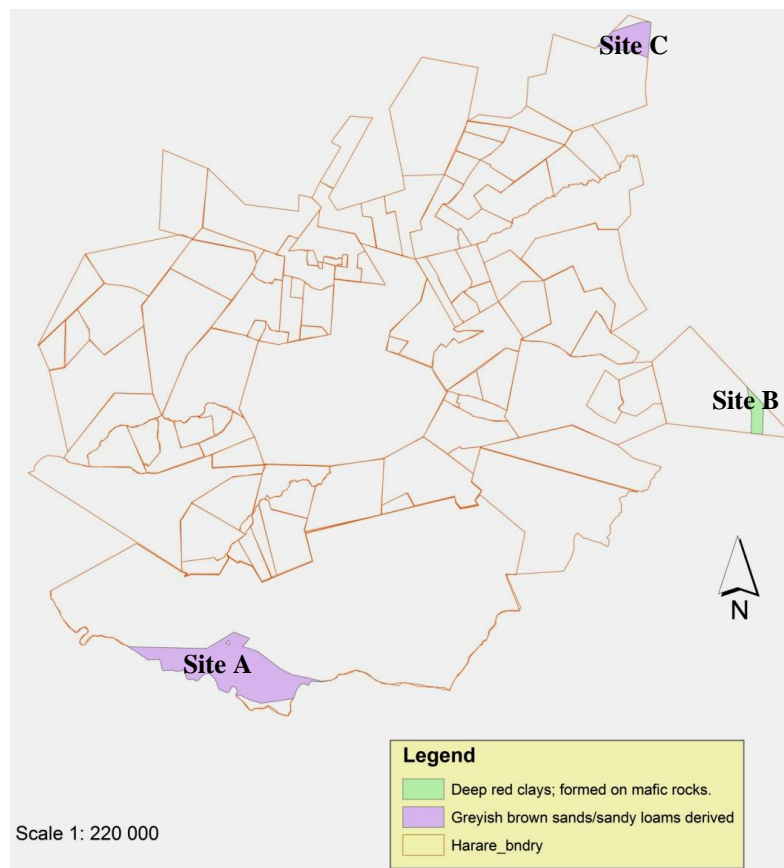


Fig. 27- Soil Types in Suitable Landfill Sites

The type of soils in the various suitable landfill sites is indicated in Fig. 27. ‘Site A’ and ‘Site C’ are situated on sandy loams. These soils consist of a large proportion of sand, silt and clay. The Sand particles add structure to the soil composition, however they also increase the drainage potential of the site and have a high rate of infiltration. Consequently developing a waste depository in these locations will require that specific geo-membranes be employed in order to separate the leachate from the subsurface ground- water system. Soil tests are required to determine the exact soil composition, structure and porosity.

‘Site B’ is located on deep red clay soil. These soils are dominated by clay particles that have a low associated rate of infiltration. Developing a waste depository at ‘Site B’ location is ideal as there is additional protection of the groundwater due to soil composition.

7.4 . Summary

7.4.1 Recommended Landfill Development Locations

The landfill development sites identified using the GIS map intersect and overlay techniques are those, which are less proximate to Harare's existing rivers, wetlands and residential developments and the Harare International Airport. However, these locations are significant distances away from the Central Business District and the Industrial sites. Identifying potential landfill development sites therefore involves appreciating the environmental and socio-economic trade-offs of each location since all the criteria cannot be satisfied simultaneously.

Chapter 8 Conclusion

8.1 Conclusion

8.1.1 Suitable Landfill Sites

This research is a preliminary scoping for potential suitable landfill development sites. The findings of this investigation unveil that potential sites for landfill development do exist within the confines of the city of Harare. The locations identified as 'suitable' for landfill development have varying characteristics and their perceived unique strengths, weaknesses, opportunities and strengths. According to the available map data, the elected sites are a significant distance away from Harare's rivers and streams and their sensitive wetland habitats. Nonetheless it is recommended that additional in depth site investigations be conducted in order to verify the current hydrogeological conditions which may have altered since the date when the maps were published. In addition, these sites are a considerable distance away from the existing residential and community developments. Moreover, these locations are situated a safe distance away from the Harare International Airport and are not expected to create frequent disruptions to the aircraft activity.

'Site C' is proximate to the Harare North neighbourhoods and is a convenient waste depository for domestic and institutional waste generated within that area. Despite its peripheral location, 'Site C' has considerable potential in light of the fact that the city of Harare is a growing and its coverage is increasing annually. This site is therefore recommended as an ideal replacement for the existing Pomona municipal solid waste depository.

'Site A' is a location with a relatively large area coverage. Therefore this site has the capacity to accommodate domestic, industrial, commercial and institutional waste. Its proximity to the central business district and industrial sites makes it an accessible location for the disposal of both commercial and industrial non-hazardous waste. Moreover, this site adjoins the Harare South neighbourhoods and may easily absorb the domestic waste generated within that area. The aforementioned reasons qualify 'Site A' as the recommended replacement for Golden Quarry municipal solid waste depository.

8.1.2 Research Constraints and Directions for Further Research

Although recommended landfill situations were derived in this investigation, the degree of exactness of the locations was limited due to the quality of the available map data. The maps acquired were at a scale of 1:30 000. Further investigations using local development plans and larger scaled maps are expedient in order to verify the outcome against the local conditions, notwithstanding a full environmental impact assessment.

The in availability of map data depicting the position of Harare's high yielding aquifers and subsurface hydrogeology was a further constraint. Consequently, the results of the GIS map overlay were only verified using the Harare Soils Distribution Map. A full qualitative verification of the elected sites is required in order to isolate the ideal sites in relation to the vegetation, elevation, topography and hydrogeology.

The questionnaire adopted in this study was only circulated to expert in land use planning and key stakeholders. However a complete public participation process is required to involve all the residents of the city of Harare and include their views in the decision model in order to achieve an socially acceptable site selection.

8.2 Concluding Remarks

Land-use suitability analysis is a strategic development-planning tool that facilitates judicious site selection. The location of hazardous facilities, such as municipal solid waste depositories, requires careful consideration in order to minimise the risks associated with the development. Identifying a suitable site for municipal solid waste disposal in Harare is a complex multi-criteria land-use decision that mandates a comprehensive analysis of all the factors involved.

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This photo of <http://www.tripadvisor.com.au/Tourism-g293760-Harare_Harare_Province-Vacations.html>Harare is courtesy of [Trip Advisor](#).> [Accessed on: 5.11.2013]
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Appendix A: Structured Interviews

1. What are the waste management challenges in Harare?
2. Where is waste currently being disposed in Harare?
3. Which are the official and unofficial solid waste disposal sites in Harare? Are they licensed or regulated in any way?
4. Do the waste depositories have sufficient capacity to cater for the waste generated in Harare? For the next 5 years? For the next 10 years?
5. Are there any strategies in place for leachate collection at the waste disposal sites?
6. Are there any strategies in place for monitoring groundwater pollution at the waste disposal sites?
7. Are there any strategies in place for methane gas monitoring at the dumpsites.
8. What has been the environmental impact of the Golden Quarry and Pomona waste disposal facilities?
9. Has there been any research or discussions on the possible location for a new municipal solid waste disposal facility?
10. Is there any legislation in place which regulates the location of waste disposal facilities, and stipulates the anticipated distance away from:-
 - a. Residential Areas
 - b. Wetlands
 - c. Rivers
 - d. Commercial Areas
 - e. Industrial Sites

Appendix B: Maps

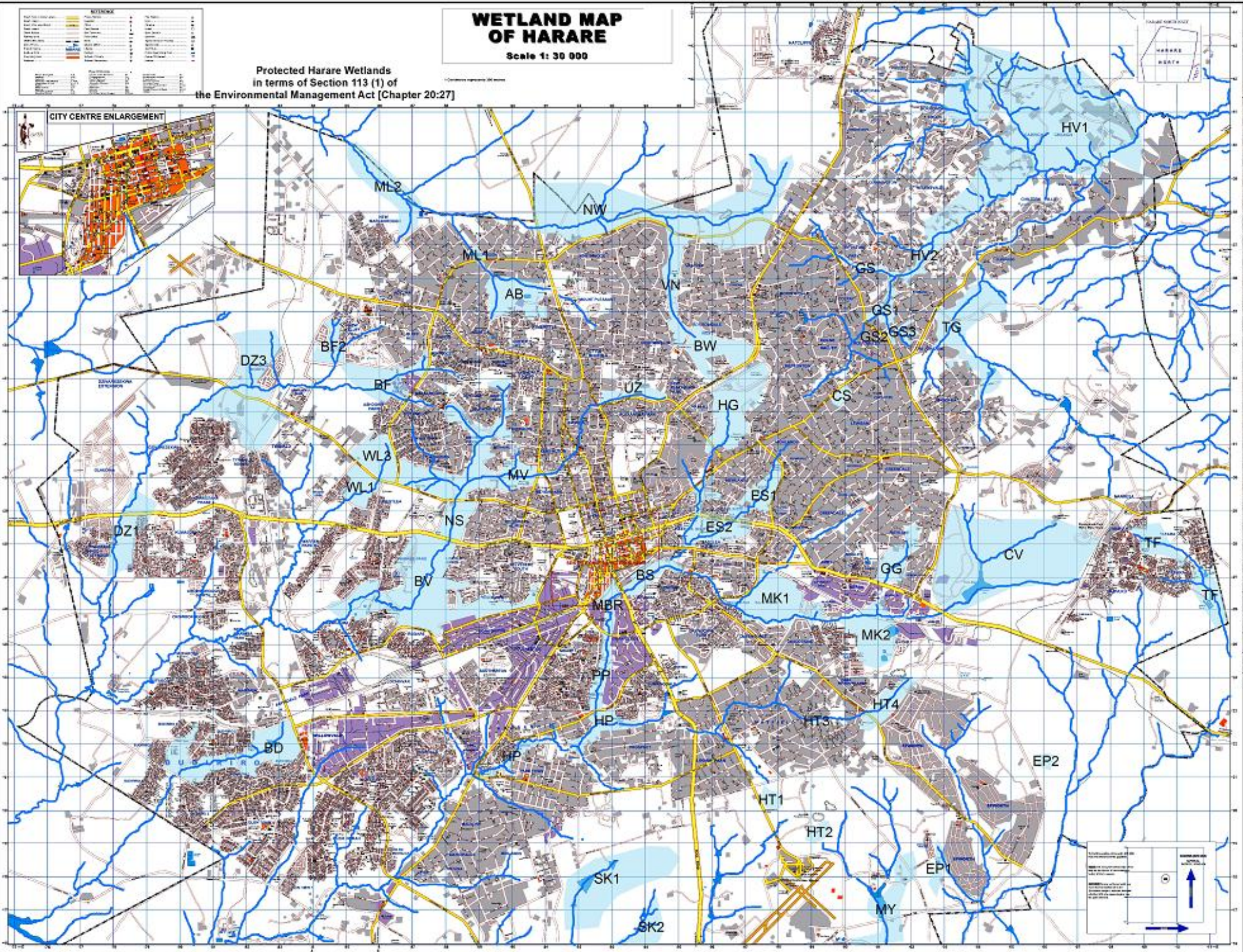
WETLAND MAP OF HARARE

Scale 1: 30 000

Protected Harare Wetlands
in terms of Section 113 (1) of
the Environmental Management Act [Chapter 20:27]

Wetland Code

- AB - Ashbrittle
- BD - Budiriro
- BF - Bluffhill
- BS - Braeside
- BV - Belvedere
- BW - Borrowdale West
- CS - Chisipite
- CV - Cleveland
- DZ - Dzivarasekwa
- EP - Epworth
- ES - Eastlea
- GG - Green Grove
- GS - Greystone park
- HG - Highlands
- HP - Houghton
- HT - Hatfield
- HV - Hellensvale
- MBR - Mbare
- MK - Mukuvisi
- ML - Malborough
- MV - Monavale
- MY - Manyame
- NS - National Sports Stadium
- NW - Northwood
- PP - Prospect
- TG - The Grange
- UZ - University of Zimbabwe
- TW - Tynwald
- VN - Vainona
- WL - Westlea



Street Map - Suveyor General's copyright preserved

Map Produced in May 2012

Appendix C: Questionnaire

FACTORS AFFECTING THE LOCATION OF A NEW SANIATRY LANDFILL IN HARARE

SECTION A : RANKING

1. Kindly rank the factors below according to the level of importance with regards to the location of the new garbage dump site.

FACTOR	RANK
Distance from Residential Areas	
Distance from Primary (Main) Road	
Distance from Wetlands	
Distance from Rivers and Streams	
Distance from Central Business District	
Distance from Industrial Areas	
Site Geology and Soils	
Slope	

RANKING KEY

1- Unimportant

3- Moderate Importance

5- Strong Importance

7-Very Strong Importance

9- Extreme Importance

SECTION B: COMPARISON OF FACTORS

Intensity of Importance	Importance	Degree of Preference
1	Equal Importance	Two factors contribute equally
3	Moderate Importance	I slightly favour one factor over another
5	Strong Importance	I strongly favour one factor over another
7	Very Strong Importance	I favour one factor very strongly compared to the other
9	Extreme Importance	I favour one factor extremely compared to the other

1. Should the dumpsite be away from residential areas or closer to the main road?

Residential Areas Vs Main Road										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Residential Area</i>	9	7	5	3	1	3	5	7	9	<i>Main Road</i>

2. Should the dumpsite be away from residential areas or away from water courses?

Residential Areas Vs Water Courses										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Residential Area</i>	9	7	5	3	1	3	5	7	9	<i>Water Course</i>

3. Should the dumpsite be away from residential areas or away from wetlands?

Residential Areas Vs Wetlands										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Residential Area</i>	9	7	5	3	1	3	5	7	9	<i>Wetlands</i>

4. Should the dumpsite be away from residential areas or in a place with suitable soils and geology?

Residential Area Vs Geology and Soils										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Residential Area</i>	9	7	5	3	1	3	5	7	9	<i>Geology Soils</i>

5. Should the dumpsite be away from residential areas or closer to the central business district?

Residential Areas Vs Central Business District										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Residential Area</i>	9	7	5	3	1	3	5	7	9	<i>CBD</i>

6. Should the dumpsite be away from residential areas or closer to the industrial sites?

Residential Vs Industrial										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Residential Area</i>	9	7	5	3	1	3	5	7	9	<i>Industrial Sites</i>

7. Should the dumpsite be away from residential areas or in a place with flat or gentle slope?

Residential Area Vs Slope										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Residential Area</i>	9	7	5	3	1	3	5	7	9	<i>Slope</i>

8. Should the dumpsite be closer to the main road or away from water courses?

Main Road Vs Water Courses										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Main Road</i>	9	7	5	3	1	3	5	7	9	<i>Water Courses</i>

9. Should the dumpsite be closer to the main road or away from wetlands?

Main Road Vs Wetlands										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Main Road</i>	9	7	5	3	1	3	5	7	9	<i>Wetlands</i>

10. Should the dumpsite closer to the main road or in a place with impermeable rocks & soil?

Main Road Vs Geology and Soils										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
Main Road	9	7	5	3	1	3	5	7	9	Geology & Soils

11. Should the dumpsite closer to the main road or closer to the central business district?

Main Road Vs Central Business District										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
Main Road	9	7	5	3	1	3	5	7	9	CBD

12. Should the dumpsite be closer to the main road or closer to the industrial sites?

Main Road Vs Industry										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
Main Road	9	7	5	3	1	3	5	7	9	Industry

13. Should the dumpsite be closer to the main road or in a place with a flat/gentle slope?

Main Road Vs Slope										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
Main Road	9	7	5	3	1	3	5	7	9	Slope

14. Should the dumpsite be away from the water courses or away from the wetlands?

Water Courses Vs Wetlands										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
Water Courses	9	7	5	3	1	3	5	7	9	Wetlands

15. Should the dumpsite be away from water courses or in a place with impermeable soil?

Water Courses Vs Geology & Soil										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
Water Courses	9	7	5	3	1	3	5	7	9	Geology & Soil

16. Should the dumpsite be away from the water courses or closer to the Central Business District?

Water Courses Vs Central Business District										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
Water Courses	9	7	5	3	1	3	5	7	9	CBD

17. Should the dumpsite be away from water courses or closer to the industrial sites?

Water Courses Vs Industry										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Water Courses</i>	9	7	5	3	1	3	5	7	9	<i>Industry</i>

18. Should the dumpsite be away from water courses or in a place with a flat/gentle slope?

Water Courses Vs Slope										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Water Courses</i>	9	7	5	3	1	3	5	7	9	<i>Slope</i>

19. Should the dumpsite be away from wetlands or in a place with impermeable geology and soil?

Wetlands Vs Soils & Geology										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Wetlands</i>	9	7	5	3	1	3	5	7	9	<i>Soils & Geology</i>

20. Should the dumpsite be away from wetlands or closer to the central business district?

Wetlands Vs Central Business District										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Wetlands</i>	9	7	5	3	1	3	5	7	9	<i>CBD</i>

21. Should the dumpsite be away from wetlands or closer to the industrial sites?

Wetlands Vs Industry										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Wetlands</i>	9	7	5	3	1	3	5	7	9	<i>Industrial Sites</i>

22. Should the dumpsite be located away from wetlands or in a place with a flat /gentle slope?

Wetlands Vs Slope										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Wetlands</i>	9	7	5	3	1	3	5	7	9	<i>Slope</i>

23. Should the dumpsite be located in place with impermeable soil or closer to the CBD?

Geology & Soil Vs Central Business District										
Factor	<i>More important than</i>				Equal	<i>Less important than</i>				Factor
<i>Geology & Soil</i>	9	7	5	3	1	3	5	7	9	<i>CBD</i>

Appendix D: Suitability Index

CRITERION	SUITABILITY	RANKING	WEIGHT
Wetkands_0-500m	Unsuitable	3	1
Wetlands_500-1000m	Unsuitable	3	1
Wetlands_500-1000m	Mid-Suitable	5	2
Wetlands_500-1000m	Mid-Suitable	5	2
Wetlands_500-1000m	Suitable	7	3
Wetlands_500-1000m	Suitable	7	3
Wetlands_500-1000m	Optimum	9	4
Wetlands_500-1000m	Optimum	9	4
Rivers_250-500m	Unsuitable	3	1
Rivers_500-750m	Unsuitable	3	1
Rivers_750-1000m	Mid-Suitable	5	2
Rivers_1000-1250m	Mid-Suitable	5	2
Rivers_1250-1500m	Suitable	7	3
Rivers_1500-3000m	Suitable	7	3
Rivers_3000-6000m	Optimum	9	4
Rivers_3000-6000m	Optimum	9	4
Residential_0-250m	Unsuitable	3	1
Residential_250-500m	Unsuitable	3	1
Residential_500-750m	Mid-Suitable	5	2
Residential_750-1000m	Mid-Suitable	5	2
Residential_1000-1250m	Suitable	7	4
Residential_1250-1500m	Suitable	7	4
Residential_1500-3000m	Optimum	9	5

CRITERION	SUITABILITY	RANKING	WEIGHT
Residential_3000-6000m	Optimum	9	6
Industrial_Area_0-1500m	Optimum	9	3
Industrial_Area_1500-3000m	Optimum	9	3
Industrial_Area_3000-4500m	Suitable	7	2
Industrial_Area_4500-6000m	Suitable	7	2
Industrial_Area_6000-7500m	Mid-Suitable	5	2
Industrial_Area_7500-9000m	Mid-Suitable	5	2
Industrial_Area_9000-12000m	Unsuitable	3	1
Industrial_Area_12000-15000m	Unsuitable	3	1
CBD_0-3000m_	Optimum	9	3
CBD_3000-6000m	Optimum	9	3
CBD_6000-9000m	Suitable	7	2
CBD_9000-12000m	Suitable	7	2
CBD_12000-15000m	Mid-Suitable	5	2
CBD_15000-18000m	Mid-Suitable	5	2
CBD_18000-25000m	Unsuitable	3	1
CBD_18000-25000m	Unsuitable	3	1
Main_Road_500-1000m	Optimum	9	2
Main_Road_1000-1500m	Optimum	9	2
Main_Road_1500-2000m	Suitable	7	1
Main_Road_2000-2500m	Suitable	7	1
Main_Road_2500-3000m	Mid-Suitable	5	1
Main_Road_3000-5000m	Mid-Suitable	5	1
Main_Road_5000-10000m	Unsuitable	3	1
Main_Road_5000-10000m	Unsuitable	3	1

