THE USE OF GEOGRAPHIC INFORMATION SYSTEM IN LANDFILL SITES SELECTION IN JOS NORTH, PLATEAU STATE

BY

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DECLARATION

I declare that the work in the dissertation entitled "***The Use of Geographic Information System in Landfill Sites Selection in Jos North, Plateau State***" has been performed by me in the Department of Geography under the supervision of Dr I. J. Musa and Dr. B Akpu. The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this dissertation was previously presented for another degree or diploma at any university.

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Signature ***Date***

CERTIFICATION

This thesis entitled **"THE USE OF GEOGRAPHIC INFORMATION SYSTEM IN LANDFILL SITES SELECTION IN JOS NORTH, PLATEAU STATE"** by Ahmed, Murtala Hassan meets the regulations governing the award of the degree of MASTERS of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

This study identifies suitable sites appropriate for solid waste landfill in the vicinity of Jos-North using Remote Sensing and of Geographic Information Systems (GIS). Remote Sensing was used for generating a landuse map of the study area and GIS was used in integrating various layers of information, practically having the same spatial reference, to produce a suitability map for solid waste landfill. The task required a number of multiple criteria, and each having some level of importance. In order to accommodate the significant role of each criteria, the Multicriteria Decision Analysis (MCDA), particularly Analytic Hierarchy Process (AHP) was employed. For this purpose, nine (9) input map layers including settlements, roads, wetlands, slope, geology, soil, landuse, floodplains, and surface water were prepared and used as constraint criteria for determining suitability. Weighted overlay tool in ArcGIS 9.3 was used for the final suitability map, and it yielded conformable results. Out of 291km^2 of the entire study area, 20.8km^2 was found to be suitable for siting sustainable landfill. The map layers related with geology, hydrogeology, and land use are based on available data. Because they are not specifically prepared for landfill site selection purpose, the information provided from these maps were not quite satisfactory. It is understood that rather than general purpose lithological map, the maps showing distribution, thickness, and characteristics of the unconsolidated superficial deposits are more helpful. Thus, for landfill siting studies, special purpose engineering geological and hydrogeological maps are required. The slope layer needs to be refined to exclude those areas along the ridges and the hill tops.

DEDICATION

To my late beloved brother Nura Ahmed Hassan,
For his dogged effort in dragging me to school against all existing discouragement,
I owe you eternal debt of gratitude!
May his soul rest in peace, amen!

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Solid waste management is an important element in public health and environmental protection (Yesilnacar & Cetin, 2005). Its main purpose is to provide hygienic, efficient and economic collection, transportation, treatment and/or disposal of solid wastes without polluting the atmosphere, soil or water resources, and the management strategy should address the issue of aesthetic (UNDP, 1997) .

The growth in municipal solid waste generation the world over has been reported to be a consequence of urbanization, industrialization, and population growth, together with improved living standard (Rao, Brinda, & Harikrihna, 2007). It is estimated that the United Kingdom produces 35 million tonnes of municipal solid waste annually (Koshy, Emma, Sarah, Tim & Kelly, 2007) and in the United States of America, more than 140 million tonnes of municipal waste is generated annually, while Japan and Germany generates 50.2 million and 43.5 million tonnes respectively, in 1993 (Sakai, *et al.*, 1996).

The situation in Africa is similar to other parts of the world. Nigeria with a population growth rate of about 2.8% per annum and an urban growth rate of about 5.5% per annum (Imam, Mohammed, Wilson & Cheeseman, 2008) generates about 20 kg of Solid waste per capita every year (Olaleye & Sangodina, 2000). Also, solid waste generated by an average Nigerian per day is estimated to be around 0.49kg while commercial centres and households contribute almost 90% of the total waste found in urban centres (Solomon, 2009).

According to a United Nations Development Programme survey of 151 cities from around the world, the second most serious problem that city dwellers face (after unemployment) is insufficient solid waste disposal (UNDP, 1997). Thus, a properly sustainable waste management practice is highly needed to handle the situation.

In developed countries, the issue of solid waste is properly handled through the effective management process of waste reduction, reuse, recycle and proper disposal. However, in developing countries, municipal solid waste management system is either not efficient or still at the rudimentary stage and as such solid waste generated has become a threat to the environment (Solomon, 2009). For instance, in Jos North, waste is generally dumped inside culverts and rivers, and at the on-set of raining season flood becomes a common scene in the city of Jos (Wuyep, 2011). As for dumping waste in the River Dilimi, a major drainage of the Jos-plateau, Abdullahi (2008) reveals the presence of heavy metals in vegetables crops planted along the river, as beyond the limit of exposure stipulated by WHO and attributes this to waste dumped into the river in addition to run-off of fertilizer from farm lands. Thus proper disposal of waste is urgently needed to achieve sustainable waste management.

According to Rao, *et al.*, (2007) to achieve a sustainable solid waste management system, policies and techniques such as waste recycling, reuse, waste reduction, thermal treatment, landfilling etc, must be in place. Out of these techniques, landfilling is the most common method adopted in many countries (Yesilnacar & Cetin, 2005). Landfill is a system for solid waste disposal onto or into land, taking social, economic and environmental matters into account (Rao, *et al.*, 2007). Sanitary landfilling is the technique of disposing of refuse on land creating no nuisance or danger to public health or safety by applying the principles of engineering to restrict the refuse within a smallest

practical volume and to cover it with a layer of earth at more frequent periods as may be required (UN-HABITAT, 2010).

In Nigeria, open or uncontrolled dumping is largely used as waste disposal method but the benefit of sanitary landfill over the Open dumping methods cannot be overemphasized because it is pollution-free thereby eliminating any health or environmental risk that may result from solid waste disposal (UN-HABITAT, 2010).

However, municipal landfill siting is becoming increasingly difficult considering that closeness of site to residential area, river, water channel or other fragile ecosystem could lead to adverse environmental pollution and degradation as well as health hazards (UN-HABITAT, 2010). According to Sakai *et al.* (1996) a properly designed and well-managed landfill can be hygienic and relatively inexpensive while a poorly designed or poorly managed landfill can create a number of environmental problems such as ground water contamination, wind-blown litters, and attraction of vermin in addition to uncontrolled emission of landfill gases such as methane. Such problems have resulted into the non-acceptance of landfills by communities (Yesilnacar & Centin, 2005).

Therefore, to protect the ecosystem from being disturbed and to ensure healthy environment for the survival of man, it becomes necessary to carefully locate landfills on environmentally suitable locations (Sakai *et al.*, 1996). Selection of sites for landfill involves an extensive evaluation process in order to identify the optimal available disposal location. This location must satisfy basic government regulations, and also take into cognizance how to minimize important factors like health, economic, environmental and social cost (Siddiqui *et al.*, 1996). In fact, different researchers have used varying criteria for site selection purposes due mainly to the fact that different criteria apply to different regions (Stinnette, 1996; Sadek & Fadel, 2006).

It is evident that, many factors must be incorporated into landfill siting decisions and Geographic Information System (GIS) together with Remote Sensing is ideal for this kind of preliminary studies due to their ability to manage large volumes of spatial data from a variety of sources. GIS is practically effective in storing, retrieving and analyzing, and also displays information according to user defined specifications (Siddiqui *et al.*, 1996). According to Kao & Lin (1996) large amount of spatial data can be processed using GIS and thus, it potentially saves time that would normally be spent in selecting an appropriate site using manual processing approach.

Multicriteria Decision Analysis (MCDA) can be used to deal with the difficulties that decision-makers encounter in handling large amounts of complex information. The principle of the method is to divide the decision problems into smaller more understandable parts, analyze each part separately and then integrate the parts in a logical manner (Malczewski, 1997).

The integration of GIS and MCDA provides a reliabl e platform for solving the landfill site selection problem, because GIS provides efficient manipulation and presentation of the data and MCDA supplies consistent ranking of the potential landfill areas based on a variety of criteria. Hence the need for this study to apply GIS in the selection of suitable landfill sites for sustainable waste management in Jos North Local Government Area (LGA) of Plateau State.

1.2 STATEMENT OF THE RESEARCH PROBLEM

One of the problems in environmental management in developing countries is inadequate disposal of municipal solid waste (Sakai *et al.*, 1996). Solid waste landfill as an ultimate alternative of disposal has been always considered and selected by the solid waste management in the cities particularly because of lower costs and easy operation

(Yesilnacar & Centin, 2005). However, the environmental pollutions and degradation of natural resources resulting from improper actions of the management of landfills have been one of the concerns of surrounding communities and distress of municipal authorities (Allen *et al.*, 2002). Identification of the situation of urban solid waste landfills is required to prevent increasing the environmental problems. There are potential public health and environmental implications associated with landfills. Some landfill sites have problems with uncontrolled leakages, litter, odour, and toxic leachate, which have the potential to contaminate surrounding land and groundwater. Landfill gas, which is a mixture of methane (CH_4) and carbon dioxide (CO_2), is produced from the breakdown of biodegradable waste in the landfill. Landfills are now recognised as the largest man-made source of CH_4 release to the atmosphere, which contributes significantly towards global warming (Dikshit , Padmavathi, & Das., 2000).

Abulsalam (2010) examined the health impact of solid waste management among residents around the Mangwaneni dumpsite in Swaziland. The respondents were stratified by the distance of their homes to the dumpsite. The first group were those residing within 200 metres radius, while the second group lived from 200 metres and beyond from the dumpsite. The study, which was conducted among 78 households, found that 82% of the respondents rejected landfills around them particularly because of odour. In another study conducted in Lagos State by Akinjare (2011) on residential property values around landfill neighbourhoods in Lagos, findings reveal that residential houses in close proximity to the landfills suffered value loss.

A study conducted by Adamu & Adekiya (2010), on the water quality of boreholes around selected landfills in Kano Metropolis, found high concentration of lead, Nickel, Copper, and Chromium above the regulatory standard of Standard Organisation of

Nigeria (SON). These could be hazardous to the ecosystem and public health, since metals are cumulative toxicants posing danger to organisms near the top of the food chain. It could also lead to bio accumulation and bio –concentration of the heavy metals in living organisms (Al-Ghazawi & Abdallah, 2008).

Yahaya, Umoh & Ameh (2011) determined the contamination level and the distribution of pathogenic substances in well water located near the municipal solid and liquid wastes in Zaria, Northern Nigeria. The study discovered high concentration of such pathogenic substances beyond WHO regulatory standard.

In order to address the problems landfills pose to communities, Wuyep (2011) carried out a study on landfill siting using GIS and Remote Sensing in Jos North. The study focused mainly on socio-economic factors, such as distance from residential areas, cost of transporting waste to dump site, and estate property cost. Findings from the study reveal that approximately 55% of the study area was unsuitable for locating landfill due to proximity to residential areas; and 15% due to agricultural lands and orchards.

However, Wuyep (2011) focused only on socio-economic factors (Residential areas, road network and landuse) whereas Siddiqui *et al.* (1996) has shown that precipitation, site topography, slope gradient, depth of underground water, geology and soil permeability play a vital role in landfill siting and thus must be considered. Thus, this study includes geologic and hydrogeologic factors, such as slope and surface permeability (soil/geology suitability to protect underground water) in addition to the socio-economic factors.

The study attempts to answer the following questions:

1. What are the Landuse Land Cover (LULC) classes in the study area?
2. What is the proportional role of slope, surface permeability, and rocky outcrop in landfill siting?
3. Which areas are suitable for siting landfills?

1.3 RESEARCH AIM AND OBJECTIVES

The aim of this study is to select suitable landfill sites for sustainable solid waste management in Jos North LGA, using Remote Sensing and GIS.

In order to achieve the stated aim of the study, the objectives are to:

i) characterize the landuse/land cover (LULC) of the area

ii) produce the factor maps required for a sustainable landfill site (slope; buffer zones for built-up-area, roads, wetland, floodplains and surface water; and surface permeability)

iii) determine the areas suitable for landfill using the weighted overlay tool in ArcGIS and Multicriteria Decision Analysis

1.4 SCOPE OF THE STUDY

The study will cover the entire administrative boundary of Jos North LGA. Selection of landfills for waste management is the focus of the study and siting criteria will be limited to elevation, slope gradient, aspect, surface permeability (i.e. geology /soil), and landuse (proximity to roads, proximity to water bodies, wetlands, floodplains and proximity to settlement areas). Of the various methods that are commonly used in Multicriteria decision analysis, the Analytical Hierarchy Process (AHP) will be adopted for the study; it gained high popularity because of easiness in obtaining the weights and capacity to integrate heterogeneous data in decision making process.

1.5 JUSTIFICATION FOR THE STUDY

Landfill is the most common method of disposing waste in Nigeria (Ogwueleka, 2009) and therefore, because of the fragile nature of landfill, sophisticated techniques need to be employed and adopted carefully in order to achieve an environmentally sustainable waste management. Selecting environmentally sustainable sites for landfills will go a long way improving the public health status of the community. In addition to reducing time and cost of site selection, GIS has the capability of providing a data bank for future monitoring programme of the landfill sites (Miles, 1999). Therefore, effective siting of landfill is guaranteed using GIS, and this would yield a reliable outcome for environmental conservation and sustainability.

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses basic concepts related to waste management, landfill siting, and Geographic Information System. In addition to that, it also captures a comprehensive review of the literature related to landfill Siting using Geographic Information System Techniques with a view to accommodate the academic contribution of this work.

2.2 CONCEPTUAL FRAMEWORK

2.2.1 Waste

Historically it has been difficult to determine the true definition of waste; with individuals, community, and nations, the meaning and interpretation differs greatly in all contexts (Hawkins & Shaw, 2006). This difficulty has led to a strict definition to ensure proper handling and disposal of waste types in accordance with laws and regulation (Hawkins & Shaw, 2006).

According to the European Commission (EC) waste framework directive (75/422 EC), "waste means any substance or object which the holder disposes of or is required to dispose of pursuant to the provisions of national law in force". On the other hand, the Federal Environmental Protection Agency (FEPA) in Nigeria does not define waste in their statue; rather the contemporary definition of waste was defined by state agencies like the Lagos State Environmental Agency (Olorunfemi, 2009). According to the Lagos State Environmental Protection edicts, "waste is any substance which constitute scrap materials or effluent or other unwanted surplus substances arising from the application of process". In complementing the definitions of waste, a summary of the

meaning of waste is outlined according to Hawkins & Shaw (2006) for the purpose of understanding the stated problem in the study area.

In summary, "a material is waste if it is:

- assigned to a waste disposal operation
- illegally disposed of or abandoned
- remitted to a specialized recovery operation
- an individual pays to have the material removed" (Hawkins & Shaw, 2006).

2.2.2 Solid Waste

Solid waste is usually used to describe non-liquid materials from domestic, trade, commercial, agricultural and industrial activities, and from public services. It consists of both solid and liquid waste but not waste water. Solid waste consists of any refuse, sludge, discarded materials, small amount of liquid, semi-solid etc. (Olorunfemi, 2009).

In many of the developing countries, the generation of solid waste has become part of daily living, and the countries are faced with the problem of solid waste generation in an almost endless fashion. The implication is serious taking into account the inefficient disposal system in many of these countries, which could eventually cause health problems and environmental degradation (Filemon & Uriarte, 2008). Sadly, the rates of solid waste generation have increased at an alarming rate over the years with lack of management system, especially the collection and disposal function (Olorunfemi, 2009).

2.2.3 Municipal Solid Waste

Municipal solid waste (MSW) refers to the material discarded for which municipalities are usually held responsible for collection, transportation and final disposal (Olorunfemi, 2009). MSW encompasses household refuse, institutional, commercial and

industrial waste that is neither waste water discharge nor atmospheric emission. The composition of municipal solid waste is a heterogeneous mixture of different types of discarded wastes. This implies that municipal solid waste often includes food waste, garden waste, paper, dry refuse, kitchen waste, discarded clothing, which are biodegradable and other fractions of non-biodegradable material such as furnishing , glass, plastics and other furnishing household material (Olorunfemi,2009).

At present, in some developing districts in Nigeria, MSW is collected in mixed state and is being dumped in environmentally very sensitive places like road sides, forests, wildlife areas, water courses, etc., causing numerous negative environmental impacts (Emeka, 2011).

2.2.4 Solid Waste Management

There is no one sustainable waste management solution which yet reigns supreme (Avernest, 2007). There are still conflicting views as to the most practical, environmentally beneficial and effective means of achieving sustainable waste management (Olorunfemi, 2009).

The overall policy aims to achieve sustainable waste management, that have been established in recent years across the whole of the European Union and many other nations are:

* to reduce the amount of waste that society produces;
* to make best use of that that is produced; and
* to choose waste management practices which minimise the risks of immediate and future environmental pollution and harm to human health. (Allen *et al.,* 2003*)*.

Over the last ten years or so the actions needed for the waste industry and individuals to follow, and which are most sustainable have been defined by the policy makers

A waste disposal method for making the choice between waste treatment and disposal options which puts landfill disposal at the bottom of the list of possible waste disposal routes is known as the waste disposal hierarchy.

2.2.5 Waste Disposal Hierarchy

1) Source reduction
2) Recycling
3) Waste transformation
4) Landfilling

Thus, Landfill have a role in this strategy in mopping up the residual waste after all pre-treatment of waste has already removed as much from the waste stream as possible, but it is a continually reducing one, and consensus among waste professionals still remains tenuously established at best (Olorunfemi, 2009) .

2.2.5.1 Source Reduction

It involves diminishing waste amount, volume and toxicity at the source of waste generation (Kreith, 1994). Source reduction is the most effective way which reduces the quantity of waste, the cost of associated with its handling, and its environmental impacts. Waste reduction may occur through the design, manufacture, and packaging of products with minimum toxic content, minimum volume of material, or a longer life and also at the household, commercial, or industrial facility through selective buying patterns and the reuse of products and material (Tchobanoglous, 1993).

2.2.5.2. Recycling

It involves (1) the separation and collection of waste materials; (2) the preparation of these materials for reuse, reprocessing, and remanufacture; and (3) the reuse, reprocessing, and remanufacture of these materials. Recycling is an important factor in helping to reduce the demand on resources and the amount of waste require disposal by landfilling (Tchobanoglous, 1993). Reusing waste products can be simply made by the public by returning drink containers to bottling manufacturers and the donation of used clothes, shoes, furniture, and electrical products to charities and retailers. Product recycling primarily involves melting glass and metals, pulping of paper waste so that the end product is useful as a raw material to manufacturers. Benefits of waste recovery include conserving finite resources, lowering the need for mining or harvesting virgin material, reducing inert residues from incinerators, and fewer demands on landfills (Kreith, 1994).

2.2.5.3. Waste transformation

It involves the physical, chemical, or biological alteration of wastes. Typically, the physical, chemical, and biological transformations that can be applied to municipal solid wastes are; (1) to improve the efficiency of solid waste management operations and system, (2) to recover reusable and recyclable materials, and (3) to recover conversion products and energy in the form of heat and combustible biogas. The transformation of waste materials usually results in the reduced use of landfill capacity (Tchobanoglous, 1993). Transformation examples include mechanical clipping, shredding, and grinding, thermal combustion, and composting organic food and yard waste (Kreith, 1994). A benefit of thermal incineration is the potential for energy generation while reducing waste volume up to 90% (Tchobanoglous, 1993).

2.2.5.4. Landfilling

It is the process by which the solid wastes that cannot be recycled nor further used; the residual matter remaining after the recovery facility and after the recovery of conversion products and energy is placed in a landfill. Although there is a public opposition to landfills, it is necessary and there is no combination of waste management technique that does not require landfilling to make them work (Olorunfemi, 2009). Landfilling includes monitoring of the incoming waste stream, placement and the compaction of waste, and installation of landfill environmental monitoring and control facilities. The advantages and disadvantages of landfill are given in Table 2.1

Table 2.1 Advantages and Disadvantages of landfills

Landfill advantages	Landfill disadvantages
Independence from other facilities	Land depreciation
Post-closure land development (ex: parks)	Wind borne paper, plastics, odor, etc.
Tipping fees from imported waste	Imported waste reducing landfill lifespan
Local employment opportunities	Public/political opposition
Potential tax from landfill	Traffic of large vehicles
Disposal strategy up to 30 years	Erosion of waste and/or cover soil
Local waste disposal	Potential risk to groundwater
Potential energy recovery from gases	Vermin/vector control

(Tchobanoglous, 1993)

Some terms used in solid waste landfilling are defined as follows:

i *Landfills* are the physical facilities used for the disposal of residual solid wastes in the surface soils of the earth. In the past, the term sanitary landfill is used to describe a landfill in which the waste placed in the landfill was covered at the end of each day. Today, sanitary landfill refers to an engineered facility for the municipal solid waste designed and operated to minimize public health and environmental impacts.

ii *cell* is used to describe the volume of material placed in a landfill during one operating period, usually one day. A cell includes the solid waste deposited and the daily cover material surrounding it. During landfill operations, waste is spread thinly and compacted before it is covered by daily cover. It usually consists of 15.24 cm to 30.48 cm (6 to 12 in) soil or alternative material which is applied to the working faces

of the landfill at the end of the each operating period. The purpose of daily cover is to control the infestation of pests, to limit windblown debris, to cover unsightly waste and to prevent infiltration of rain and snow melt into compacted waste.

iii *lift* is a complete layer of cells over the active area of the landfill. Typically, landfills consist of a series of lifts. The final lift includes the cover layer. The term bench (or terrace) is commonly used where the height of the landfill will exceed to 15.24 m to 22.86 m (50 to 75 ft). Benches are used to maintain the slope stability of the landfill, for the placement of surface water drainage channels, and for the location of landfill gas recovery piping. The final cover layer is applied to the entire landfill surface after all landfilling operations are finished. It usually consists of multiple layers of soils and geomembrane materials which are designed to enhance surface drainage, intercept percolating water, and support surface vegetation.

iv Leachate is known as the liquid collected at the bottom of the landfill. In general, leachate is a result of the percolation of precipitation, uncontrolled runoff, irrigation water into the landfill, the water initially contained in the waste and also infiltrating groundwater. It contains a variety of chemical constituents derived from the solubilization of the materials deposited in the landfill and from the products of the chemical and biochemical reactions occurring within landfill.

v Landfill gas is the mixture of gases within a landfill. It mainly consists of methane (CH_4) and carbon dioxide (CO_2). These are the principal products of the anaerobic decomposition of the biodegradable organic fraction of the municipal solid waste in the landfill. Other components of landfill gas include atmospheric nitrogen and oxygen, ammonia, and trace organic compounds.

vi Landfill liners are materials (both natural and manufactured) used to line the bottom area and below grade sides of a landfill. Liners usually consist of layers of compacted clay and geomembrane material designed to prevent migration of landfill leachate and landfill gas.

vii Landfill control facilities include liners, landfill leachate collection and extraction systems, landfill gas collection and extraction systems, and daily and final cover layers.

2.2.6 Common Landfilling Methods

The principal methods used for landfilling of municipal solid waste are; (1) excavated cell / trench, (2) area, and (3) canyon.

2.2.6.1 Excavated cell/trench method

The excavated cell/trench method of landfilling is suitable for areas where an adequate depth of cover material is available at the side and where the water table is not near the

surface. Typically, solid wastes are placed in cells or trenches excavated in the soil. The excavated soil from the site is used for daily and final cover. The excavated cells or trenches are usually lined with synthetic membrane liners or low permeability clay or a combination of the two to limit the movement of both landfill gases and leachate (Tchobanoglous, 1993). A variation of this method is the artesian or zone of saturation landfill. These landfills are constructed below the naturally occurring groundwater table. Special provisions should be made to prevent groundwater from entering the landfill and to control the movement of leachate and gases from completed variation of this method is the artesian or zone of saturation landfill. These landfills are constructed below the naturally occurring groundwater table. Special provisions should be made to prevent groundwater from entering the landfill and to control the movement of leachate and gases from completed cells. Usually the site is dewatered, excavated and then lined. The dewatering facilities are continued until the site is filled to avoid the creation of uplift pressures which may cause the liner to heave and rupture (Adams, Cromier & Lai 1998).

2.2.6.2 Area method

The area method is used when the terrain is unsuitable for the excavation of cells or trenches. High groundwater conditions necessitate the use of the area type landfills. Site preparation includes the installation of a liner and leachate control system. Cover material must be carried by truck or earthmoving equipment from adjacent land or from borrow-pit areas. In locations with limited availability of material compost produced from waste can be used as cover. Other techniques include the use of movable temporary cover materials such as soil and geomembranes. Temporarily placed soil and

geomembranes over a completed cell, can be removed before the next lift is begun. (Tchobanoglous, 1993)

2.2.6.3 Canyon/Depression method

In this method, canyons, dry borrow pits, and quarries are used for landfills. The techniques to place and compact solid wastes in canyon/depression landfills vary with the geometry of the site, the characteristics of the available cover material, the hydrology and geology of the site, the type of the leachate and gas control facilities to be used, and the access to the site. Typically, filling for each lift starts at the head end of the canyon and ends at the mouth to prevent the accumulation of water behind the landfill. Canyon/depression sites are filled in multiple lifts, and the method of operation is the same as the area method. If a canyon floor is reasonably flat, the initial landfilling may be carried out using the excavated cell/trench method. The availability of adequate material to cover the individual lifts and to provide a final cover over the entire landfill is very important. Cover material is excavated from the canyon walls or floor before the liner system is installed. Borrow pits and abandoned quarries may not contain sufficient soil for intermediate cover, so that it may have to be important (Tchobanoglous, 1993)

2.2.7 Municipal Solid Waste Management in Developing Countries

Globally, waste generation has been increasing with increasing wealth and economic growth. In developing countries, the waste generation is growing rapidly and may keep increasing in quantum as a result of improvement in standard of living, economic activities and population growth (UN-HABITAT, 2010).

In most of these nations, the issues of Municipal Solid Waste Management are of immediate concern, and problematic. For example, in some African countries, one to two thirds of the solid waste generated is not collected. As a result, the uncollected

waste, usually end up in the surrounding environment or drainage or open dump. They are confronted with many aspects of problems such as, inadequate service coverage and operational inefficiencies of services, limited utilization of recycling activities and inadequate landfill disposals (UN-HABITAT, 2010).

In many of the municipalities of Sub-Saharan Africa (SSA), wastes are often dumped at any convenient location, drainage or open dumps as a result of inadequacies in operational capacity and institutional framework for proper management (Emeka, 2011). In fact, until the late 1980s, solid waste management policies and programs in SSA were set up by national institutions with little or no coordinated effort in ensuring efficiency and effectiveness in collection, transportation, transfer and disposal. These persistent problems in many cities of less developed SSA are largely due to poor management practices (AFDB, 2002).

However, in the last decade, institutional and social changes have dramatically been occurring, thereby creating awareness of the significant impact of the waste stream on environment among the public, and ensuring capacity building in the overall management scheme of solid waste (AFDB, 2002). Many countries across the region have made efforts to improve solid waste management practices. An example of such a country with waste issues that has made efforts in the management of solid waste is Nigeria (Emeka, 2011).

2.2.8 Municipal and Solid Waste Management in Nigeria

Solid waste management has become a major concern in developing countries like Nigeria. Already most cities are faced with the twin problems of population growth and rapid expansion.

The volume of solid waste being generated is increasing compared to the ability of the existing system in managing the generated waste. In Nigeria, solid waste management is characterized by inefficient collection methods, insufficient coverage of the collection system and improper disposal of solid waste (Emeka, 2011). Across Nigeria, municipal solid wastes are collected from pick up points and transported by vehicle directly to the dump sites. The collection, transfer, transport and disposal activities are largely achieved through the participation of private companies and an informal sector known as Scavenger (see figure 2.1). Usually, waste collection and disposal are restricted to accessible areas.

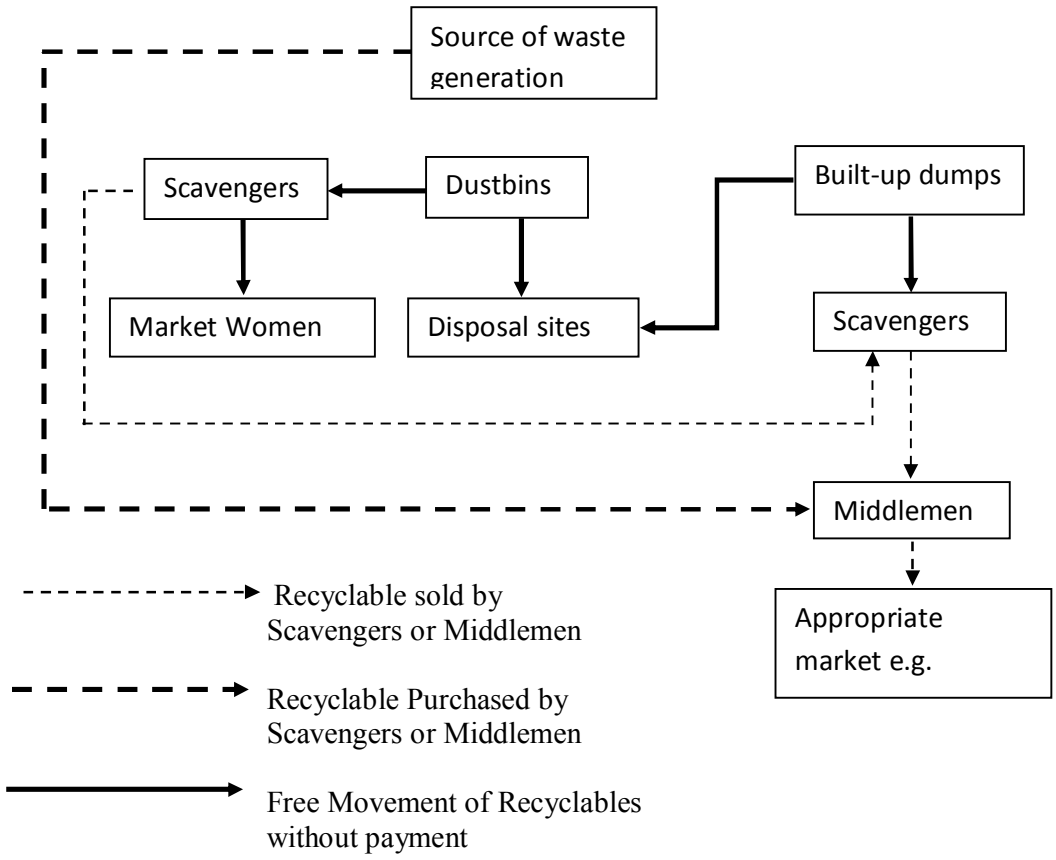


Figure 2.1 Illustrations of Informal Sector Activities in MSW Management in Nigeria (Agunwamba, 2003).

Until 1990 heaps of solid waste that deface cities and landscape as a result of indiscriminate disposal was a common scene in many municipalities. This motivated the federal government of Nigeria to promulgate Decree number 58 for the establishment of a Federal Environmental Protection Agency (FEPA) on 30 December 1988.

Following the federal government initiative and action, each state government in the country established State Environmental Protection Agency (SEPA) for the sole purpose of waste management. In essence, the national waste management structure is in three tiers i.e. federal, state and local environmental authorities.

In spite of the formulation of FEPA and state environmental policy, much but not enough has been achieved in the overall management process. Waste collection is still irregular and poorly transported, uncontrolled recycling, use of open dumps and inadequate and improper siting of landfill sites still prevails, thereby endangering public health and the environment (Emeka, 2011).

In general, the level of economic activity as reflected in the gross domestic product of any country determines the rate of solid waste generation, because the higher the rate of production and consumption, the more waste is generated (Olorunfemi, 2009)..

In developing countries, the generation of waste ranges from 0.3 to 0.5kg/person/day, while in developed countries it ranges from 1.6 to 2.0 kg/person/day (Filemon & Uriate, 2008). In Nigeria, the accelerated growth of population, increasing economic activities and change in consumption behaviour has resulted in a quantum jump in solid waste generation, ranged from 0.44 to 0.66 kg/capita/day; with 25 million tonnes of municipal solid waste generated annually (Ogwueleka, 2009). Table 2.2 shows the waste generation rates in some states in Nigeria and the various agencies that are responsible for the task.

Table 2.2 Typical Waste Generation in Some Cities in Nigeria

City	Population	Agency	Tonnage per month	Density (kg/m3)	Kg/capita/day
Lagos	8,029,200	Lagos State Management Authority	255,556	294	0.63
Kano	3,348,700	Kano state environmental protection agency	156,676	290	0.56
Ibadan	307,840	Oyo state environmental protection commission	135,391	330	0.51
Kaduna	1,458,900	Kaduna state environmental protection agency	117,825	300	0.60
Port Harcourt	1,053,900	Rivers state environmental protection agency	114,433	320	0.58
Makurdi	249,000	Urban development Board	24,242	340	0.48
Onitsha	509,500	Anambra state environmental protection agency	84,137	310	0.53
Nsukka	100,700	Enugu state environmental protection agency	12,000	370	0.44
Abuja	159,900	Abuja Environmental protection Agency	14,785	280	0.66

Source: (All Sites Engineering Ltd, in Ogwueleka, 2009)

2.2.9 Geographic Information System (GIS)

GIS is a computer system that integrates hardware and software, and links non spatial attributes with geographically-referenced data which allows the user to layer different types of information together to allow manipulation and analysis of databases to produce new maps and tabular data.

GIS is characterized by a diversity of application and has a widespread use by a heterogeneous group of users. It is an integrating system which links together a diversity of fields, like computing, surveying, geography, economics and etc. Due to this, it is almost certain to be difficult to define GIS (Longley, 2005).

Geographical information systems evolved from the collection and compilation of spatial data, and through its functionalities it can consistently and intelligently coalesce into a final geo-product. This final information product is interactive and offers organizations, institutions and individual users a host of capabilities for analysis.

Traditionally GIS use was associated static data, longer time and involved only a few specialized users. Today that is all changing. GIS can now associate and utilize relatively dynamic data, short time, and involve many users. Geographic information can facilitate decision support system and can even solve a variety of complex problems. The spatial output obtained from a GIS is virtually boundless, limited only by the adeptness of the user and data availability (Mokhtar *et al.*, 2008).

2.2.10 Application of GIS in waste management

GIS can function as a decision support tool for municipal solid waste management. In general, the use of GIS in waste management can be cumbersome and large, considering that its application with regard to operations and planning is largely dependent on spatial data. There is a lot of planning and management aspects in waste management which GIS can be used to store data concerning waste producers, amounts and types of waste produced, planning waste collection points, optimal transporting route, optimal locations for transfer stations, and for selection of areas suitable for waste disposal and locating new landfills. In addition, GIS can be used to monitor existing status of waste implication on the environment since it can combine different datasets ranging from

land use, topography, hydrographic network, environmental protection zones, soil types, population, etc (Emeka, 2011). GIS can add value to waste management applications by providing outputs for decision support and analysis of waste management databases (Singh, 2009).

2.2.11 Landfill Site Selection

The major goal of the landfill site selection process is to ensure that the disposal facility is located at the best location possible with little negative impact to the environment or to the population. For a sanitary landfill siting, a substantial evaluation process is needed to identify the best available disposal location which meets the requirements of government regulations and best minimizes economic, environmental, health, and social costs. Evaluation processes or methodologies are structured to make the best use of available information and to ensure that the results obtained are reproducible so that outcomes can be verified and defended (Siddiqui *et al.,* 1996).

An effective technique should have the following characteristics (Lane *&* McDonald, 1983):

1. The technique should evaluate all land in a systematic and impartial way that can be reasonably considered available for landfill.

2. The technique should clearly establish the relative suitability of land for absolute suitability or minimum acceptable standards. These criteria or standards can vary from area to area depending on different constraints on available land or different public concerns. The technique should illustrate which lands are better or worse for sanitary landfills, rather than which lands are suitable or unsuitable.

3. The technique should be practical and be based on commonly available information.

4. The technique should be adaptable to computerized analysis.

5. The technique should be designed to explain clearly and directly the analysis and results in a format easily understandable by the officials and the general public.

The use of maps containing various landfill selection criteria is a simple and common method to determine landfill suitability. Maps containing data such as geology, soils, water quality, and floodplains are superimposed on one another to determine a final map of landfill suitability. Low technology techniques consist of the use of manual overlays and hand drawn maps in order to determine landfill suitability. Simple overlays can be produced with tracing paper or acetate. However, low technology cartographic procedures are time consuming and the accuracy of the final products depends on the cartographer (Schwartz, 2001).

Geographic Information Systems (GIS) are ideal for preliminary site selection studies because it can manage large volumes of spatially distributed data from a variety of sources and efficiently store, retrieve, analyze and display information (Siddiqui *et al.,* 1996). Using GIS for site selection not only increases the objectivity and flexibility but also ensures that a large amount of spatial data can be processed in a short time. Relatively easy presentations of GIS siting results are also one of the advantages (Kao & Lin, 1996).

2.2.12. Criteria for Landfill Siting

There are a number of criteria for landfill site selection. These are environmental criteria, political criteria, financial and economical criteria, hydrologic and hydrogeologic criteria, topographical criteria, geological criteria, availability of

construction material and other criteria. Each criterion will be discussed briefly as follows:

2.2.12.1. Environmental Criteria

a) Ecological value of the flora and fauna

The direct and indirect spatial use of a landfill will destroy the actual vegetation and fauna. When making a decision, the ecological value of the actual vegetation and fauna should be evaluated carefully for the candidate area. Ecological value is based on diversity, naturalness and characteristic feature. An example of indirect use is the disturbance of the quietness in the surroundings caused by the activities on the landfill.

b) Odour and dust nuisance

A new landfill should not be located within a distance of a housing area because of the dust and odour emissions. Dependent of the local wind direction and speed, the safe distance necessary to locate a landfill site should be determined to prevent sensing dust and odour. The problems of odour and dust can also be minimized by proper soil cover.

c) Nuisance by traffic generation

A new landfill will generate more traffic. How much more traffic depends of the distance to the collection area, the kind of transport and the use of transfer stations. Access roads passing through housing areas will cause more nuisance than access roads through the open country side. So, routing vehicle traffic through industrial, commercial or low density population areas decreases the noise impacts of landfill related vehicles.

d) Risks for explosion or fire

Because of the presence of landfill gas, there is a chance for explosion and/or fire. Soil cover also functions to smother fires and to form a barrier preventing the spreading of

fires. Proper policing of incoming trucks can further reduce fire risk by minimizing the dumping of flammable loads (Wilson, 1977).

e) Other nuisance for neighbouring area

Other nuisance includes vermin that is attracted by the organic parts of the waste on the landfill (rats, mice, birds, insects), windblown litter, noise caused by construction, compaction or trucks on the landfill. The daily cover is a solution for nuisance developed by the presence of vermin. Continuous grading of soil cover to fill in low spots is essential to prevent the development of stagnant pools of water in which mosquitoes can breed.

f) Ecological, scientific or historical areas

Especially national parks and natural conservation areas and also historical areas are not suitable for the location of a landfill.

g) Tourist/recreation areas

A new landfill should not be planned within an existing recreational area or adjacent to it. However, a landfill is possible in some kinds of recreation areas like car/motor racing. Also the final use of a landfill can be planned as a recreational area.

2.2.12.2 Political Criteria

a) Acceptance by the local municipalities

The political acceptance of a new landfill location can differ in each region and sometimes the potential sites are located in different regions. The level of political acceptance has influence on the willingness of the local municipalities to make their regional physical plans and to give permission for the construction of a landfill. The unwillingness will cause to a delay of the decision on the landfill location.

b) Acceptance by the pressure groups involved

The acceptance by the public of a landfill in their own region or municipality is an important factor in the decision making process. The so-called NIMBY (not in my backyard) syndrome is becoming a common attitude. The influence of the public is significant if there are local groups which are well organized and having good relations with the local authorities and the media (papers, radio and television). The level of the public acceptance can be measured how far the local pressure groups are succeeding to delay the decision making process.

c) Property of the landfill area

The ownership of the needed land for the landfill is very important. Public ownership is easier than private ownership because the private ownership will give problems with the cost of the land. Sometimes, expropriation is needed and this procedure will cause delays.

2.2.12.3 Financial and Economical Criteria

a) Costs of land

Costs of the land depend on the land prices which can differ for each location. The actual use of the land is important for the price which influences the level of compensation for the owner or actual users. The potential landfill with the lowest costs is more preferable.

b) Costs for the access of the landfill

Costs for the access of the landfill depend on the condition and the presence of roads close to the landfill. If reconstruction of actual roads is needed, the costs will increase. Because of that road network is an important factor to locate a landfill site.

c) Transport costs

Transport costs are determined by the transport distances from the source of waste generation, the way of transport and the way of collection. The other factors affecting transport costs are the need for waste transfer stations and the possibility to use railways.

d) Costs for personnel, maintenance and environmental protection

The costs for personnel will not differ so much between the different potential landfill sites. Maintenance depends on the availability of soil needed for the daily or regular covering and for the stability of the landfill. If the soil is not available in the area, it should be imported which increases the maintenance costs. Extra technical provisions should be placed to prevent the pollution of the soil, groundwater and surface water at the landfill. Monitoring the drainage system and the quality of the leachate and surface water are also important factors in the maintenance costs. The potential landfill with the lowest maintenance costs is more suitable for a landfill.

e) Costs for the after-care

The costs for after-care is not only dependent on the kind of final use but also on provisions to monitor the groundwater quality, existence of gas, the winning of gas, the stability of the completed landfill. Needed provisions are depending on the characteristics of the filled waste, the kind of subsoil, the hydrogeological situation, and the kind of final use.

2.2.12.4 Hydrologic/Hydrogeologic Criteria

a) Surface water

The landfill site should not be placed within surface water or water resources protection areas to protect surface water from contamination by leachate. Safe distances from

meandering and non-meandering rivers should be achieved to prevent waste from eroding into rivers and major streams. In case of a high velocity of the surface flow there will be more dilution of an eventually contamination. The potential landfill location with the highest velocity of the overland flow will get the highest ranking score.

The major concern of siting landfills within floodplains is the downstream effect from waste carried away during episodes of higher water levels. Since major rivers have a higher discharge and greater downstream influence, no landfill should be sited within the floodplains of major rivers (Bagchi, 1994). The construction of a landfill within the 100-year flood stage of a minor river or stream is not safe.

b) Groundwater

To protect subsurface drinking water, landfills should not be situated over high quality groundwater resources. Fresh groundwater (total dissolved solids>1000 mg/l) should be avoided or protected with a compound liner system and monitoring wells (Bagchi, 1994). Since potential lechate leaks will travel downgradient, landfills should be placed greater than 304.8 m (1000 feet) upgradient from water wells. Aquifer depths less than 15.24 m (50 feet) should be considered less suitable than sites with a depth-to-groundwater of 60.96 m (50 to 200 feet) (Bolton, 1995). Table 2.3 show landfill suitability based on depth to groundwater.

Table 2.3: Groundwater depth and landfill suitability (Bolton, 1995)

Depth of Groundwater	Suitability
Over 60 meters	High
15-60 meters	Moderate
Under 60 meters	Low

A high velocity of the groundwater flow is increasing the spreading of eventually leachate beneath the landfill. The velocity of the groundwater flow is dependent of porosity of the soil and the filtering speed. The potential landfill location with the lowest velocity of the groundwater flow is more suitable for a landfill.

A high groundwater level or a nearby high river level will cause more risk to pollute the groundwater or river water. The potential landfill location with the lowest groundwater or river level is more suitable for a landfill.

Impermeable layers in the subsoil are minimizing the risk of polluting the groundwater. Especially, clay layers have a low permeability. The location with subsoil layers which have a high impermeability is more preferable to locate a landfill.

2.2.12.5 Topographical Criteria

The topography of an area is an important factor on site selection, structural integrity, and the flow of fluids surrounding a landfill site because it has important implications for landfill capacity, drainage, ultimate land use, surface and groundwater pollution control, site access and related operations (Wilson, 1977). Deciding the type of landfill design (area-, trench-, and depression-type landfills) is directly related to topography of a site.

Flat and gently rolling hills that are not subjected to flooding are the best sites for area- and trench-type landfills. However, this kind of topography is also suitable for other land uses like agriculture, residential or commercial development that lead to higher land prices.

Depressions such as sinkholes commonly associated with unstable caverns should be avoided because they may cause to contamination of groundwater sources of drinking

water. Other topographical depressions resulting from human activities, such as stone quarries, clay pits, and strip mines can be reclaimed by using landfills. The floor of these depressions typically consists of low permeable formations such as clay, siltstone, or shale. Clay pits are more suitable for depression-type landfills whereas sand gravel pits should be avoided according to permeability, except when the bottom formations are impermeable (Schwartz, 1997).

The potential for slope failure is related to the degree or grade of the topography. Slope failure underneath or adjacent to landfills, will result in waste containment failure and release of debris into the surrounding area. Land with slopes greater than 15% should be considered unsuitable for waste disposal sites (Bagchi, 1994).

The regional topography also has a direct impact on the flow of surface run-off, run-on and drainage from a waste disposal site. Run-off refers to rainwater or leachate that drains overland away from the facility and run-on refers to drainage overland on to any part of the facility. Sites with little need for control of run-on from upland and slow run-off are preferable. Run-on is controlled by berms and stream diversion. Run-off control is affected by the velocity of water traversing the site (Oweis & Khera, 1990). To limit the potential spread of contaminated runoff, a landfill should not be located on the divides of major drainage basins (watersheds).

2.2.12.6 Geological Criteria

The geology of an area will directly control the soil types created from the parent material, loading bearing capacity of the landfill's foundation soil, and the migration of leachate. Rock and its structure type will determine the nature of soils and the permeability of the bedrock. Geologic structure will influence the movement of leachate and potential rock-slope failure along joints and tilted bedding planes.

Comparing extreme permeability rates, unfractured crystalline rocks will transmit little (if any) fluids whereas poorly cemented sandstones will allow rapid transport of fluids. Due to higher permeability rates, sandstone is less suitable as a landfill bedrock than other sedimentary rocks such as limestone and shale. Limestones are more suitable than shales due to susceptibility of the carbonate rocks to dissolution from low pH leachate, and are commonly associated with discontinuities and karst features such as collapses, sinkholes, and caverns. Shale formations are well suited for landfill sites since shales commonly act as a retarding bed slowing or confining the transmission of fluids.

Table 2.4 various rock types and their suitability for landfill siting (Bolton, 1995).

Rock Type	Suitability
Unfractured crystalline	Very High
Shale and clay	High
Limestone	Fair to Poor
Sandstone	Poor to Very Poor
Unconsolidated sand/gravel	Unsuitable

The structure and orientation of discontinuity planes will have a direct impact on the movement of leachate and on the structural integrity of the bedrock material. Sites composed of tilted rocks greater than 45 degree dip have the potential for rock-slope failure along discontinuities and should be considered an unstable area. Leachate flow will follow down-dip directions. To limit the spread of leachate, landfills should not be situated on the axis of anticlines and structural domes. In addition to the spreading of landfill leachate, anticlines and domes are often associated with oil and natural gas fields and should be avoided. In contrast, synclines and structural basins are the best sites for leachate to pool into.

Regions that are faulted are not suitable for landfill because a fault can act as a conduit of leachate transport and can reduce the structural integrity of bedrock supporting the landfill and its equipment.

2.2.12.7 Availability of Construction Material

Sanitary landfill design usually involves an adequate source of soil with textures appropriate for daily and final covering (Brady & Weil, 1996). Soil is important in landfill development for three basic reasons:

- Cover: Material used to cover the solid waste daily and when an area of the landfill is completed. The permeability of the final cover will greatly influence the quantity of leachate generated.
- Migration control: The material that controls leachate and methane movement away from the landfill. An impermeable formation will retard movement; a permeable soil will provide less protection and may require installing additional controls within the landfill.
- Support: The soil below and adjacent to the landfill must be suitable for construction. It must provide a firm foundation for liners, roads and other construction.

An optimal landfill soil will have moderately low permeability, sufficient bearing capacity to support equipment, a pH of at least 5, a low erodibility potential, and a high cation exchange capacity. However, a site's soil characteristics may change laterally, at depth, or the soil may not be present in sufficient volume. As shown in the Table 2.5. , fine grained soils are more suitable for landfills than coarse grained soils (Oweis and Khera, 1998). However, properties of clays including low drainage rates, shrink/swell

potential, and low workability usually reduces a clay soils suitability against soils with a silty clay texture.

Table 2.5: Soil textures and landfill suitability

Soil Type	Suitability
Silt to very fine silty clay	Very High
Clay	High
Mixed	Moderate
Sandy	Low
Clean sand/gravel	Unsuitable

Source: Oweis and Khera, 1998; Brady and Weil, 1996

A high susceptibility to soil consolidation (peat and clay soils) is causing an unstable foundation of the landfill. An unstable foundation can lead to damages of the bottom liners and/or the drainage system. The location with the lowest susceptibility to soil consolidation is more suitable for a landfill.

2.2.12.8 Climate

The site selection process must consider climate characteristics such as prevailing winds, precipitation; evapotranspiration and temperature variations because they are related to odours, dust, leachate generation, blowing litter, cover soil and erosion (Wilson, 1977).

2.2.12.9 Other Criteria

a) Residential and urban areas

Landfills may not be constructed on sites within a distance of less than 1000 m to settlements according to regulation on solid waste control in Turkey (Waste Disposal Directive of Turkey, 1991). Only if there are natural barriers like hills, trees or forests between the landfill site and the settlements, the construction of landfills in a distance

less than 1000m to settlements may be allowed after approval of the Ministry of Environment and upon order of the highest local authority and the concerned municipality.

b) Military areas

Areas used for the testing of military equipment or training of military personnel are not open for public usage.

c) Airports

The presence of birds is a real danger for airplanes. Because birds are attracted especially by organic waste, landfills should be located at a certain distance from airports.

d) Industrial areas

Industrial areas are not principally excluded as location of a landfill. Dependent of the kind of industry such as not sensible for dust or food factories, an industrial area or close to it is suitable for a landfill. An advantage of an industrial area is the presence of infrastructural provisions.

e) Difficult infrastructural provisions

If the location of the new landfill come across with existing infrastructural provisions such as cables, roads or existing plans for drainage, it is very difficult to make the location suitable for the use as a landfill.

2.2.13 Spatial Multicriteria Decision Analysis (MCDA)

Decision Analysis is a set of systematic procedures for analyzing complex decision problems. These procedures include dividing the decision problems into smaller more understandable parts; analyzing each part; and integrating the parts in a logical manner

to produce a meaningful solution (Malczewski, 1997). MCDA techniques can be used to identify a single most preferred option, to rank options, to list a limited number of options for subsequent detailed evaluation, or to distinguish acceptable from unacceptable possibilities (Dodgson, 2000).

2.2.13.1 Steps of Spatial Multicriteria Decision Analysis (MCDA)

Any spatial decision problem can be structured into three major phases: intelligence which examines the existence of a problem or the opportunity for change, design which determines the alternatives and choice which decides the best alternative (Simon, 1960). The major elements involved in spatial decision making process are discussed below.

A) Problem Definition

A decision problem is the difference between the desired and existing state of the real world. It is a gap which is recognized by a decision maker. Any decision making process begins with the recognition and the definition of the problem. This stage is in the intelligence phase of decision making and it involves searching the decision environment for conditions, obtaining, processing and examining the raw data to identify the problems. The GIS capabilities for storage, management, manipulation and analysis are used in this stage which provides major support (Malczewski, 1999).

B) Evaluation Criteria

After the determination of the problem, the set of evaluation criteria which includes attributes and objectives should be designated (Keeney & Raiffa, 1976). This stage involves specifying a comprehensive set of objectives that reflects all concerns relevant to the decision problem and measures for achieving those objectives which are defined as attributes. Because the evaluation criteria are related to geographical entities and the relationships between them, they can be represented in the form of maps which are

referred as attribute maps. GIS data handling and analyzing capabilities are used to generate inputs to spatial decision making analysis (Malczewski, 1999).

C) Criterion Weights

A weight can be defined as a value assigned to an evaluation criterion which indicates its importance relative to other criteria under consideration. Assigning weights of importance to evaluation criteria accounts for (i) the changes in the range of variation for each evaluation criterion, and (ii) the different degrees of importance being attached to these ranges of variation (Kirkwood, 1997); there are four different techniques when assigning the weights: Ranking, Rating, Pairwise Comparison and Trade of Analysis Methods.

1. Ranking Methods

This is the simplest method for evaluating the importance of weights which includes that every criterion under consideration is ranked in the order of decision maker's preferences. Due to its simplicity, the method is very attractive. However, the larger the number of criteria used, the less appropriate is the method. Another disadvantage is lack of theoretical foundation.

2. Rating methods

The method requires the decision maker to estimate weights on the basis of a predetermined scale. One of the simplest rating methods is the point allocation approach. It is based on allocating points ranging from 0 to 100, where 0 indicates that the criterion can be ignored, and 100 represents the situation where only one criterion need to be considered. Another method is ratio estimation procedure which is a modification of the point allocation method. A score of 100 is assigned to the most important criterion and proportionally smaller weights are given to criteria lower in the

order. The score assigned for the least important attribute is used to calculate the ratios. Again the disadvantage of this method like ranking method is the lack of theoretical foundation. And also the assigned weights might be difficult to justify.

3. Pairwise Comparison Method

The method involves pairwise comparisons to create a ratio matrix. It takes pairwise comparisons as input and produce relative weights as output. The pairwise comparison method involves three steps:

i. Development of a pairwise comparison matrix: The method uses a scale with values range from 1 to 9. The possible values are presented in Table

ii. Computation of the weights: The computation of weights involves three steps. First step is the summation of the values in each column of the matrix. Then, each element in the matrix should be divided by its column total (the resulting matrix is referred to as the normalized pairwise comparison matrix). Then, computation of the average of the elements in each row of the normalized matrix should be made which includes dividing the sum of normalized scores for each row by the number of criteria. These averages provide an estimate of the relative weights of the criteria being compared.

iii. Estimation of the consistency ratio: The aim of this is to determine if the comparisons are consistent or not. It involves the following operations:

- Determine the weighted sum vector by multiplying the weight for the first criterion times the first column of the original pairwise comparison matrix, then multiply the second weight times the second column, the third criterion times the third column of the original matrix, finally sum these values over the rows,

- Determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously,
- Compute lambda(λ) which is the average value of the consistency vector and Consistency Index (CI) which provides a measure of departure from consistency and has the formula below:

  $$CI= (\lambda - n)/(n-1)$$

- d) Calculation of the consistency ratio (CR) which is defined as follows:

  $$CR = CI / RI$$

Where RI is the random index and depends on the number of elements being compared and CI is the converting index.

If CR is < 0.10, the ratio indicates a reasonable level of consistency in the pairwise comparison, and if CR ≥ 0.10, the values of the ratio indicates inconsistent judgments.

The advantages of this method can be summarized that only two criteria have to be considered at a time, it can be implemented in a spreadsheet environment (Kirkwood, 1997) and it is incorporated into GIS based decision making procedures (Eastman, Kyem &Toledano, 1993; Janskowski, 1995). On the other hand, the relative importance of evaluation criteria is determined without considering the scales on which the criteria are measured. Another disadvantage is that if you have many criteria, the amount of pairwise comparisons that should be made will be very large.

4. Trade-off Analysis Method

In this method, decision maker is required to compare two alternatives with respect to two criteria at a time and assess which alternative is preferred. Trade-offs define unique set of weights that will allow all of the equally preferred alternatives in the trade-offs to

get the same overall value/utility. There is an assumption in this method that the trade-offs the decision maker is willing to make between any two criteria do not depend on the levels of other criteria (Malczewski, 1999).

The weakness of this method is the decision maker is presumed to obey the axioms and can make fine grained in difference judgements. On the other hand, the method can be implemented within the spreadsheet environment (Kirkwood, 1997).

D) Decision Rules

The criterion map layers and weightings must be integrated to provide an overall assessment. This is accomplished by an appropriate decision rule or aggregation function (Chankong & Haimes, 1983). Since a decision rule provides an ordering of all alternatives according to their performance with respect to the set of evaluation criteria, the decision problem depends on the selection of best outcome. The most often used decision rules are discussed below:

1. Simple Additive Weighting (SAW)

Simple additive weighting which is also known as weighted linear combination or scoring methods is a simple and most often used mulltiattribute decision technique (Malczewski, 1997; Janssen, 1992; Eastman *et al.*, 1993). The method is based on the weighted average. An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by decision maker followed by summing of the products for all criteria. The simple additive weighting method evaluates each alternative, Ai, by the following formula:

$$\sum * = ij\ j\ i\ x\ w\ A$$

Where xij is the score of the ith alternative with respect to the jth attribute, wj is the normalized weight.

If the scores for the criteria are measured on different measurement scales, they must be standardized to a common dimensionless unit before the SAW method. The simplest procedure for standardizing the raw data is to divide each raw score by the maximum value for a given criterion.

The advantage of this method is that it is a proportional linear transformation of the raw data which means that the relative order of magnitude of the standardized scores remains equal. One disadvantage is that the lowest standardized value does not necessarily equal to zero which makes the interpretation of the least attractive criterion score difficult.

The SAW methods can be implemented using any GIS having overlay capabilities. The GIS based Simple Additive Weighting method involves the following steps:

a. Definition of the set of evaluation criteria (map layers) and the set of feasible alternatives,
b. Standardization of each criterion map layer,
c. Definition of the criterion weights,
d. Construction of the weighted standardized map layers,
e. Generation of the overall score for each alternative using the overlay operation,
f. Ranking of the alternatives according to the overall performance score (Malczewski, 1999).

There are two assumptions in the SAW method; the linearity and additivity of attributes which are very difficult to meet in many spatial decision situations (Hwang & Yoon,

1981; Bodily, 1985; Lai & Hopkins, 1989). Linearity means that the desirability of an additional unit of an attribute is constant for any level of that attribute. For example, this assumption implies that an additional 10 ha in a parcel of land is valued the same regardless of whether it is added to a land of 100 or 1000 ha. Whereas additivity means that there is no interaction (complementary) effect between attributes (Malczewski, 1997).

The SAW method is quite widely used in real world due to its easiness. It can be implemented both in raster and vector GIS environment and operationalized using any GIS system having overlay capabilities or implemented in a spreadsheet environment (Kirkwood, 1997) However, the ignorance of the definition of the units of measurement and little theoretical foundation are the disadvantages of this method.

2. Analytical Hierarchy Process (AHP)

The AHP developed by Saaty (1980) is a technique for analyzing and supporting decisions in which multiple and competing objectives are involved and multiple alternatives are available. The method is based on three principles: decomposition, comparative judgment and synthesis of priorities.

In the AHP, the first step is that a complex decision problem is decomposed into simpler decision problems to form a decision hierarchy (Erkut & Moran, 1991). When developing a hierarchy, the top level is the ultimate goal of the decision. The hierarchy decreases from the general to more specific until a level of attributes are reached. Each level must be linked to the next higher level. Typically a hierarchical structure includes four levels: goal, objectives, attributes and alternatives. The alternatives are represented in GIS database. Each layer consists of the attribute values assigned to the alternatives (cell or polygon) which are related to the higher level elements (attributes).

Once decomposition is completed, cardinal rankings for objectives and alternatives are required. This is done by using pairwise comparisons which reduces the complexity of decision making since two components are considered at a time. It involves 3 steps: (1) development of a comparison matrix at each level of hierarchy (2) computation of weights for each element of the hierarchy and (3) estimation of consistency ratio which is mentioned in Pairwise comparison section. The final step is to combine the relative weights of the levels obtained in the above step to produce composite weights. This is done by means of a sequence of multiplications of the matrices of relative weights at each level of the hierarchy. First, the comparison matrix is squared and the row sums are calculated and normalized for each row in the comparison matrix. This process is continued when the difference between the normalized weights of the iterations become smaller than a prescribed value (Saaty, 1990).

The AHP has widespread use due to its flexibility, easy to use. It is also incorporated into GIS environment (Banai-Kashani, 1989; Eastman *et al.*, 1993; Jankowski, 1995; Siddiqui *et al.*, 1996) and can be used in two distinctive ways within GIS to derive weights and combine them with attribute map layers and to aggregate the priority for all levels of the hierarchy structures. In addition, the AHP can even be implemented in spreadsheet environment (Kirkwood, 1997). However, ambiguity in relative importance, inconsistent judgments by decision maker and the use of 1 to 9 scale can be thought as the disadvantages of this method. The ratio scale makes sense when dealing with something like distance, or area which has natural ratio scales, but not when dealing with phenomena like comfort, image, or quality of life, for which no clear reference levels exists. Furthermore, for large problems too many pairwise comparisons must be performed (Malczewski, 1999).

3. The value/utility function methods

The method is based on multiattribute utility theory (Keeney & Raiffa, 1976). The value function approach is applicable in the decision situation under certainity (deterministic approach) which assumes that the attributes are known with certainity whereas the utility function approach is convenient for the uncertainity conditions (probabilistic in nature).

The GIS based value/utility function involves the following steps:

i. Determination of the set of attributes (attribute map layers) and the set of feasible alternatives.

ii. Estimation of the value (utility) function for each attribute and use the function to convert the row data to the value (utility) score map layer

iii. Derivation of the scaling constants or weights for the attributes

iv. Construction of the weighted value (utility) map layers; that is, multiply the weights of importance by the value (utility) map layers

v. Combination of the weighted value (utility) maps by summing the weighted value (utility) map layers

vi. Ranking of the alternatives according to the aggregate value (utility); the alternative with the highest value (utility) is the best alternative.

The value/utility function involves two elements: (1) the single attribute utility/value function to transform attribute levels into an interval utility/value scale, (2) the trade off analysis for defining the weights (Keeney, 1980). By multiplying the utilities by the weights, the trade-offs among the attribute utilities are taken into account in the multiattribute utility function. The overall utility or value for any alternative is a weighted average of the single attribute utilities. This method is similar to SAW

method except the score xij is replaced by a value or utility derived from the value/utility function.

There are two assumptions of preferential independence which refers that the relative preferences of attributes are not altered by changes in other attributes and utility independence which means that the utility function over single attribute does not depend on the other attribute (Malczewski, 1999).

One of the most important advantages of this method is the above assumptions which enables decision maker to focus initially on deriving utility function for one attribute at a time. The method provides a better theoretical foundation for describing the utilities. However, the method is impractical and it is difficult to obtain a mathematical representation of decision maker's preferences, because assessing utility functions with even a moderate number of criteria is very time consuming and tedious. In addition, the method neglects the existence of spatial relationships among spatial alternatives (Malczewski, 1997).

4. The Ideal Point Methods

In the ideal point method the alternatives are ranked according to their separation from an ideal point. The ideal point is defined as the most desirable, weighted, hypothetical alternative (decision outcome). The alternative, closest to the ideal point is the best alternative. The separation is measured in terms of metric distance (Janssen, 1992; Malczewski, 1997).

One of the most popular ideal point methods is the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) developed by Hwang & Yoon (1981).

The GIS based ideal point method involves the following steps:

i. Determine the set of feasible alternatives,

ii. Standardize each attribute map layer,

iii. Define the weights assigned to each attribute ($0 \leq w \leq 1$, $\Sigma w = 1$),

iv. Construct the weighted standardized map layer by multiplying each value of the standardized layer by the corresponding weight,

v. Determine the max value for each of the weighted standardized map layers (the values determine the ideal point),

vi. Determine the mean value for each weighted standardized map layer (the values determine negative ideal point),

vii. Using a separation measure, calculate the distance between the ideal point and each alternative,

viii. Using the same separation measure, determine the distance between the negative ideal point and each alternative,

ix. Calculate the relative closeness to the ideal point,

x. Rank the alternatives according to the descending order of ideal point.

Although the ideal point methods can be implemented both in raster and vector GIS, the technique is especially suitable for the raster GIS (Carver, 1991; Janskowski & Ewart, 1996; Malczewski, 1996). The method provides complete ranking and information on the relative distance of each alternative to the ideal point. In this method, an alternative is treated as an inseparable bundle of attributes which makes the method an attractive approach when the dependency among attributes is difficult to test or verify (Malczewski, 1997).

5. Outranking Methods

These methods which are also known as concordance methods are based on a pairwise comparison of alternatives. They provide an ordinal ranking and sometimes only a partial ordering of the alternatives which means that it can only express which alternative is preferred but cannot indicate how much. The best known outranking method is the Elimination and Choice Translating Reality (ELECTRE I) and several modifications of this method have been suggested (ELECTRE II, III, IV, PROMETHEE I and II) (Vincke, 1989).

The basic elements of this method is concordance measures which are the set of all criteria for which alternative i is not worse than the competing alternative i' and disconcordance measures which are the set of all criteria for which alternative i is worse than the competing alternative i' (Nijkamp & van Delft, 1977). These indicators are calculated for all pairs of alternatives and then the alternatives with the highest concordance value and with the lowe disconcordance value are found. There are formulas suggesting to determine overall score for each alternative based on these indicators (Massam, 1988).

The GIS based outranking method involves several steps:

i. Determination of the set of feasible alternatives
ii. Standardization of each attribute
iii. Definition of the weights assigned to each attribute ($0 \leq w \leq 1$, $\Sigma w = 1$)
iv. Generation of the concordance matrix by calculating the concordance indices for each pair of alternatives
v. Summation of the rows of the concordance matrix to obtain the overall score for each alternative

vi. Ranking the alternatives according to the descending order of the sum of the concordance indices (Ci), the alternative with the highest value of Ci is the best alternative (Malczewski, 1999).

The advantages of this method include that least amount of information from decision maker is required and it can consider both objective and subjective criteria. However, complete ranking of the alternatives may not be achieved and since the method requires comparison across alternatives, it cannot be implemented directly by using cartographic modeling techniques in a GIS (especially for raster GIS). The method provides an ordinal ranking (Malczewski, 1999).

6. Ordered Weighted Average (OWA)

The OWA method has been developed in the context of fuzzy set theory (Yager, 1988). There are three basic types of aggregation operators on fuzzy sets (1) operators for the intersection of fuzzy sets (the MIN operations), (2) operators for the union of fuzzy sets (the MAX operations), and (3) averaging operators (Eastman et al., 1993). Yager (1988) introduced an aggregation technique based on the ordered weighted averaging (OWA) operator, which is a generalization of the three basic aggregation functions. OWA is a weighted sum with ordered evaluation criteria. Thus, in addition to the criterion weights which are assigned to evaluation criteria to indicate their relative importance, order weights are used. The order weights are associated with the criterion values on the location by location basis. They are assigned to a given location's attribute values in decreasing order without considering from which attribute map the value comes (Malczewski, 1997; Malczewski, 2002).

7. Goal Programming

The goal programming method was originally proposed by Charnes and Cooper (1961). It is a form of linear programming for multiple goals (evaluation criteria). Linear programming identifies from the set of feasible solutions the point which optimizes a single objective, whereas goal programming determines the point that best satisfies the set of goals in the decision problem which aims to minimize the deviations from the goals.

Three basic approaches to goal programming can be distinguished:

(i) Weighted goal programming: The objective is to find a solution that minimizes the weighted sum of the goal deviations. The weights represent additional information reflecting the decision maker's preferences with respect to the deviation variables (Malczewski, 2002).

(ii) Chebyshev goal programming: It can be considered as a specific form of the weighted goal programming approach which seeks the solution that minimizes the worst unwanted deviation from any single goal.

Instead of using subjective notations to set the aspiration levels for the objectives, a set of single optimization problems is solved to arrive at the best and worst possible weights of each objective. The best values are then used as aspiration levels for the objectives. Then, the deviation from those aspiration levels should be minimized so that the worst deviation from any single goal aspiration level is minimized (Malczewski, 1997).

(iii) Lexicographic goal programming: In this method, the objective functions are ordered according to their importance. The most important function is minimized first, then on the set of optimal solutions with respect to the first

function the second function is minimized, and so on, until a unique solution is obtained or all the specified functions are minimized (Carver, 1991).

The major advantage of this method is its computational efficiency. Goal programming approach provides an efficient linear programming environment and can be incorporated into GIS procedures by integrating standard mathematical programming software such as LINDO (Malczewski, 1997). However, the standard goal programming methods require the decision maker specify fairly detailed information about priorities and the importance of goals in the form of weights which is a difficult task to provide meaningful preference weights on a cardinal scale (Nijkamp, 1979). The cardinal weight and lexicografic methods have a strong tendency to generate inefficient solutions. This inefficiency problem seriously limits the utility of goal programming methods (Malczewski, 1997).

8. Compromise Programming

It is a MODM method based on the displaced ideal concept which assumes that the choice among alternatives depends on the point that is used as a reference (Zeleny, 1982). This point is the ideal point which defines the optimal value for each objective considered separately. Compromise programming attempts to minimize the distance from the ideal solution.

The advantage of this method is its simple conceptual structure. The set of preferred compromise solutions can be ordered between the extreme criterion outcomes and consequently, an implicit trade off between criteria can be performed. However, there is no clear interpretation of the various values of the parameter p which gives the importance of the maximal deviation from the ideal point. Therefore, the selection of

the best alternative within the reduced set of compromise alternatives must be made based on intuition (Malczewski, 1997).

2.2.13.2 Sensitivity Analysis

In many decision rules it is assumed that complete information is available so that the criterion outcomes of each alternative are precisely known. However, in real world situations, this is not the case and analysis should be made to investigate whether the preliminary conclusions are robust or not. Sensitivity analysis aims to identify the effects of changes in the inputs which are geographical data and the decision maker's preferences on the outputs, in other words, on the ranking of alternatives, if the changes do not significantly affect the outputs, then the ranking is assumed as robust and satisfactory. If the result is unsatisfactory, it should be return to the problem formulation step (Malczewski, 1999 & Belton *et al.*, 2002).

2.3 LITERATURE REVIEW

2.3.1 Introduction

This section provides a review of previous works which have similar objectives with this work and identify academic gap therein which this work satisfies. The review focuses on siting criteria and methodology.

2.3.2 Landfill Siting Criteria

Esmali (1972); Helms & Clark (1970) relied on conventional location models for solid waste management in the late 1960s and focused on financial optimism which includes the operation costs of the facility, the costs of the transportation of waste to the facility and the revenues generated by the facility such as energy (methane gas).

Lane & McDonald (1983) considered only environmental properties such as underground water, slope gradient and surface permeability, ignoring important social/economic factors such as landuse.

Bagchi (1994) provided the following constraint criteria to allow for maximum protection of the ecosystem. Thus: landfill should not be located within 100 feet (30.48 m) of any non-meandering stream or river, and at least 300 feet (91.44 m) from any meandering stream or river, large ponds, lakes, and reservoirs should have a buffer zone of land to prevent blown debris and runoff from harming aquatic habitats, large bodies of water (greater than 20 acres (80937.45 m^2) of surface area) should be at least 100 feet (30.48 m) from any landfill site and if the regional drinking water is supplied by surface water impoundments, it may be necessary to exclude the entire watershed that drains into the reservoir from landfill sites

Siddiqui *et al.* (1996) considered environmental characteristics of the site such as precipitation, site topography, slope gradient, depth of underground water, geology and soil permeability; and proximity to the populations. In this situation adequate consideration is given to the public health of the community. Environmental factors like underground water and fresh surface water needs to be protected from contamination to ensure safe drinking water for the human population, and for the fresh water to protect aquatic lives therein.

Dikshit, Padmavathi & Das (2000) considered biophysical elements such as water, wetlands, critical habitats, and wells to reduce the risk of contamination from landfill.

Al-jarrah & Abu-Qdais (2004) considered the following factors: land slope, soil characteristics, depth to groundwater, surface water, environmentally rare or endangered

species breeding areas, distance to residential, religious and archaeological sites, land use, major infra- structure systems (e.g. electric transmission lines, water or sewer pipelines), seismic activity, land cost, distance from high way, distance from waste generation source, site capacity, and distance from air port run way.

Word Bank (2004) provides a comprehensive list of factors together with their constraint criteria, which should be considered in siting landfills. See Appendix I

Babalola & Busu (2010) included 12 factors covering both environmental and socio-economic situations, namely: distance from road network, infiltration map, elevation, groundwater table, wind orientation, distance from residential area, distance from surface water, and distance from sensitive areas, precipitation, slope, and aspect.

Abulsalam (2010) examined the health impact of solid waste management among residents around the Mangwaneni dumpsite in Swaziland. He basically focused only on population. The study, which was conducted among 78 households, found that 82% of the respondents rejected landfills around them particularly because of odour. Also, Adamu & Adekiya (2010) focused only on the water quality of boreholes around selected landfills in Kano Metropolis. The outcome of the work revealed high concentration of lead, Nickel, Copper, and Chromium above the regulatory standard of Standard Organisation of Nigeria (SON). These could be hazardous to the ecosystem and public health, since metals are cumulative toxicants posing danger to organisms near the top of the food chain. Akinjare (2011) focused only on residential property values around landfill. His findings revealed that residential houses in close proximity to the landfills suffered value loss. It could also lead to bio accumulation and bio – concentration of the heavy metals in living organisms. A similar study that focuses on

only one major factor is Yahaya, Umoh & Ameh (2011), which determined the contamination level and the distribution of pathogenic substances in well water located near the municipal solid and liquid wastes in Zaria, Northern Nigeria. The study discovered high concentration of such pathogenic substances beyond WHO regulatory standard.

Wuyep (2011) carried out a study on landfill siting using GIS and Remote Sensing in Jos North. The study focused mainly on Socio-economic factors, such as distance from residential areas, cost of transporting waste to dump site, and estate property cost. Findings from the study reveal that approximately 55% of the study area was unsuitable for locating landfill due to proximity to residential areas; and 15% due to agricultural lands and orchards.

With the exception of Babalola & Busu (2010) all the works cited here reserved huge gaps on one point or another; especially those that focused only on one criterion. Therefore, this work is following the comprehensive pattern adopted by Babalola & Busu (2010) however with some specific modification. Precipitation of the study area covered by this work seems to be monotonous and thus insignificant. Sensitive areas as identified by Babalola & Busu (2010) to mean historic sites is also irrelevant in as much as most of the historic sites are within residential areas, and once residential areas are protected they also stand to be protected. However, in addition to factors observed by Babalola & Busu (2010) this work includes two additional factors: flood risk zone and wetlands. This work is also going to adopt the constraint criteria provided by the World Bank (2004) guidelines.

2.3.3 Multicriteria Decision methods

Different methods of site selection for waste disposal have been developed over the last decades to provide more efficient waste disposal allocation.

During the 1980s and 1990s, people became aware of the potential of pollution due to waste disposal which led to more restrictive environmental regulations and to increase the emphasis given to the recycling and waste reduction (Leao, Bishop & Evans, 2001). As the landfill site selection process depends on a variety of laws, regulations and factors, large volume of spatial data should be evaluated and processed. To overcome this difficulty, GIS is commonly used to select suitable sites for landfill (Baban & Flannagan, 1998; Allen *et al.*, 2002).

For general GIS, although it is very useful in siting experiences, lacks the ability to locate an optimal site when compactness and other factors are considered at the same time. For this purpose, a mixed integer programming model was developed to obtain a site with optimal compactness by Kao & Lin (1996) and extended to include multiple siting factors. However, because the computational time with a conventional mixed integer programming package for solving the model is time consuming and impractical, a raster based C program for landfill siting with optimal compactness was developed (Kao, 1996).

A multiobjective optimization model is developed to determine the efficient aggregation of land parcels to use as a solid or hazardous waste landfill by Minor & Jacobs (1994). A constraint which measures compactness and contiguity as a function of the outside perimeter and area of the sub-region is introduced in this model which optimally selects and sizes the landfill site and considers land purchase cost, compactness and contiguity.

A network geographic information system (GIS) was developed to improve the effectiveness of a complex municipal solid waste landfill siting procedure and make siting related information available to the general public (Kao, 1996).

Because of the complexity and dependency of different decision groups, design of solid waste management systems requires consideration of multiple alternative solutions and different criteria. Multicriteria Decision Analysis (MCDA) approach is commonly used to solve the landfill site selection problem and provide decision makers the most satisfactory and preferable alternative.

In the study done by Cheng, Chan & Huang (2003) Simple Weighted Addition method, Weighted Product method, TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution), Cooperative Game Theory and ELECTRE methods of MCDA were used and compared to get the most preferable solution of solid waste management. Results of the study revealed the robustness of MCDA, where it appeared to be more realistic than the TOPSIS method.

To overcome the weakness of different multi objective programming models which is the ignorance of qualitative and subjective considerations such as environmental and socio-economic factors an integrated multicriteria decision analysis and inexact mixed integer linear programming approach for solid waste management was developed and the five MCDA methods which were used in the previous study of authors were adopted to evaluate the landfill site alternatives (Cheng, Chan & Huang, 2003).

A decision modelling procedure is developed based on the Analytical Hierarchy Process to locate obnoxious facilities by Erkut & Moran (1991). For preliminary landfill site screening, fuzzy set theory and the Analytical Hierarchy Process (AHP) are integrated

into a raster-based geographical information system (Charnpratheep, Zhou & Garner, 1997).

Siddiqui *et al.* (1996) developed a methodology to find best locations for landfills by integrating GIS and Analytical Hierarchy Process (AHP) which is called spatial-AHP. As a corollary to Siddiqui *et al.* (1996) GIS based weighted linear combination (WLC) is created for selecting suitable sites for animal waste using a raster GIS. The selected factors affecting the suitability of the site are weighted using the Analytical Hierarchy Process (AHP) which employed an objectives oriented comparison technique to formulate the pairwise comparison matrix (Basnet, Apan & Raine, 2001).

Wuyep (2011) adopted the Ranking Method in assigning weight to the various criteria involved and it is the simplest method for evaluating the importance of weights which includes that every criterion under consideration is ranked in the order of decision maker's preferences. However, the larger the number of criteria used, the less appropriate is the method. Another disadvantage is lack of theoretical foundation in deciding the weights and has assigned the weights rather arbitrarily, without comparing the criteria and classes (Malczewski, 2000).

This work will adopts Analytical Hierarchy Process (AHP) which has the following advantages over the classical site suitability analysis techniques (regression analysis). First, it provides a structured approach to measuring suitability by "decomposing" the suitability analysis problem into hierarchical units and levels. This allows a systematic and more in-depth analysis of the factors which may be better understood when "decoupled" or "deconstructed" into their lower and more specific forms or indicators. Second, AHP relies less on the completeness of the data set, and more on "expert"

opinions or observations about the different factors and their perceived effects on land suitability. Third, the approach is more transparent and hence more likely to be accepted especially when the suitability analysis will ultimately serve as a basis for land allocation. Fourth, AHP allows for the participation of both experts and stakeholders in providing the suitability measure of a land relative to a proposed land use. Such framework allows the incorporation and accommodation of both qualitative and quantitative criteria for land suitability assessment analysis (Malczewski, 2000). AHP is well documented in published literatures (Saaty 1980, 1995; Mendoza 1989, 1997; Kangas 1992, 1993; Peterson, Silsbee & Schmoldt, 1994; Reynolds & Holsten 1994; Pukkala & Kangas 1996).

CHAPTER THREE

STUDY AREA AND METHODOLOGY

3.1 STUDY AREA

3.1.1 Location

The study area lies between Latitude 9^{o} 51' N and 10^{o} 04' N and longitude 8^{o}48' E and 8^{o} 59' E. (See Figure 3.1). Jos North shares boundary with Bassa LGA to the West, Bauchi State to the North, Jos-East LGA to the East and Jos-South LGA to the South. It occupies 291km^2 landmass.

3.1.2 Climate

Temperatures on the Jos Plateau are lower than the surrounding areas, with minima of 15.5°C to 18.5°C to maxima of 27.5°C to 30.5°C. On the Plateau, the rainfall is around 2,000 millimetres (mm) in the wetter southwest, and declines to around 1,500 mm in the northeast.The heavier rains in the south and west are due to the moisture-bearing winds meeting the escarpment at this point (White, 1983).

3.1.3 Landforms

The Jos-plateau is the largest landmass above 1,000m in Nigeria and is approximately 250 kilometers (km) by 150 km in size. It comprises high plains about 1,300m above sea level and a number of granite hill ranges that can reach heights of over 1,900m. On the west and south sides the plateau is demarcated by a scarp 500m to 700m in height, but on the plateau's northern side the transition to the lower plains is less abrupt (White, 1983). Jos North is surrounded by hills except on its northern part. To the east are Dogon Dutse and Shere Hills, which rise to over 1,300m and 1,400m respectively above sea level; whereas on the western side it is surrounded by the Jenta Hills, which also rises to over 1,300m above sea level (Ahmed, 2008).

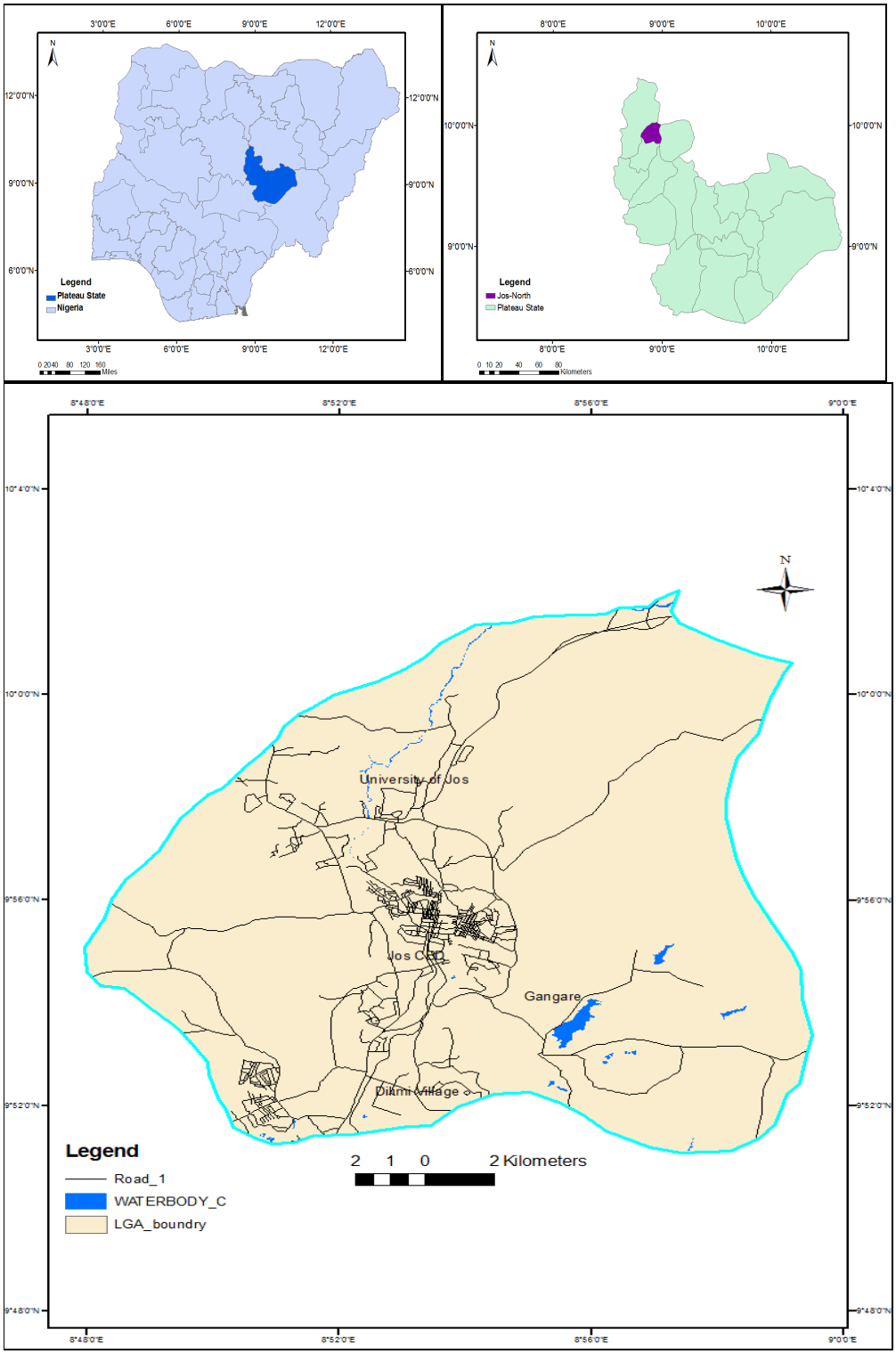


Figure 3.1: Jos North Local Government Area
Source: Department of land and Survey, Ministry for land and Survey, Plateau State

3.1.4 Soils

The granites are particularly resistant to erosion, and generally form shallow and sandy soils. In some areas there are also basaltic rocks, which weather to form relatively deep clay loams. The latter of these have reasonable agricultural potential and are farmed for crops including potatoes (White, 1983).

3.1.5 Vegetation

White (1983) identifies this ecoregion as an isolated vegetation unit within the Guineo-Congolian/Sudanian Regional Transition Zone. Savanna woodland is likely to have been the climax ecotone of this ecoregion, but human activities have resulted in extensive and severe degradation. The vegetation is dominated by savannah species, but also includes a number of species with South or East African affinities. The most numerous tree species in the remaining woodland are *Isoberlinea doka*, with *Vitex doniana*, *Lannea schimperi*, and *Uapaca somon* also being common on the fringes of the Naraguta Hills. Along streams *Syzygium guineense* and a *Berlinea* sp. are common. White (1983) lists the following rupicolous species found in bushland and scrub forest in Jos-North: *Carissa edulis, Dalbergia hostilis, Diospyros abyssinica, D. ferrea, Dodonaea viscosa, Euphorbia desmondii, E. kamerunica, E. poissonii, Ficus glumosa, Kleinia cliffordiana, Rhus longipes, R. natalensis, Ochna schweinfurthiana, Olea capensis, Opilia celtidifolia,* and *Pachystela brevipes.*

3.1.6 Population

Jos North has a population of 429, 300 people and a population density of 1475 person per square Km, (National Census 2006). Major indigenous groups are the Berom, the Angas, the Afizare, and other tribes include Hausa, Yoruba, and Igbo. The town was established in the 1915, it grew rapidly after the British discovered vast Tin deposits in

the vicinity. The tin mining led to the influx of migrants, mostly Hausas, Igbos, Yorubas and Europeans who constitute more than half of the population of Jos. Local enterprises include Food processing, beer brewing, and the manufacture of cosmetics, soap, rope, jute bags, and furniture. Jos is a centre for automobile repairs and construction industry. It is major source of tourist attraction in the country. All these livelihood opportunities contribute in the growth of the population of the city (Abdullahi 2008).

Therefore, the large population of Jos, coupled with lots of economic activities is capable of generating large amount of waste, and thus necessitating proper measures for handling waste management.

3.2 METHODOLOGY

The methodology flow diagram is shown in figure 3.2

3.2.1 Types and Sources of Data

To achieve the aim and objectives of this study, both Primary and Secondary data were used. The Primary data include SPOT 5 Satellite Imagery with 2.5m spatial resolution acquired in 2010, obtained from National Centre for Remote Sensing (NCRS). This was used to extract the LULC of the study area.

The following form the Secondary source of data:

I. Soil Map of the study area on a scale of 1:1:300,000 was acquired from FAOportal.com. It was used to determine the permeability of various soil types in the study area.
II. Geology Map of the study area on a scale of 1:100,000, prepared by the Geologic Survey of Nigeria was used to determine the permeability of various geologic formations in the study area.

III. The study utilised STRM (Shuttle Rader Topography Mission) DEMs derived from SAR (synthetic aperture radar) data collected in February 2000 (Rabus *et al.* 2003) **(http://edcsns17.cr.usgs.gov/srtmdted2)**. STRM DEMs are available at 90m resolution; the absolute vertical accuracy of SRTM DEM values has been reported to be significantly better than the specification of 16 meters for the mission (Bourgine & Baghdadi 2005). The slope layer of the study area was extracted from the STRM DEM.

IV. Existing literature from journals, textbooks, conference proceedings, seminar papers, thesis and reports, and web references.

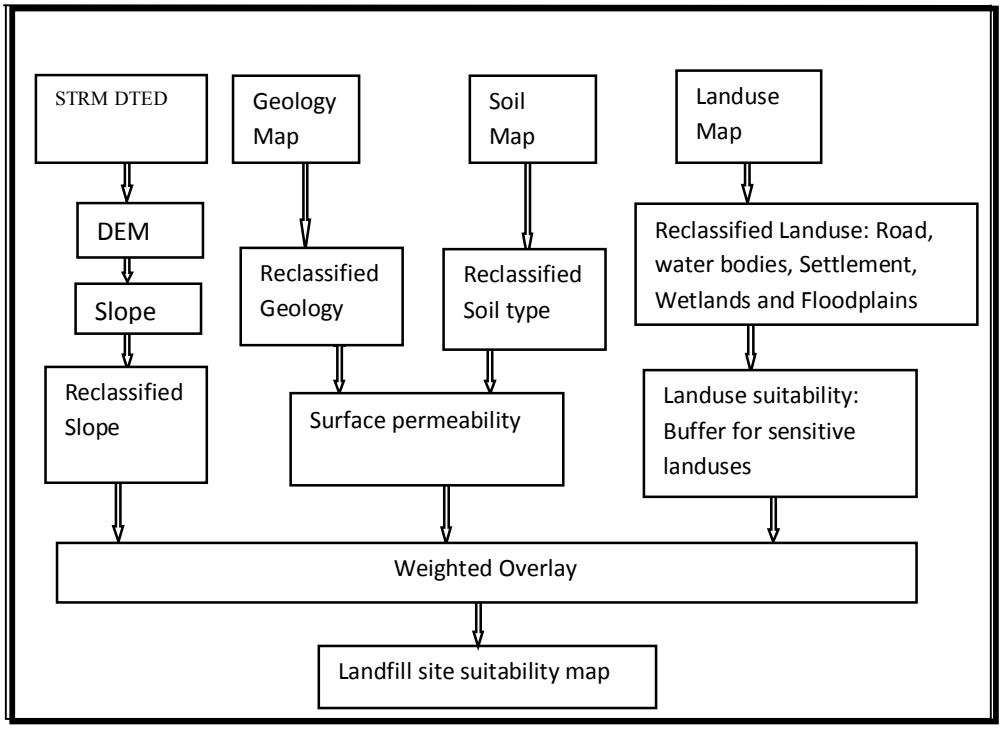


Figure 3.2: Methodology Flow Diagram

3.2.2 Data Processing Procedure

3.2.2.1 Image Processing

SPOT 5 imagery of the study area obtained from the National Centre for Remote Sensing (NCRS) was imported into ArcGIS 9.2 environment; registered using four Ground Control Points read from UTM graticules maps. For registration process, the following parameters were adopted: UTM zone 32 and datum WGS 1984. A subset covering Jos North LGA was extracted from the full scene of the imagery. Because the Imagery is orthrectified, there was no need for Geometric and Radiometric correction as well as Image enhancement.

3.2.2.2 Image Classification

Image classification is a procedure to categorize all pixels in an image of a terrain into land cover classes (Reddy, 2008). Image classification was carried out using the manual supervised image classification in Arc GIS 9.2; land use/land cover classes were identified and digitized into separate unique classes based on the classification scheme by Anderson (1976) (table 3.1): Agriculture, Built-up-land, Natural forest/Plantation, Water body, and wetland and Bare surfaces. See table 3.1 and figure 3.3

Table 3.1: Land use land cover classification scheme

Code	Landuse/Land cover Categories
1	Agriculture
2	Built-up-land
3	Natural forest/Plantation
4	Water body
5	Bare surfaces

Source: Adopted from Anderson 1976.

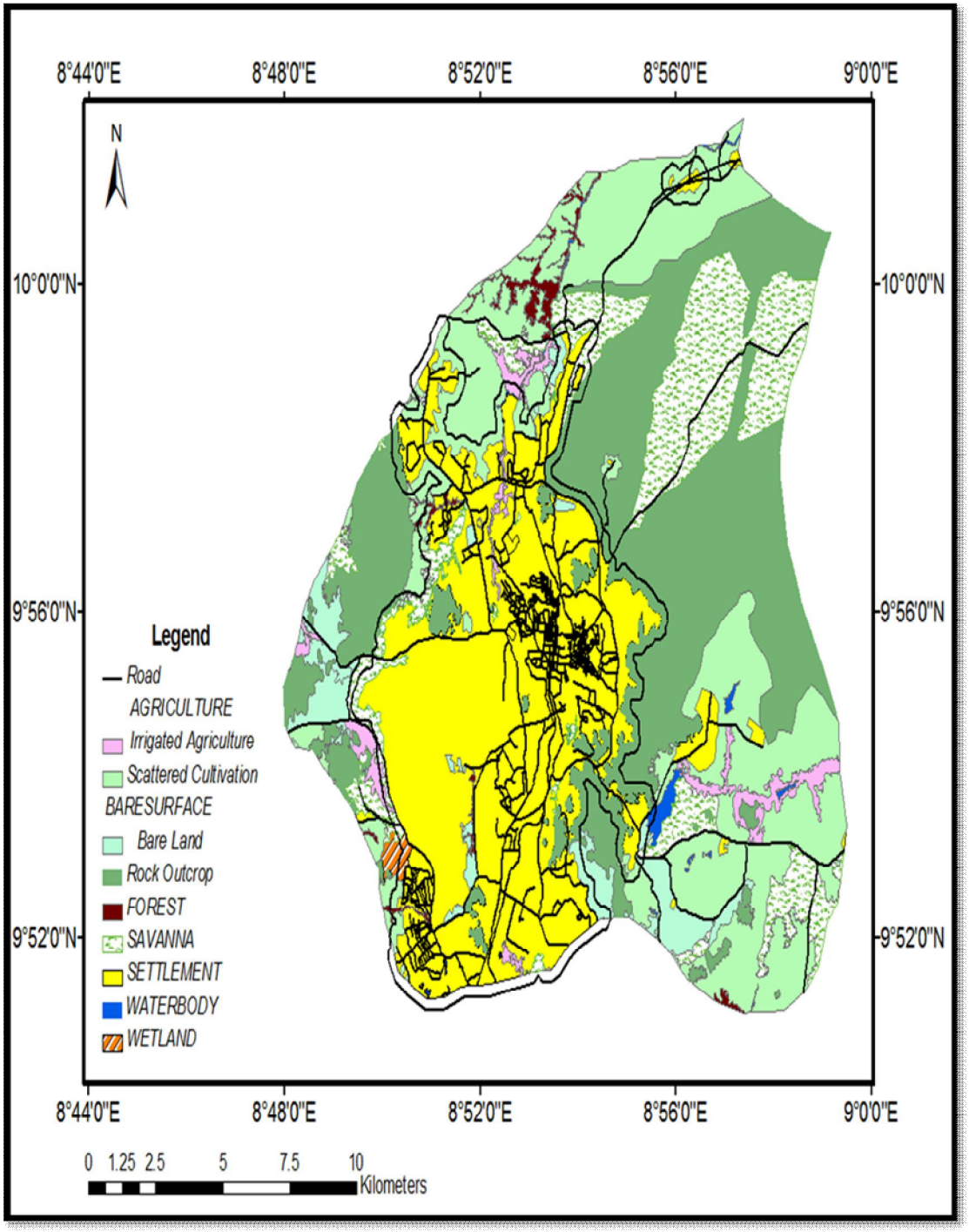


Figure 3.3 Landuse/landcover classes of Jos north

3.2.2.3 Digitization of Soil and Geology Maps

i) Soil

Soil map of the study area was scanned & imported into ArcGIS, and then registered using four Ground Control Points read from UTM graticules maps. For registration process, the following parameters were adopted: UTM zone 32 and datum WGS 1984. Then the map was digitized and different classes of soil were grouped based on textute and structure. See figure 3.4

ii) Geology

The geological map of the study area is compiled from available reports and maps obtained from the Plateau State Ministry for land and Survey. The geology map was scanned & imported into ArcGIS, and then registered using four Ground Control Points read from UTM graticules maps. For registration process, the following parameters were adopted: UTM zone 32 and datum WGS 1984. In the study area, there are twelve different lithologies and a database including symbol, lithology and description was prepared in GIS environment for these lithologies (See figure 3.5).

3.2.2.4 Buffering for Roads, Surface water and Built-up-areas

Buffer distances of 100m and 250m was created for roads; surface water, Wetland and built-up-areas respectively to satisfy minimum requirement for suitability for siting landfill. Proximity tool in analysis tools of ArcGIS 10.1 was used in creating the buffer distances. (See figure 3.6, 3.7 and 3.8).

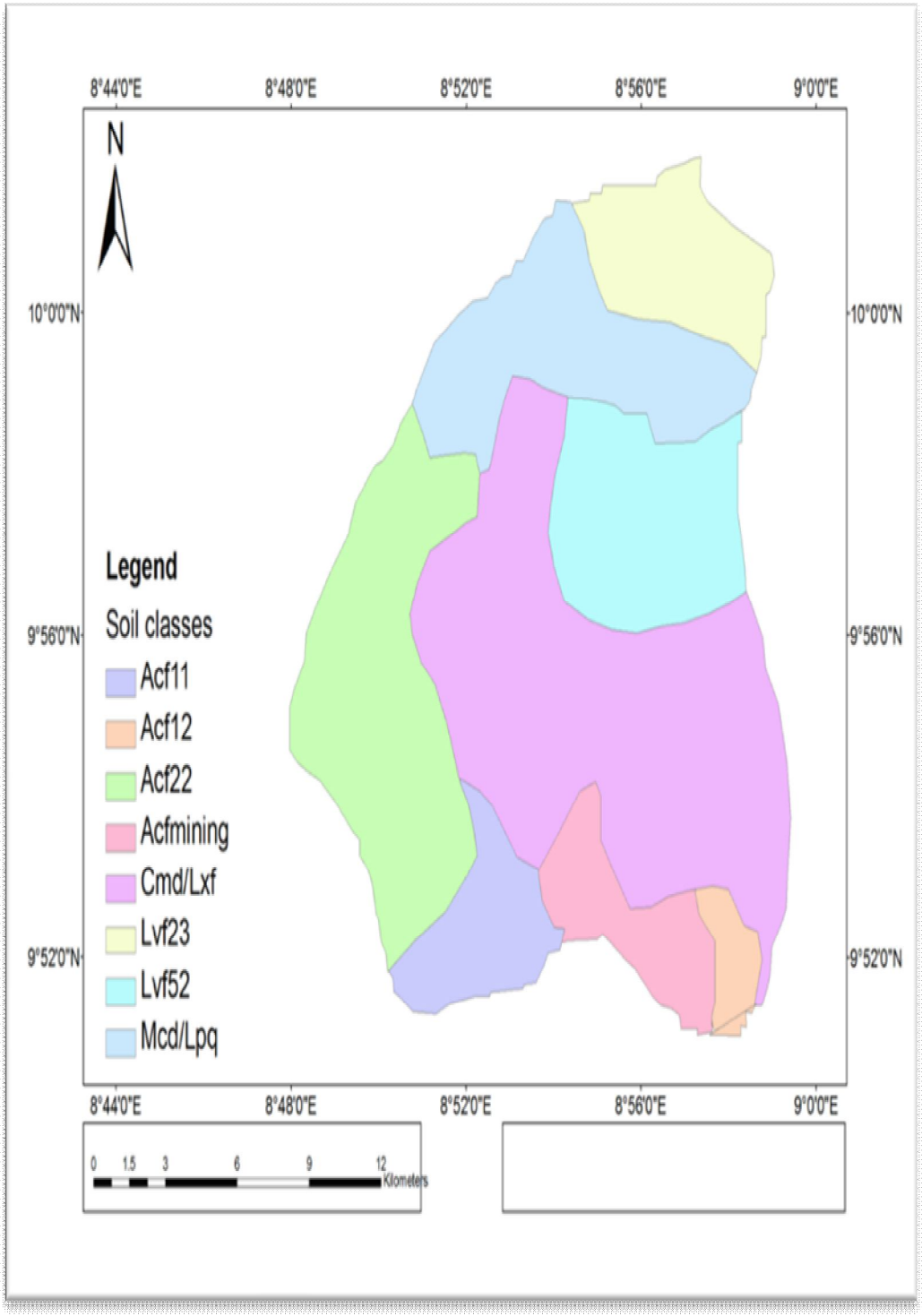


Figure 3.4: Soil classes of the study Jos North LGA

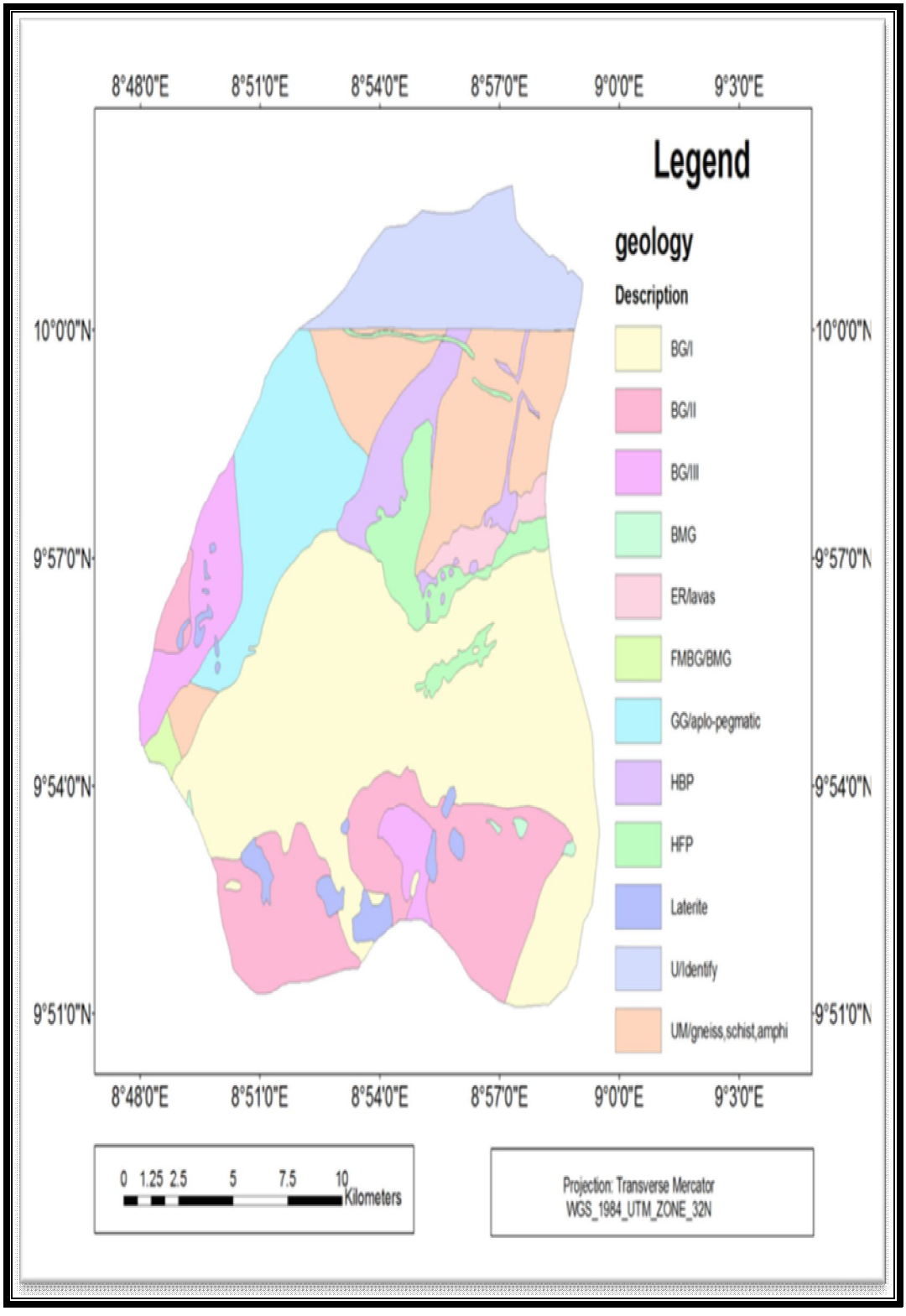


Figure 3.5: Geology classes of Jos North LGA

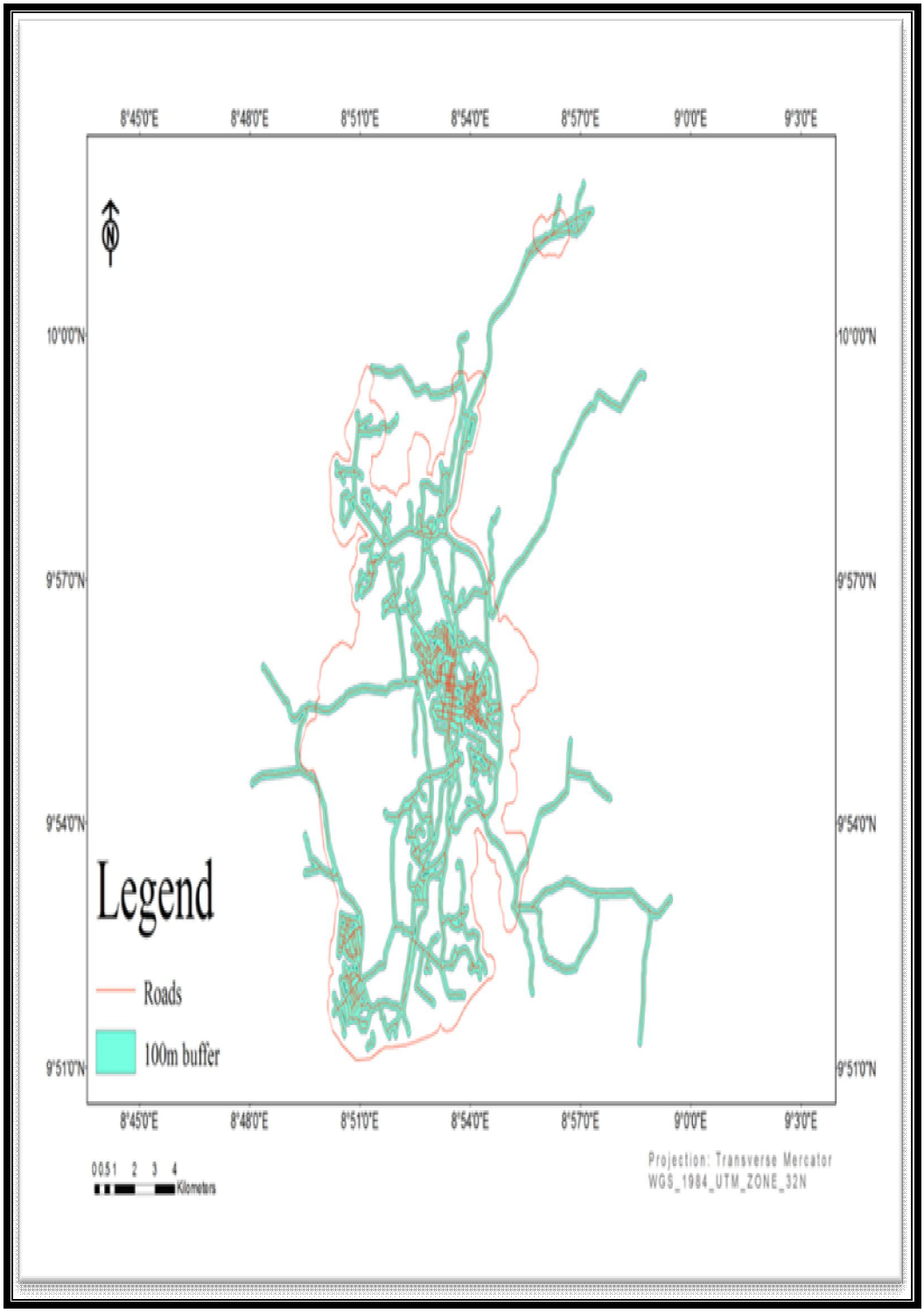


Figure 3.6: 100m Buffer for road network

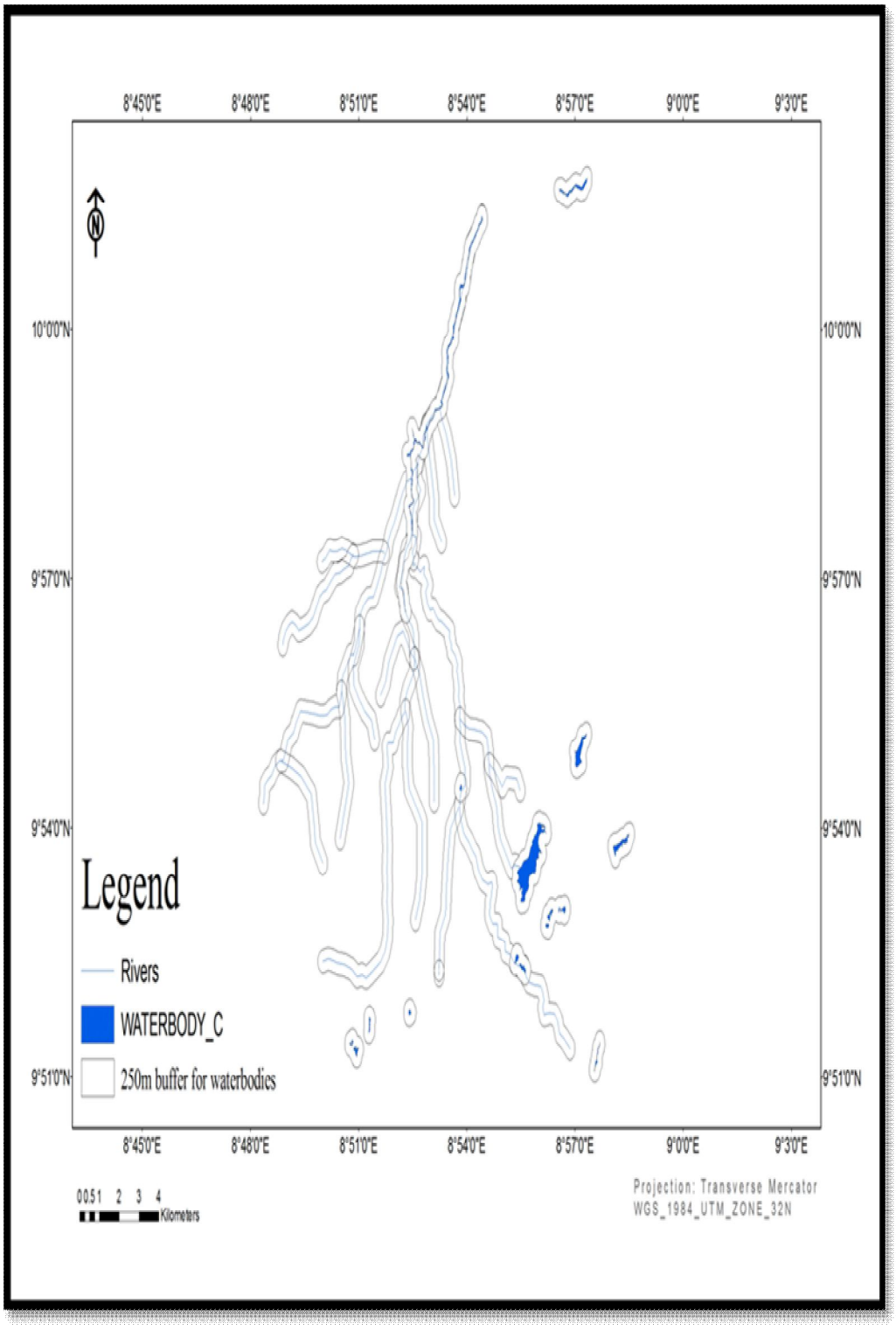


Figure 3.7: 250m Buffer for surface water

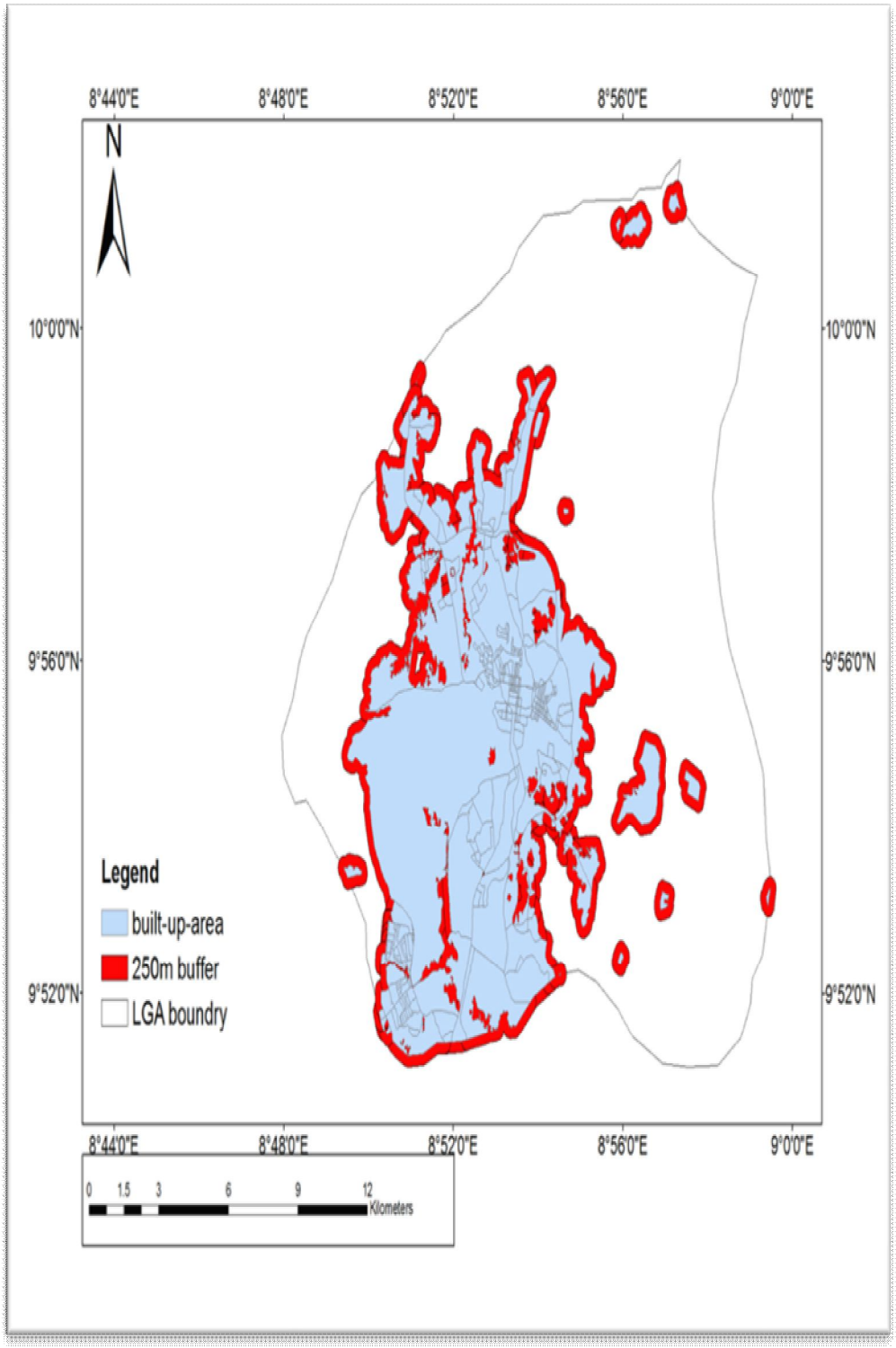


Figure 3.8: 250m Buffer for built-up-area

3.2.3 Framework of Site Suitability Decision-Making

The decision making of site suitability analysis for Landfill is analysed using the following flow chart (Figure 3.6) which, depicts the conceptual flow of the research.

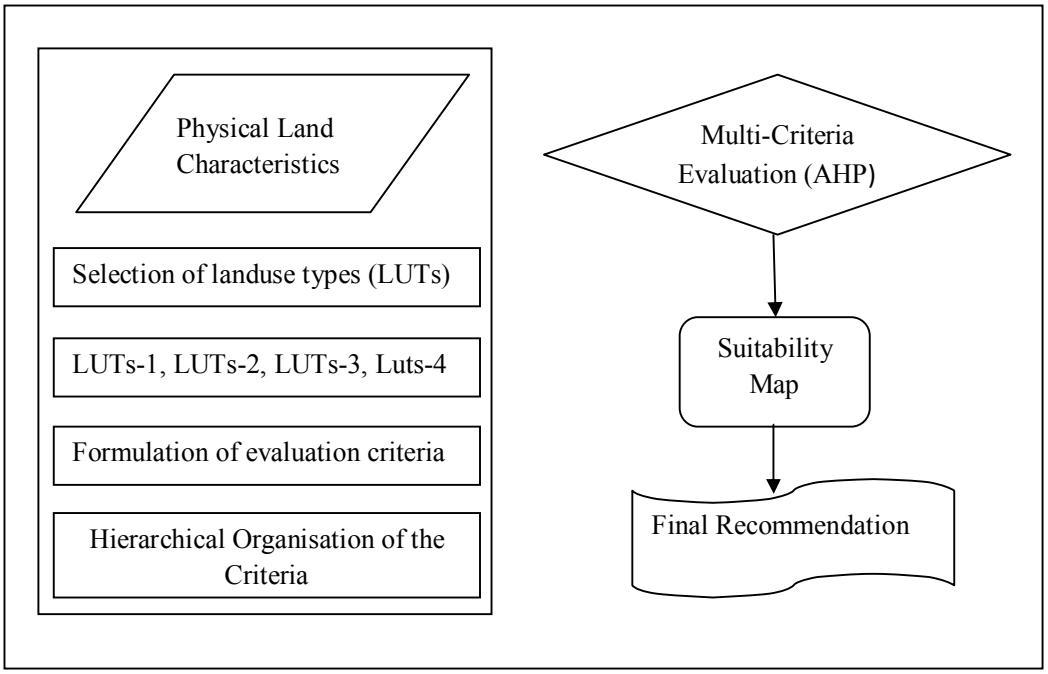


Figure 3.9: Conceptual Flow of Research Approach

3.2.4 Selection of the Evaluation Criteria

The following evaluation criteria were considered to address the Landfill site suitability decision-making:

- Landuse
    - Agriculture
    - Built-up-area
    - Vegetation
    - Bare surface
    - Surface water
    - Wet land
    - Roads

- Soil
  - Permeability
- Geology
  - Permeability
- Slope
  - Slope gradient

3.2.5 Hierarchical Organisation of the Criteria

Malczewski (1999) states that relationship between the objectives and attributes have hierarchical structure. At the highest level, one can distinguish the objectives and at the lower levels, the attributes can be decomposed. See figure 3.7

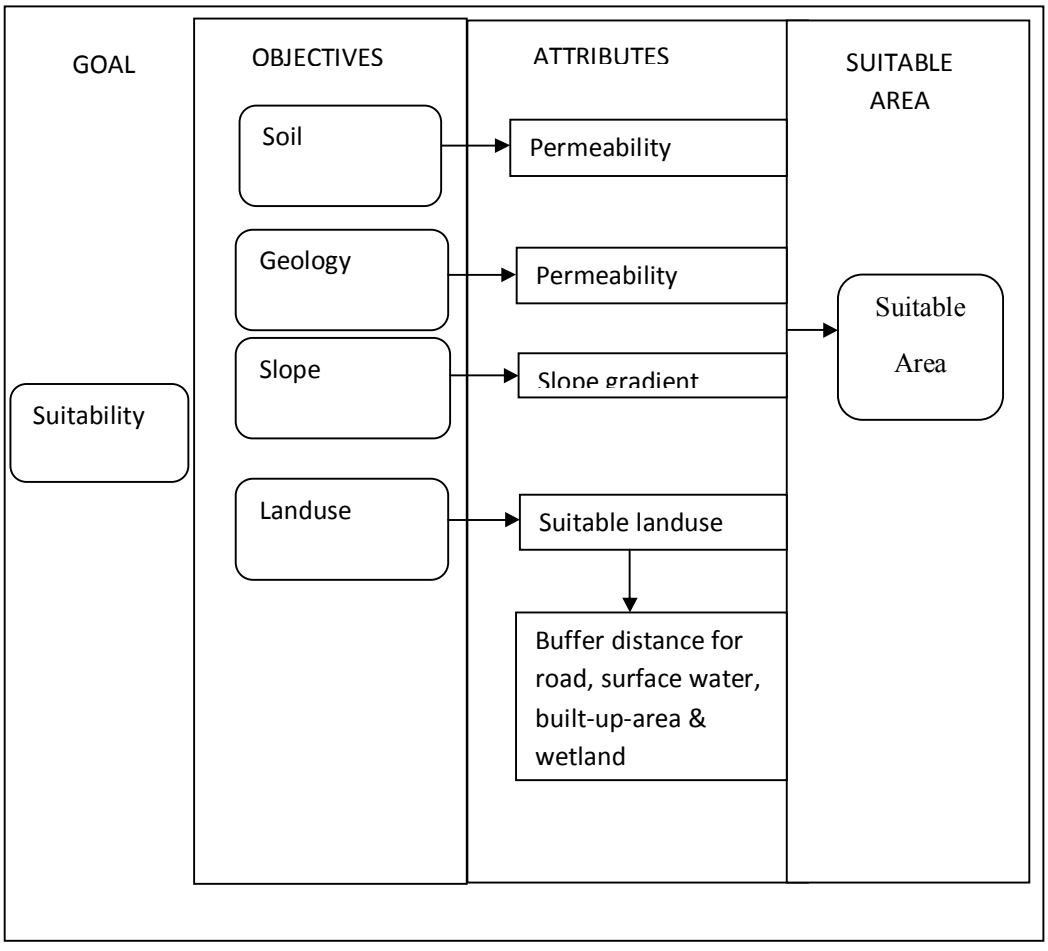


Figure 3.10**:** Hierarchical Organization of the Criteria Considered for the Study

The primary issue in Multi-Criteria Evaluation is concerned with how to combine information from several criteria to form a single index of evaluation. The procedure by which this is achieved follows the logic developed by Thomas Saaty (1977) under the Analytical Hierarchy Process (AHP) with a weighted linear combination; applying a weight to each criterion followed by a summation of the results to yield a suitability map (Malczewski 2000).

3.2.6 Procedures of AHP:

1 developing a pair wise comparison matrix for each criterion

2 normalizing the resulting matrix

3 averaging the values in each row to get the corresponding rating

4 calculating and checking the consistency ratio

1) The relative importance of each criterion or factor is evaluated against other criteria. Many studies have used expert-derived paired comparison for evaluating criteria (Saaty 1980; Banai-kashani 1989; Pereira & Duckstein 1993; Jiang & Eastman 2000). This method involves performing ratio estimates for each pair of criteria. The criterion weight is expressed in percentages, with the total equating 100 percent or 1.0. See table 4.1

2) Data for each criterion is standardized/ normalized. A common method for standardization is linear transformation. The following formula can convert interval or ratio data into a standardized scale of 0.0 to 1.0:

$$Si = \frac{xi - xmin}{xmax - xmin}$$ (Malczewski, 2000)

Where S_i is the standardization value for the Original value X_i, X_{min} is the lowest original value, and X_{max} is the highest original value. However, if the original data are

not nominal or ordinal, the above equation can be used. In such cases, a ranking procedure based on expertise and knowledge can convert the data into a standardized range such as 0 to 1, or 0 to 100.

3) The index value is calculated for each unit area by summing the weighted criterion values and dividing the rest by the total of the weights:

$$I = \sum_{i=1}^{n} wi\ xi$$ (Malczewski J. 2000)

Where *I* is the index value, *n* is the number of criteria, w_i is the weight for criterion *i,* and x_i is the standardized value for criterion *i*.

4) **Consistency Ratio (CR)** is used to check for the consistency of judgement amongst the criteria.

- Benchmark of Consistency ratio (CR) is less than (<) 0.1
- In practice, a value of 0- 0.1 is considered satisfactory.
- Any higher value at any level indicates that the judgements warrant re-examination.

CR = CI / RI

CI- consistency index, reflects the consistency of one's judgement

$$CI = \frac{\lambda max - n}{1 - n}$$

 – is calculated by averaging the value of the consistency vector (calculated factor weight)

RI- Random Index reflects the random inconsistency indices and the **CI** represents the consistency index.

Table 3.2: Random Inconsistency Indices (RI) for N-10

1	2	3	4	5	6	7	8	9	10
0.00	**0.00**	**0.58**	**0.9**	**1.12**	**1.24**	**1.32**	**1.41**	**1.46**	**1.49**

Source: Saaty (1980)

After assigning weight to the various criteria accordingly, the weighted overlay tool in the ArcGIS environment is employed to overlay the various criteria to produce the suitability map. It is this output map that provides areas suitable for siting environmentally sustainable landfills.

3.2.7 Field check of suitable sites

In order to confirm the reliability of the results derived from the analysis, field check is carried out to determine the accuracy and suitability of available suitable sites. This is achieved by overlying a transparent image of the study area from Google Earth to enable easy identification of features that can serve as guide during the field exercise. Then, the selected sites are visited to confirm the outcome of the result.

CHAPTER FOUR

RESULTS PRESENTATION AND DISCUSSION

4.1 Introduction

This section presents and discusses the results of findings obtained from data processing. It also illustrates suitability determination for factor maps required as criteria for landfills site suitability analysis.

4.2 Suitability Determination

4.2.1 Landuse

Six major landuse classes were identified as follows: Agriculture, Vegetation, Built-up-land, Bare surface, Water body and Wetland. Bare surface, Agriculture and Vegetation were further divided into sub-classes (table 4.1).

Table 4.1: Landuse land cover classes of Jos-North (2011)

Code	**Landuse/Land cover Categories**	**Sub-types**	**Area (km^2)**	**Area (%)**
1	Agriculture	Scattered Cultivation	66	22.7
		Irrigated Cultivation	6	2.1
2	Built-up-land	-	87	29.9
3	Vegetation	Forest	2.6	0.9
		Savannah	36.3	12.5
4	Water body	-	1.5	0.52
5	Bare surface	Rock outcrop	80	27.5
		Bare land	11	3.8
5	Wetland	-	0.8	0.3

For the purpose of this study, benchmark suitability was determined based on available facts in the literature and consultation with experts at the National Centre for remote Sensing (NCRS), Jos. It was observed that, Agricultural land, forest vegetation, rocky outcrop, built-up-area, water body and wetland should be avoided completely, and be considered unsuitable for siting landfill. Therefore, considering landuse alone for landfill suitability, only 16.3% of the study area equivalent to 48.1 km^2 is suitable for siting landfill. See figure 4.1

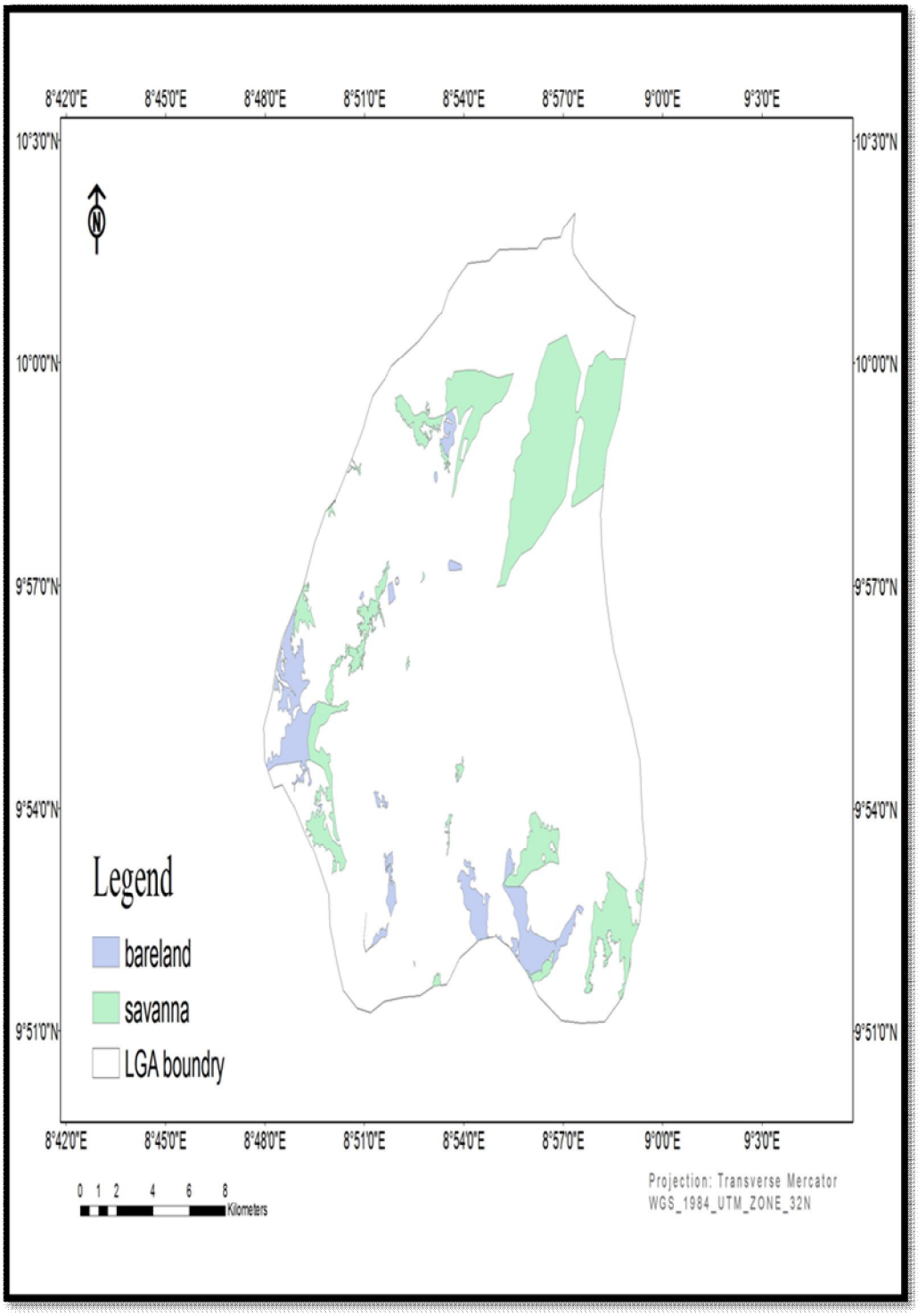


Figure 4.1: Suitability for Landuse

4.2.2 Slope

Slope map was generated from Digital Elevation Model (DEM). The distribution of slope values in the study area ranges between 0 and 89.99° (see figure 4.2). There are many suggestions about slope in the literature, regarding its suitability for siting landfill. As stated by Allen (2000) and Oweis *et al.* (1990), areas with slopes greater than 15° should be avoided for a landfill site. According to Lin(1999), the appropriate slope for constructing a landfill is about 8-12%, because too steep of a slope would make it difficult to construct and maintain and too flat of a slope would affect the runoff drainage. High slopes can favour leachate drainage to flat areas and water bodies and cause contamination. Areas whose slope is greater than 20% are not suitable to allocate landfills (Leao *et al.,* 2003).

By considering reliable suggestions in the literature, slope was classified into two groups according to suitability; 0-15, and >16. About 56% of the study area is having a slope gradient of less than 16^0 and thus considered suitable for siting landfill (see figure 4.3).

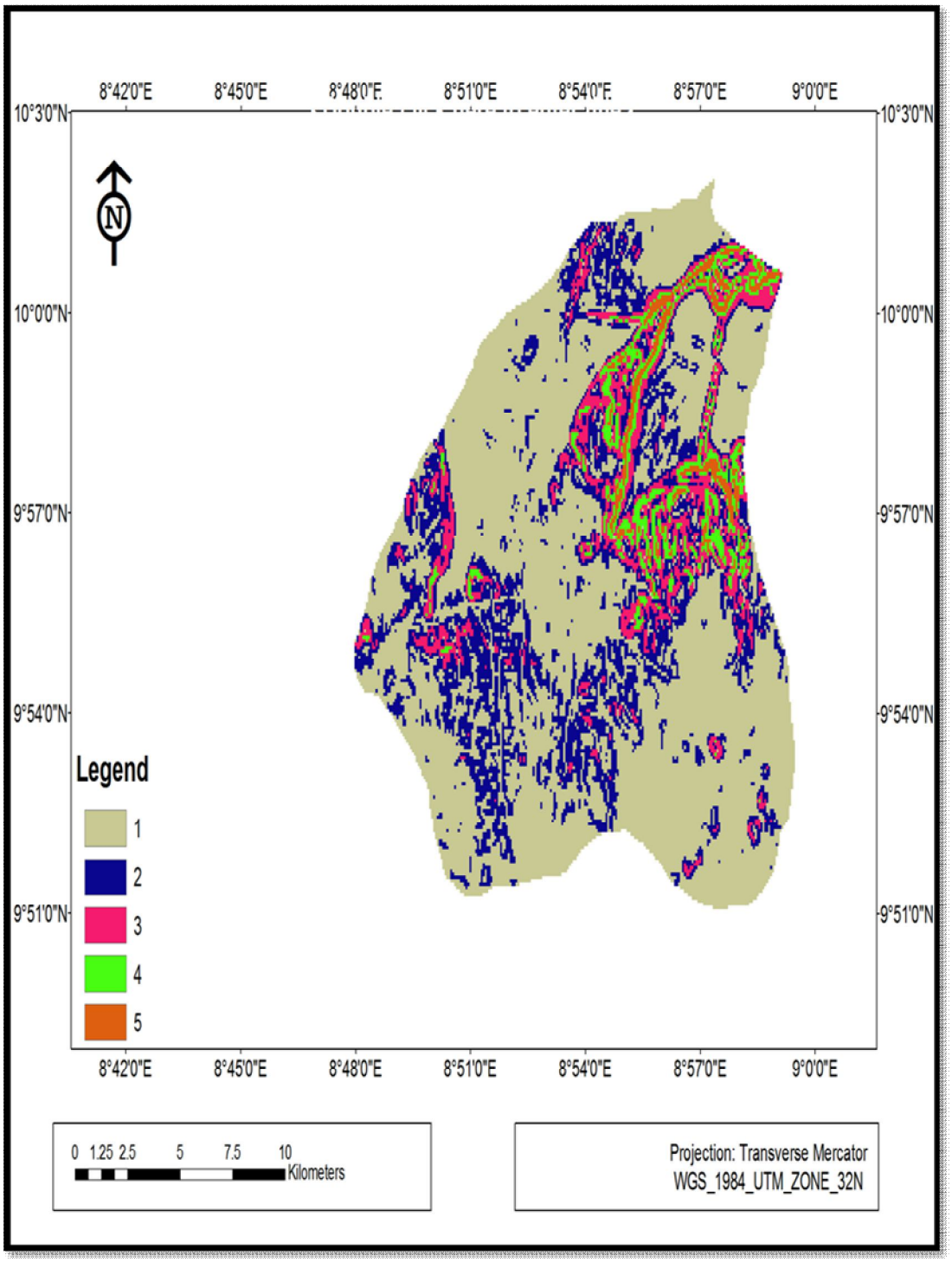


Figure 4.2 : Classified slope of Jos-North LGA

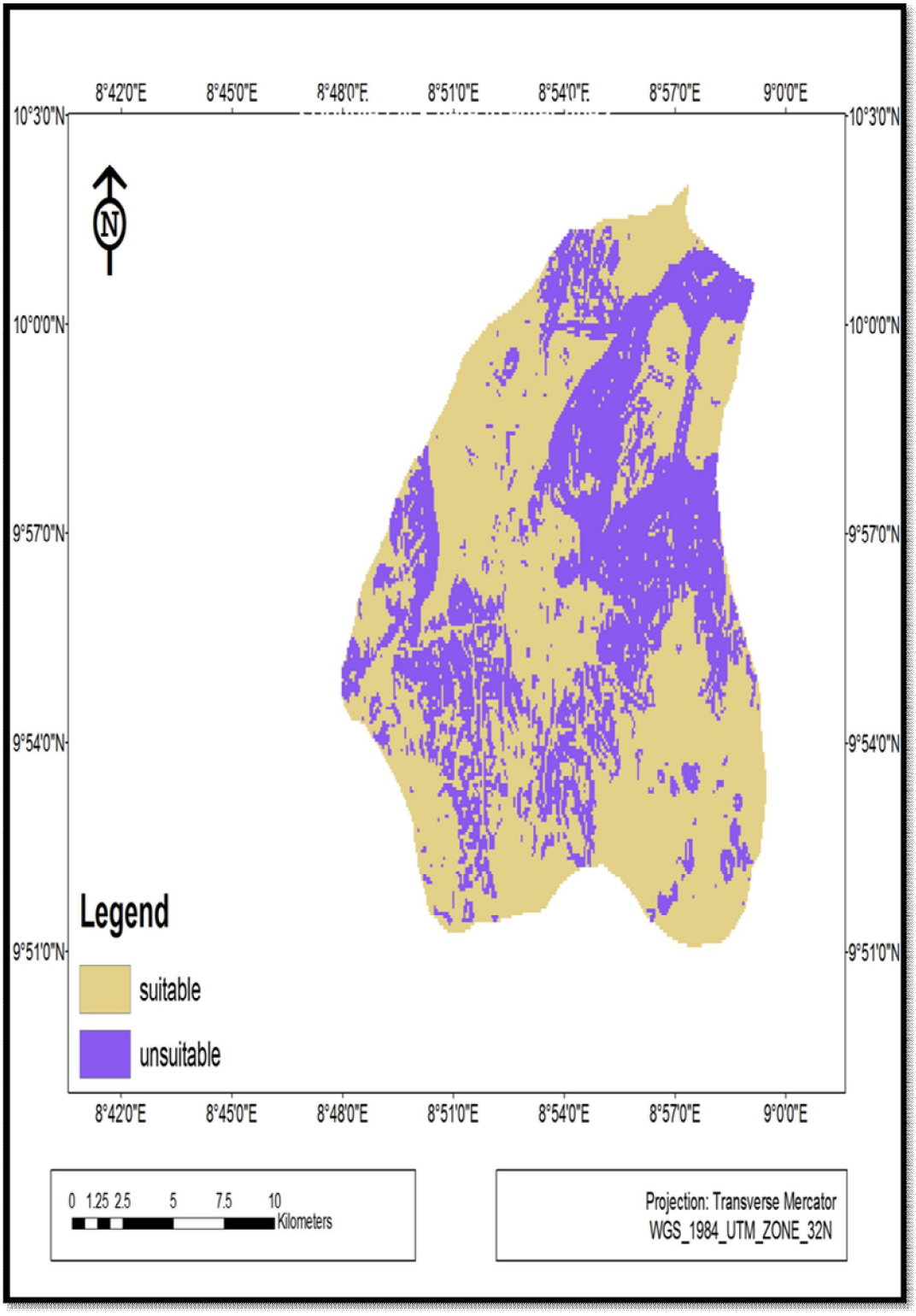


Figure 4.3: Suitability for Slope

4.2.3 Soils

Jos-North is characterised by the following soil classes: Cambisols (Cmd), Luvisols (Lvf), Acrisols (Acf), Leptosils (Lpq) and Lixisols (Lxf). These classes are spread spatially across the study area; some homogeneously confined to specific area and some heterogeneously mixed-up. See table 4.2

Table 4.2: Soil classes

Type	**Permeability Status**	**Suitability Status**
ACF 11	Moderate	Suitable
ACF 12	Moderate	Suitable
ACF 22	Moderate	Suitable
ACF Mining 3	Moderate	Suitable
LVF 23	High	Unsuitable
LVF 52	High	Unsuitable
Cmd-Lxf	Low	Suitable
Cmd-Lpq	Moderate	Suitable

Source : Sonneveld (1996) adopted and modified

The various soil classes identified in table 4.2 and figure 3.4 were further reclassified into two: suitable and unsuitable: with suitable accounting for 80% of the total landmass of the study area equivalent to 233km^2. See table 4.3 and figure 4.4

Table 4.3: Soil Types and Landfill Suitability

Soil types	**Suitability**	**Area (Km^2)**	**Area (%)**
Acf11,12,22; Acf mining; Cmd/Lxf; & mcd/Lpq	Suitable	233	80
Lvf 23 & Lvf 52	Unsuitable	58	20

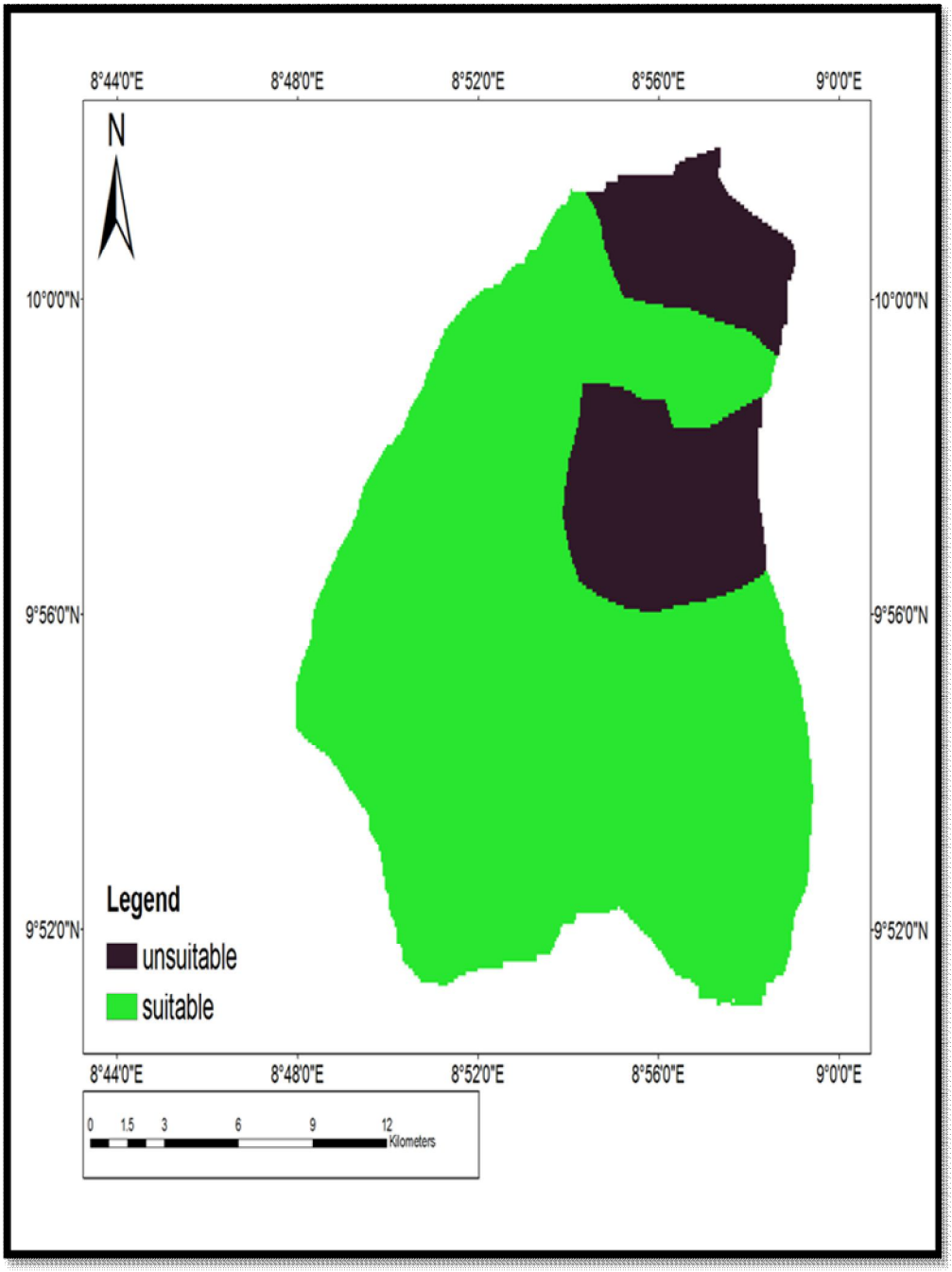


Figure 4.4: suitability for soil classes

4.2.4 Geology

The lithologies are grouped and ranked according to their suitability for landfill siting which is given in Table 4.4. The vector map of lithology is then converted to a raster map to be finalized for analysis.

Table 4.4: Geology classes

Type	**Symbol**	**Permeability**	**Suitability status**
Granite Gneisis I, II, III	GG	Moderate	Suitable
Biotite-Microgranite	BMG	Low	Suitable
Biotite Granite	BG	Low	Suitable
Hornblend-Biotite Porphyries	HBP	High	Unsuitable
Hornblend-fayalite Porphyries	HFP	High	Unsuitable
Early Rhyolites	ER	Low	Suitable
Undifferentiated Migmatite	UM	High	Unsuitable
Laterite	-	High	Unsuitable
Biotite-Muscovite-Granite	BMG2	Moderate	Suitable

Source: Autio and Hjerpe (2003), adopted and modified

The various lithological formations identified in table 4.4 were further reclassified into two: suitable and unsuitable. Formations suitable for siting landfill account for 61% of the total landmass of the study area. See table 4.5 and figure 4.5

Table 4.5: Various Geologic formations and Landfill Suitability

Lithologies	**Suitability**	**Area (Km^2)**	**Area (%)**
GG, BMG, BG, ER, BMG2	Suitable	201	69
HBP, HFP, UM & Laterite	Unsuitable	90	31

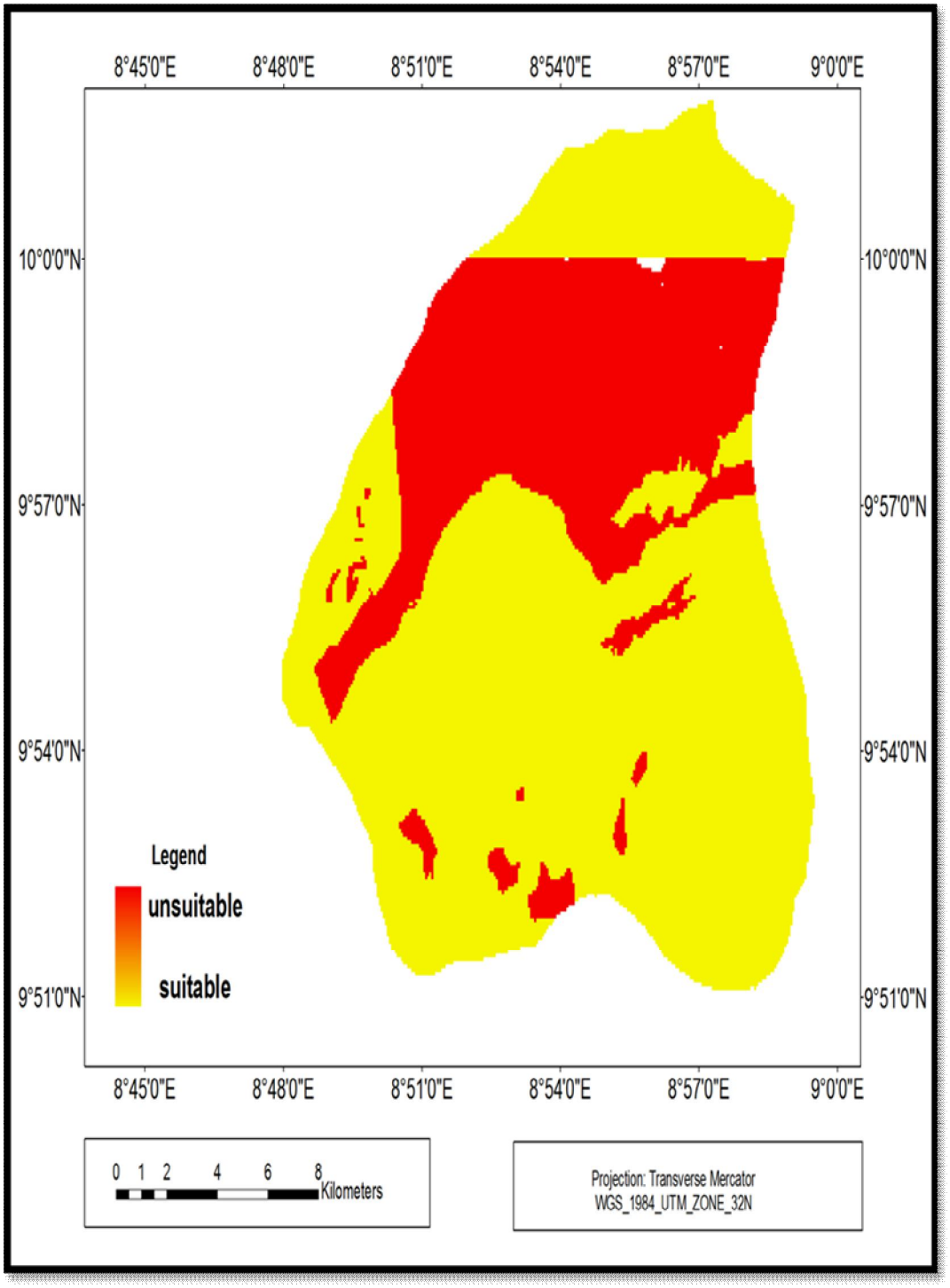


Figure 4.5 Suitability for Geology

4.2.5 Flood-risk-zone

In literature, there is a common suggestion that flood-risk-zones should be avoided in the case of landfill site selection to reduce the risk of contaminating overland drainage (Lin, 1999). If land slope is less than 15 % and the area within 50m from the bank of an active river, flood-risk exists (Kao *et al*., 1996). Thus flood-risk-zone was determined considering these factors. In this study, 50m buffer within the bank of major streams with slope less than 15% is regarded as flood-risk-zone and therefore, considered unsuitable for siting landfill. (Figure 4.6a & 4.6b)

According World Bank (2004), the landfill site should not be placed within a floodplain subject to 10-year floods. It can be placed within floodplains of secondary streams if any embankment is built and that 100m buffer should be placed around flood potential zones to exclude them completely from the suitability frame. Therefore, this study considers areas within 100m buffer around flood vulnerable areas as unsuitable for siting landfill. See figure 4.6c & 4.6d

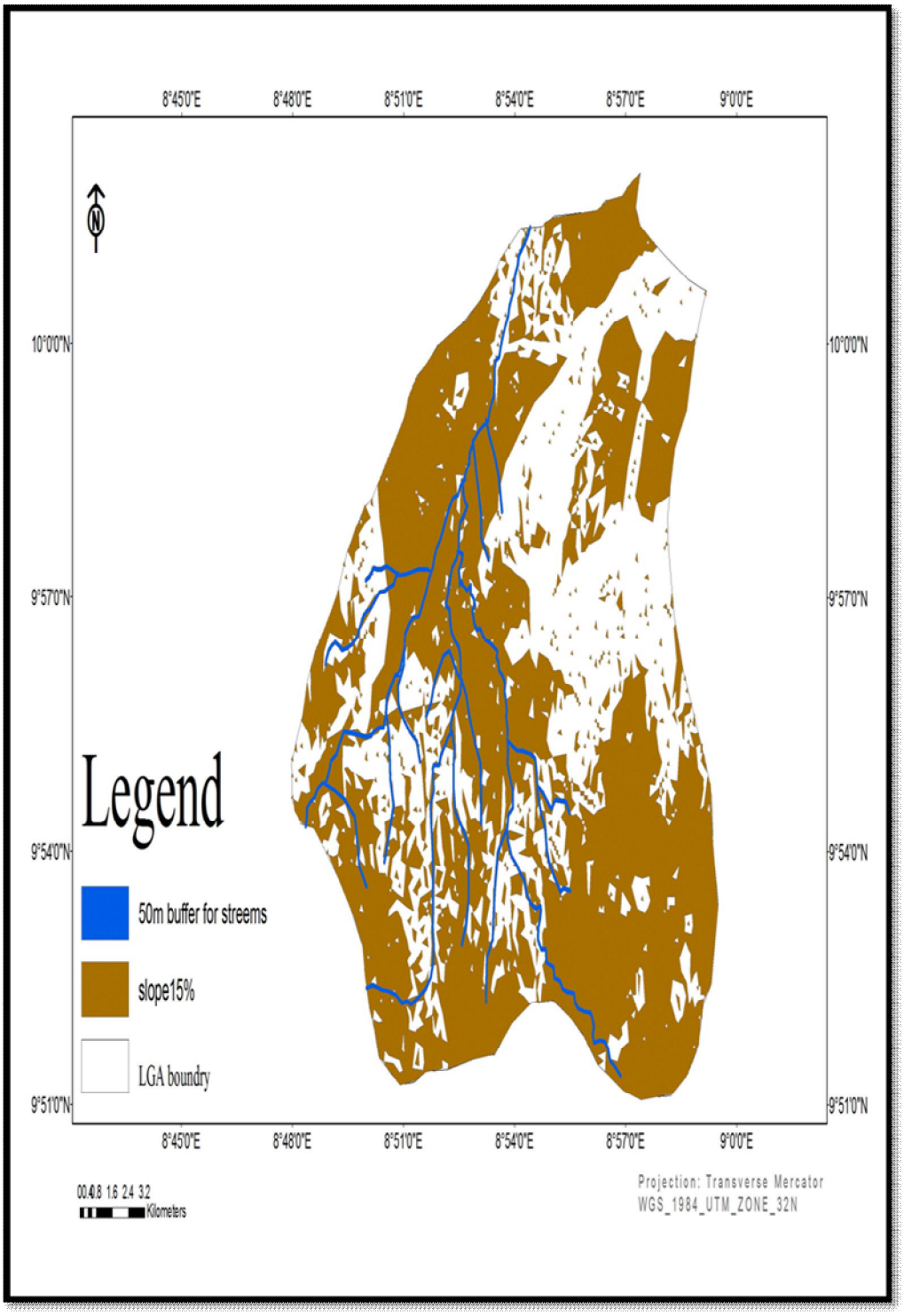


Figure 4.6a factors determining flood-risk-zone (15% slope and 50m buffer for major streams)

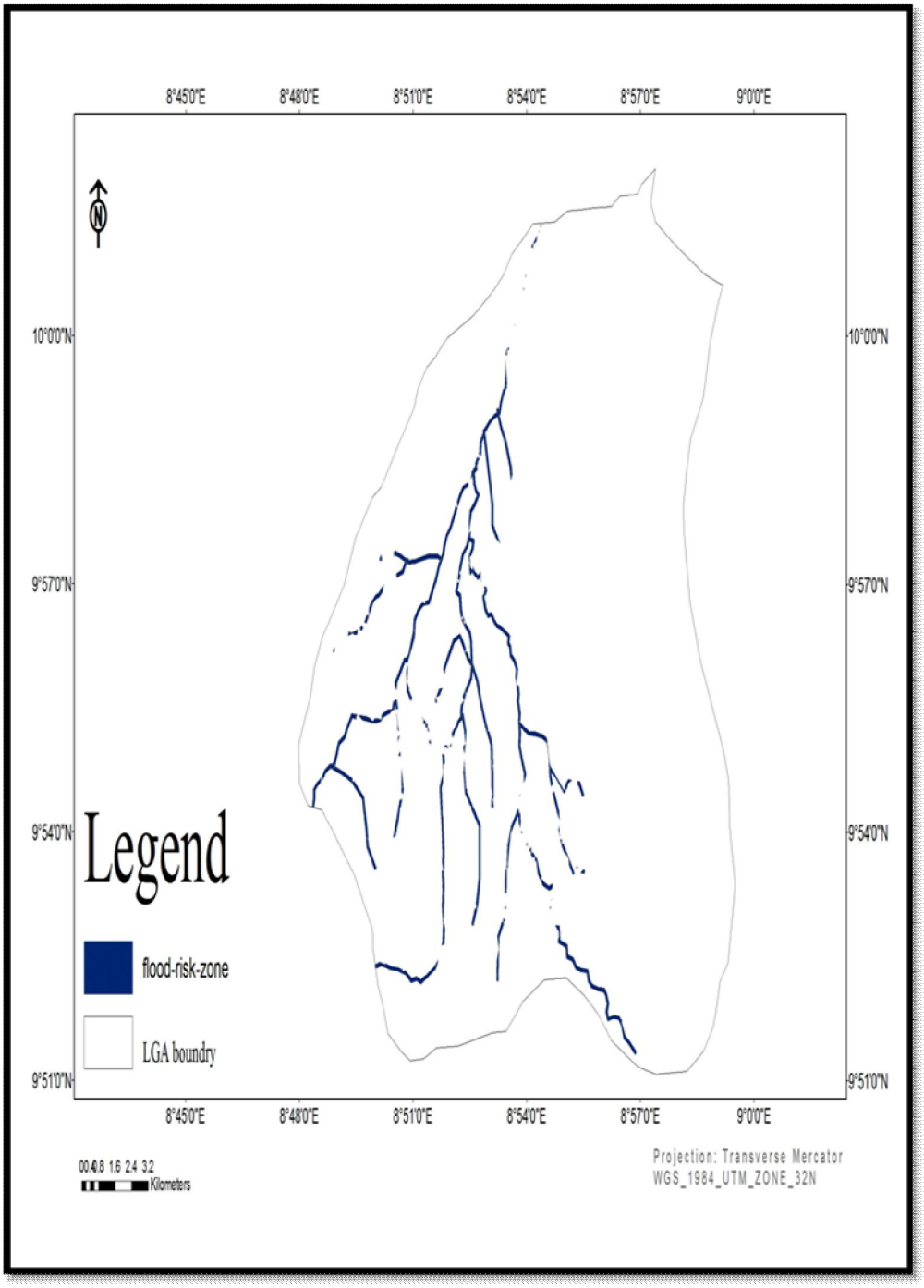


Figure 4.6b flood-risk-area

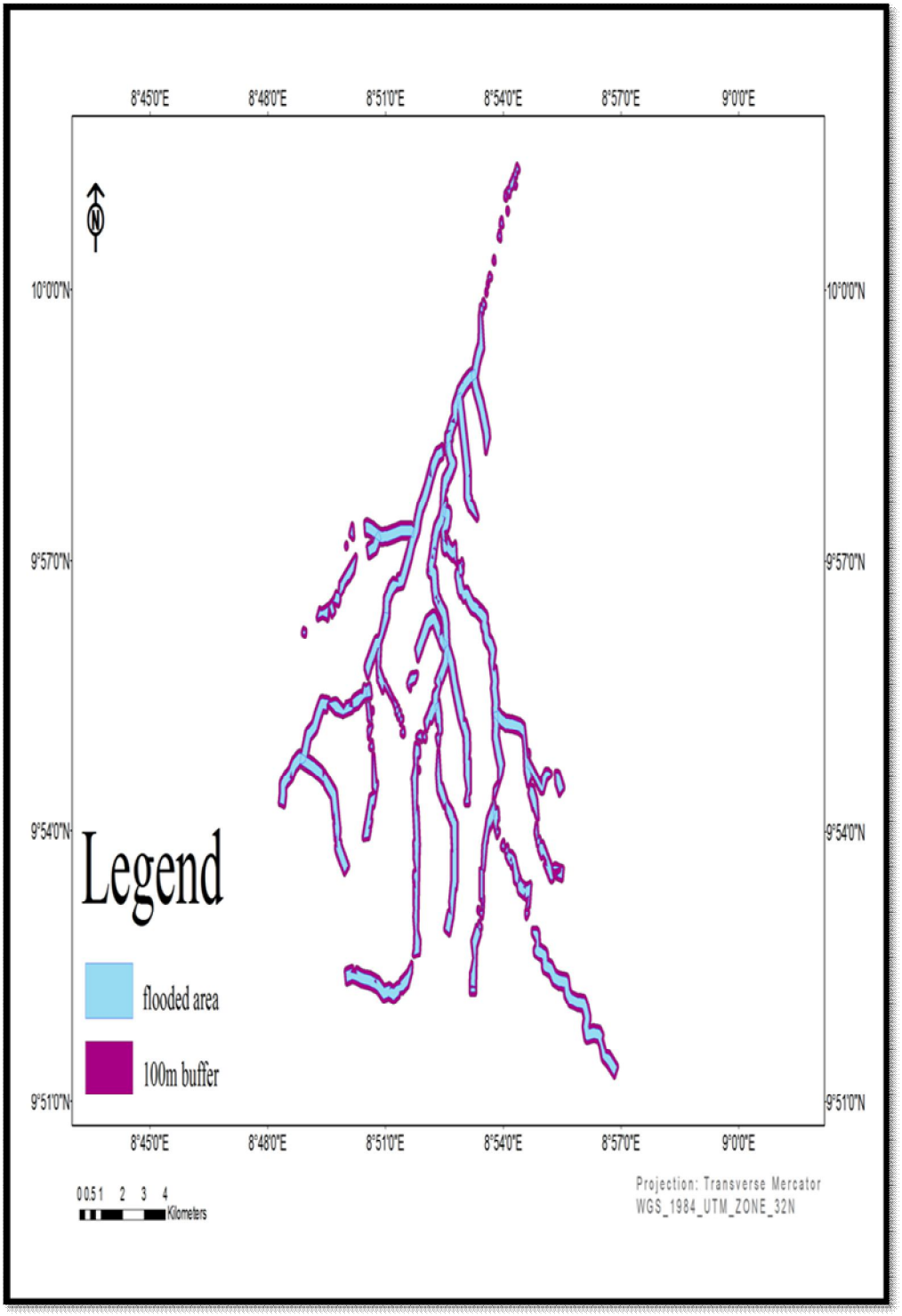


Figure 4.6c, 100m buffer for flooded area

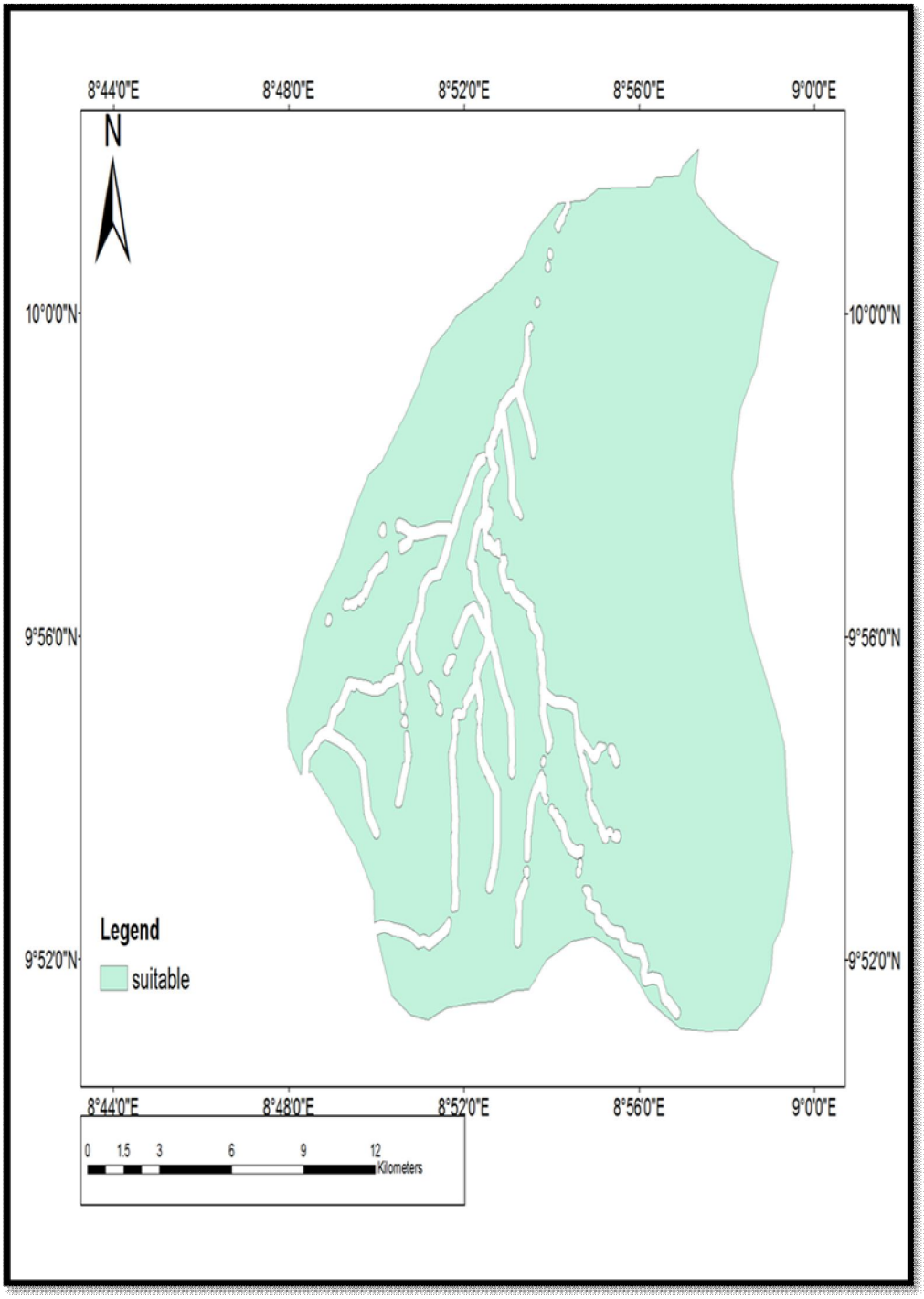


Figure 4.6d, suitability for flood

4.2.6 Roads

There are many suggested buffer zone distances in literature. Minimum distance from road network is imported in order to avoid visual impact and other nuisances. Therefore, 100m buffer was applied around the entire road network and considered unsuitable for siting landfill, and the remaining area outside the buffer zone is considered suitable. See figure 4.6

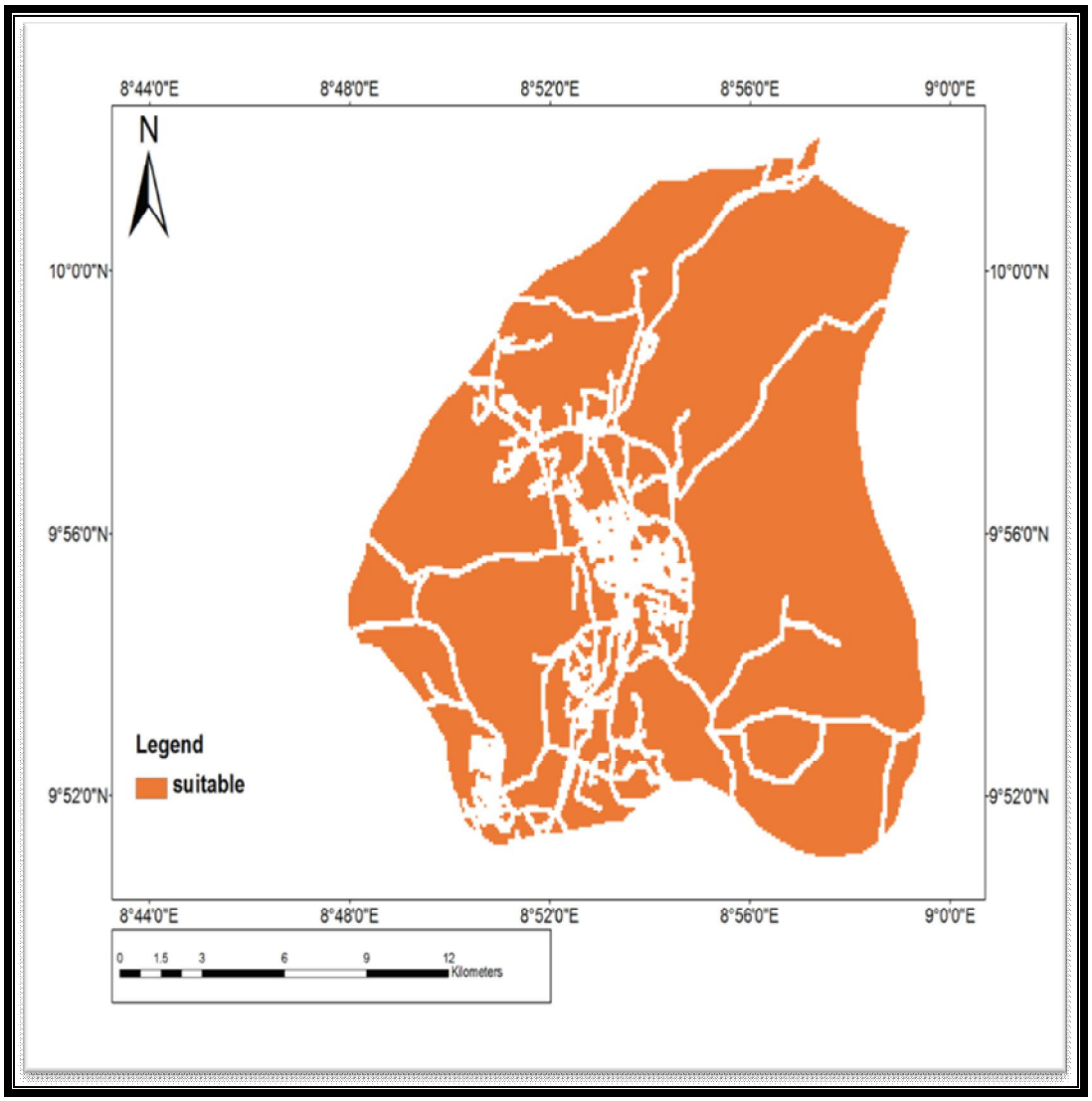


Figure 4.7: suitability for roads

4.2.7 Surface water

To have an input map for surface water; first streams were digitized as line and Dams and pounds as polygon data from Satellite imagery of the study area acquired in 2010. The line and polygon data was assigned 250m buffer distance to protect rivers, dams and other water bodies in the study area from contamination.

Areas outside the buffer zone are considered suitable for siting landfill, while all surface water body surrounded by the buffer are designated unsuitable. See figure 4.8

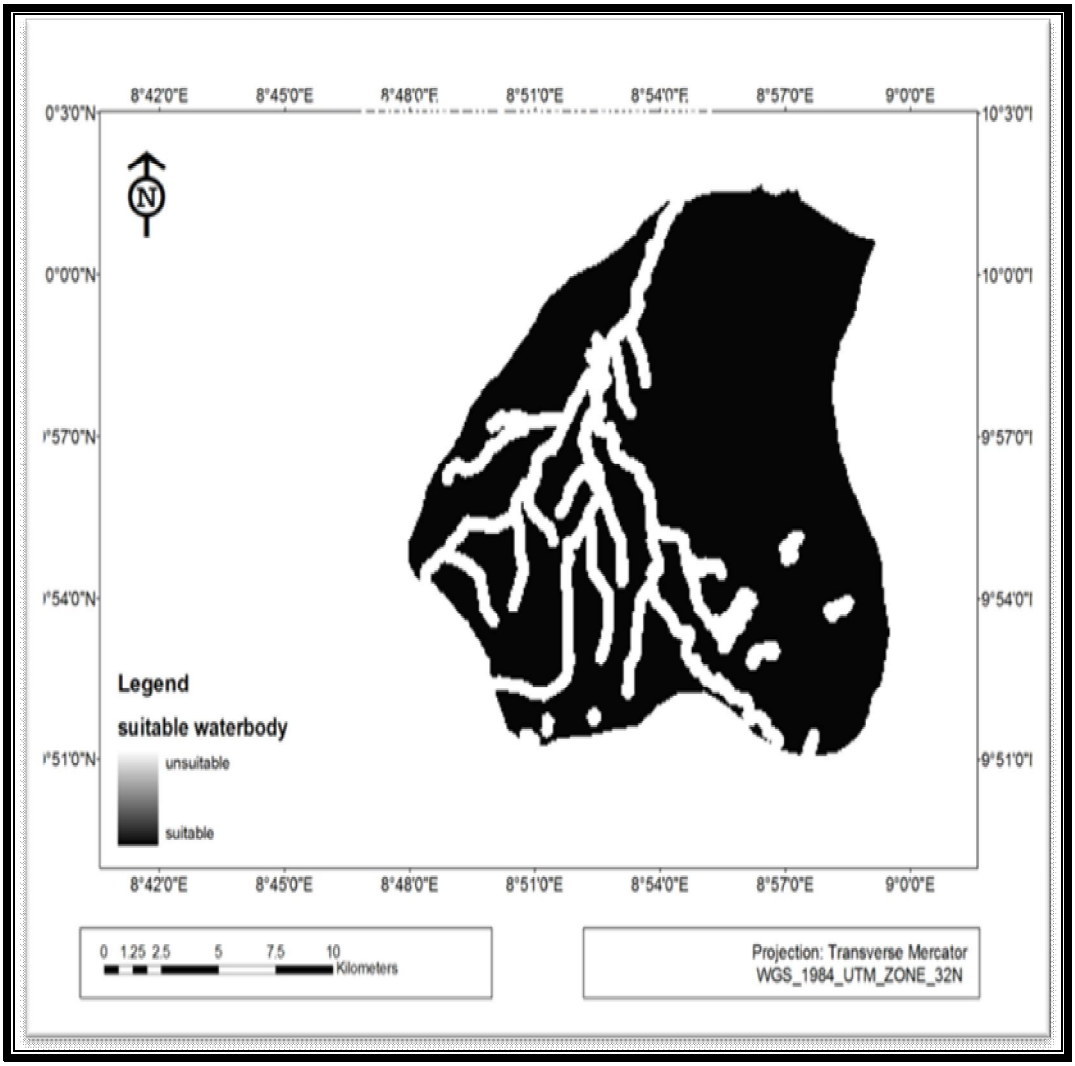


Figure 4.8: suitability for water bodies

4.2.8 Built-up-area

According to Allen (2000), the buffer distances for towns and villages within a population greater than 500 people are determined as 500 m; and for private residences, businesses, and social and community buildings as 250 m by Cantwell (1999), whereas Siddiqui *et al.* (1996) suggests that no new landfill site should be located closer than 0.4 km (250m).

By considering all suggested safe distances in the literature, minimum distance for the study area is determined as 250m. The distance was used to create buffer zones around built-up-area which excludes them from the suitability frame, designating them as unsuitable for siting landfill. After exclusion of absolutely unsuitable areas for a landfill site, the remained areas are classified as suitable. See figure 4.9a & b.

Suitability for built-up-areas account for 64% of the of the study area, equivalent to 186km^2, and fairly different from Wuyep (2011) which obtained 56% of suitability as accounted for by Built-up-area. Except for the role of other factors in the suitability framework, considering built-up-areas alone would have made adequate provision for more than enough land space for siting landfill.

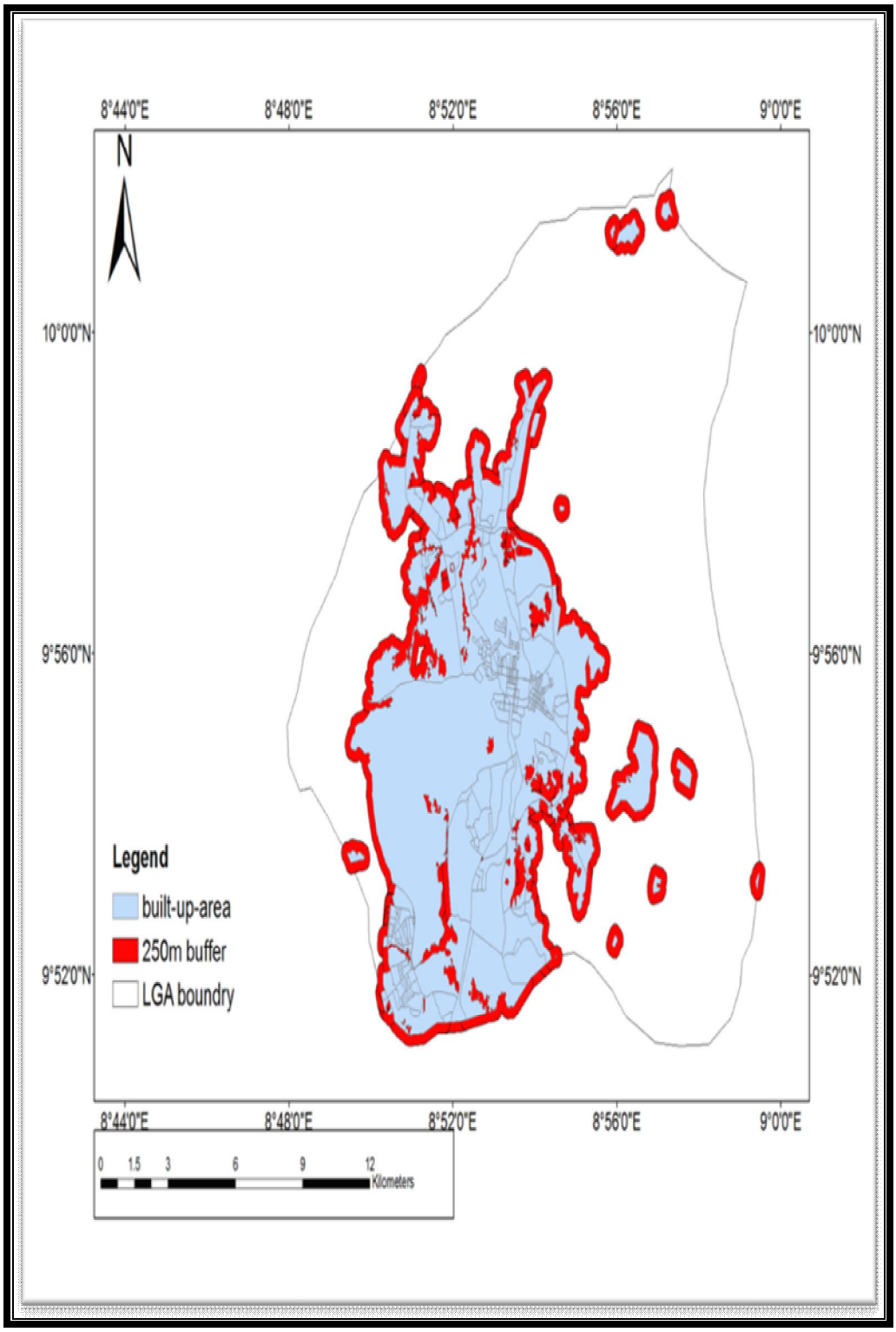


Figure 4.9a: 250m buffer for built-up-area

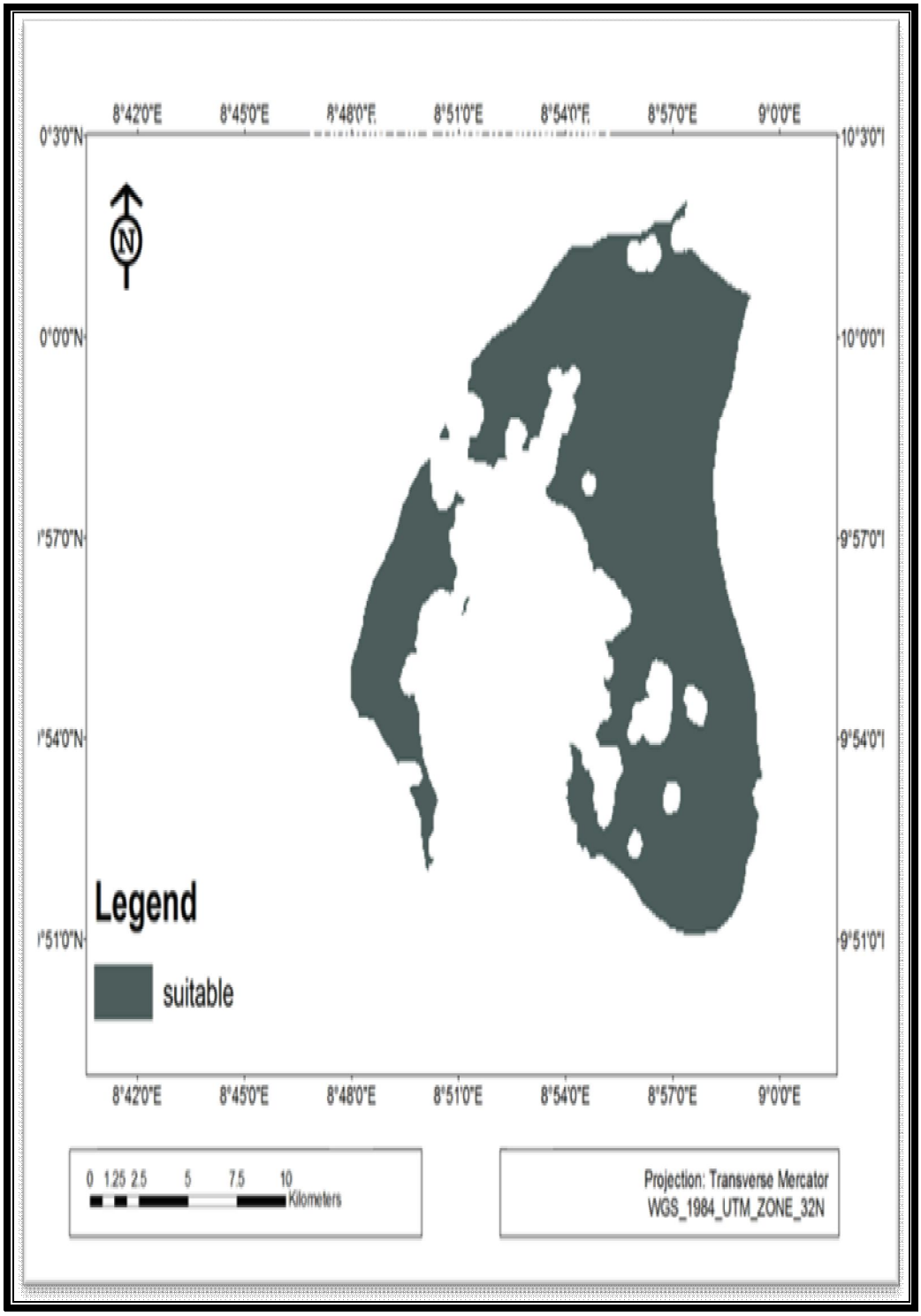


Figure 4.9b: suitability for built-up-area

4.2.9 Wetland

Wetland was also extracted from the LULC of the study area (figure 3.3). The buffer distance was determined as 250 m (Allen, 2001). The 250m distance was used to create buffer zones around the wetlands to protect it from being used as landfill site. Therefore, wetlands surrounded by a 250m buffer are considered unsuitable for siting landfill. After exclusion of absolutely unsuitable areas for a landfill site, the remained areas were classified as suitable. See figure 4.10a & b.

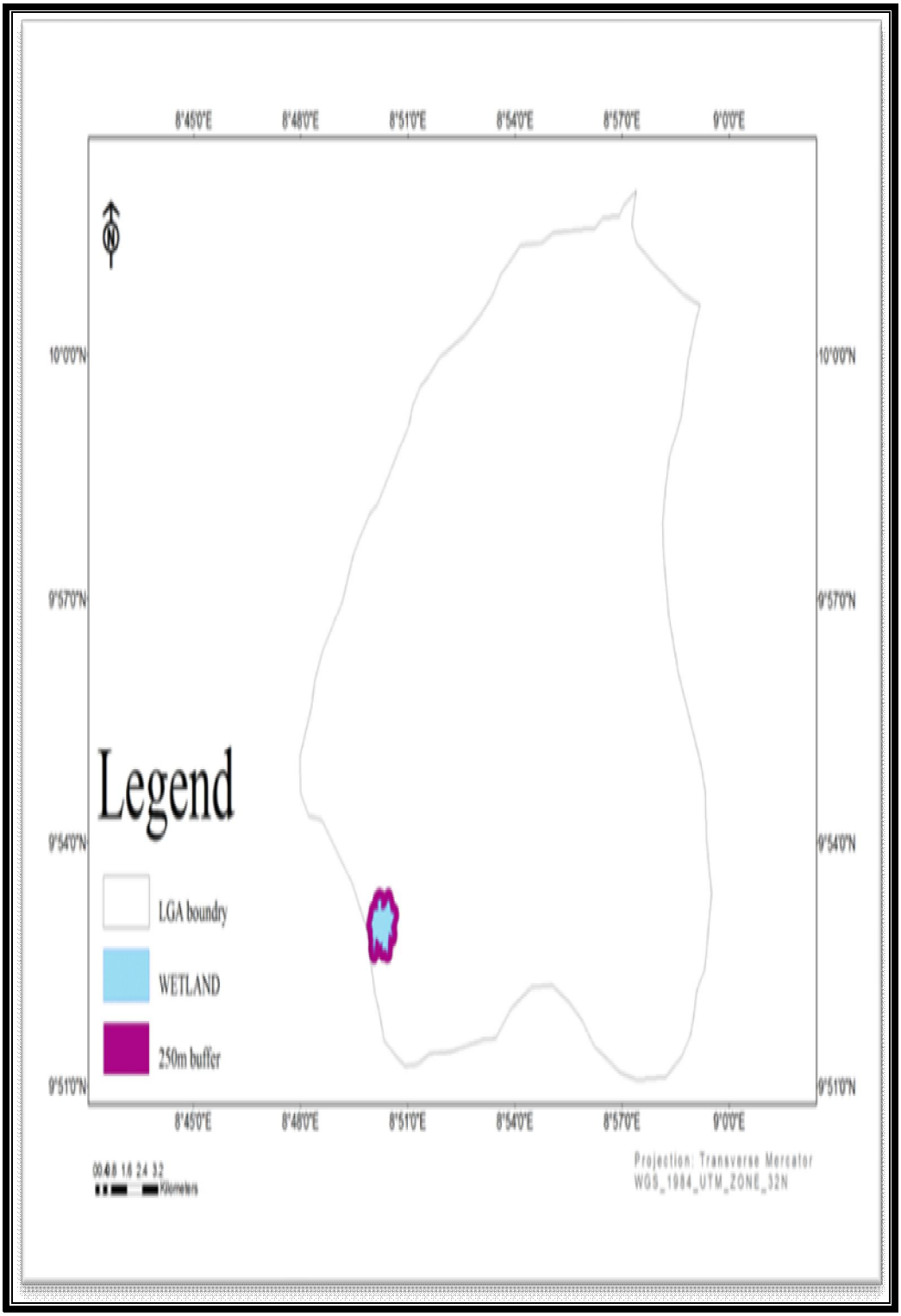


Figure 4.10a, 250m Buffer for Wetland

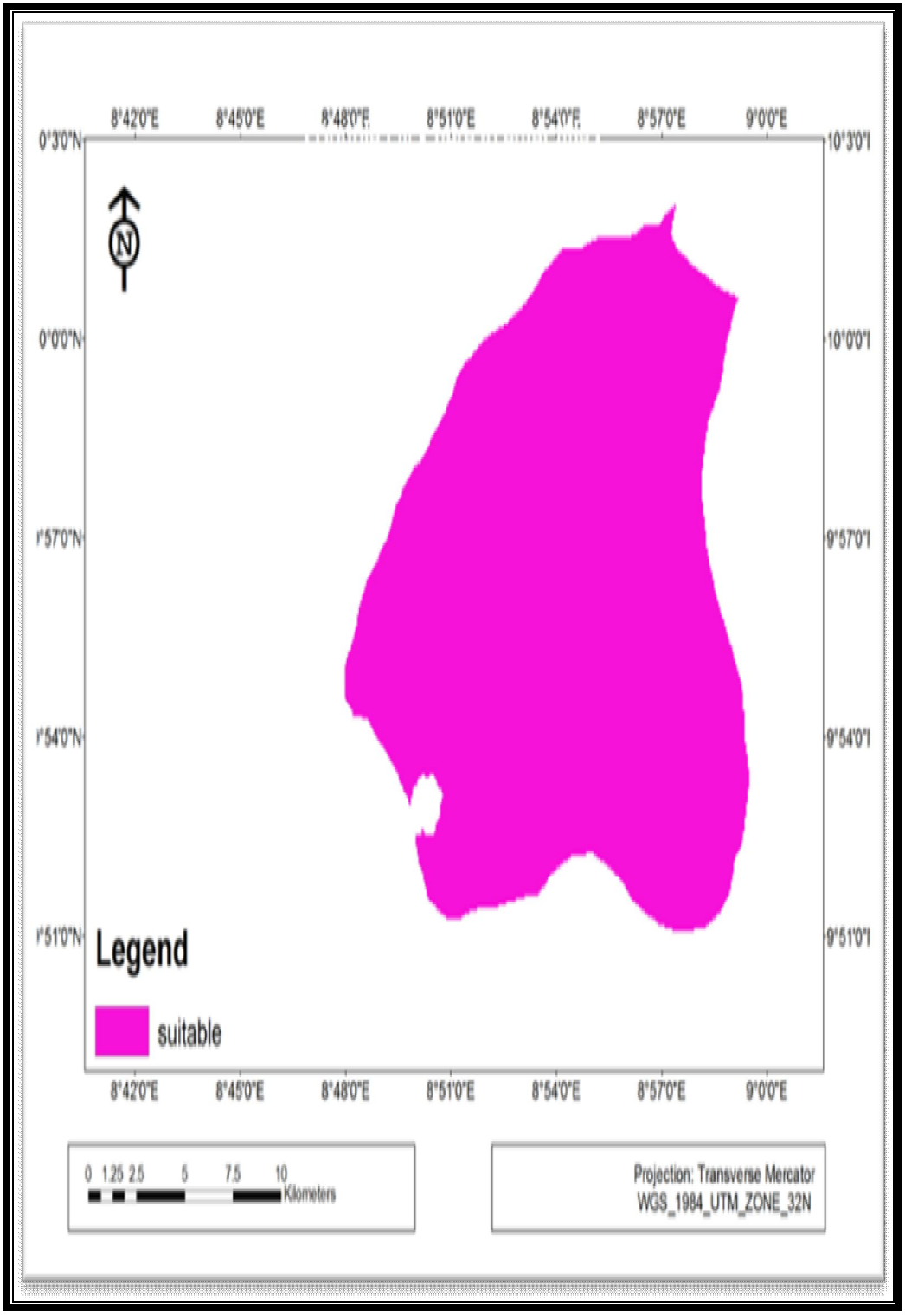


Figure 4.10b, Suitability for Wetland

4.3 Analysis

4.3.1 Introduction

In this Section, after the preparation of all input data (factor maps); the Multicriteria Decision Analyses was used to analyze the data and derive a suitability map for landfill. Before the application of AHP, the areas restricted by rules and physical constraints are excluded from the study area which are assigned 0 during the data preparation stage. The exclusion of certainly unsuitable areas is done by mask Erase operation in Spatial Analysis tool in ArcGIS environment. To prepare a mask of unsuitable areas, all data layers are multiplied by each other so that if any pixel has a value of 0 coming from any layer, then the value of that pixel will become 0 which means that the pixel is completely unsuitable to locate a landfill site. The white areas in the mask are excluded areas. See figure 4.11.

In this study, all input data required for the analyses are generated from four map sources, which are SRTM DETD, geological map, soil map and landuse map. The landuse map was used to derive 7 input data layers such as surface water, wetlands, roads, agriculture, vegetation, bare surface and built-up-areas. The geological and soil map layers were compiled from available maps.

During the preparation of geological map layer of the study area, due to the lack of the coordinate system in the geological maps, the registration process was carried out by using the lithological boundaries, roads, streams and settlement areas with the help of topographical base maps.

During the selection of the landfill siting criteria, the data availability was considered. The political and financial/economical criteria were excluded because these were out of the scope of this study. The ecological value of the flora and fauna could not be

considered due to the lack of data for the study area. The climatic characteristics of the region were determined, however, they are not used as a layer because similar climatic conditions prevail throughout the area. The availability of construction material is not considered as a separate layer, however, during ranking of the lithological units this factor was taken into consideration.

The size of the pixels is selected for all produced maps as 25 by 25 m by rule of thumb and all the input data maps were resampled according to a reference raster which is the Digital Elevation Model.

In this study, the interaction between layers was tried to be kept at minimum. For example, geology has a direct control on topography and soil, but they are used as different layers because geology and topography layers have different impacts on the site selection process. As for soil, 8% of the geology layer is not available, therefore including the soil layer will compliment geology in that regards. In this study, when applying the GIS based AHP, which is an expert dependent method, the weights were directly assigned between 1 and 10.

4.3.2 Implementation of AHP

Analytical Hierarchy Process (AHP), was used to locate the candidate landfill sites. The input layers were produced by ranking method which is the simplest. The method includes ranking of every class in a map under consideration in the order of decision maker's preferences. However, this method can be criticized for the lack of the theoretical foundation.

In the AHP, the first step is that a complex decision problem is decomposed into simpler decision problems to form a decision hierarchy. When developing a hierarchy, the top

level is the ultimate goal which is in this case landfill site selection. After the decomposition stage is completed, cardinal rankings for criteria are determined which is done by pairwise comparisons. Two alternatives and the importance relation between them are considered at a time which provides easier ranking. The comparison matrix developed for 9 criteria is shown in table 4.6. After the comparison matrix is developed, the composite weights are produced by means of a sequence of multiplication.

First, the decision matrix is squared; the row sums are calculated and then normalized. This procedure is continued till the differences between normalized weights of the iterations are reached to a very small value. After the weights for each criterion is obtained, the geoformula operation is used to generate the overall score of the a

4.3.3 Procedures of AHP:

1 developing a pairwise comparison matrix for each criterion (table 4.6)

2 normalizing the resulting matrix (table 4.6)

3 averaging the values in each row to get the corresponding rating (table 4.6)

4 calculating and checking the consistency ratio (table 4.6)

Consistency Ratio (CR) is 0.03, within the acceptance level (0.1); therefore the Pair-wise comparison matrix is adequately satisfactory. The CR as on percentage scale is 1%, meaning that there is 99% confidence that consistency is maximally achieved in the pairwise matrix.

The pairwise comparison matrix and the eigenvector values together with the consistency ratio, were computed using the Goepel, K. D., BPMSG AHP Excel template with multiple inputs,version xx.xx.xx – http://bpmsg.com, Singapore 2013.

After assigning weight to the various criteria accordingly, the weighted overlay tool in the ArcGIS environment was employed to overlay the various criteria to produce the suitability map. It is this output map that provides areas suitable for siting sustainable landfills. See figure 4.11

Table 4.6: Pairwise Comparison Matrix and Order Weights for the Chosen Criteria

Matrix		Landuse	Geology	Soils	Slope	Waterbody	Built-up-area	flooded area	Wetland	Roads	normalized principal Eigenvector	Weights
		1	2	3	4	5	6	7	8	9		
Landuse	1	1	1	1	1	3	3	5	5	5	18.7%	0.187
Geology	2	1	1	1	1	3	3	5	5	5	18.7%	0.187
Soils	3	1	1	1	1	3	3	5	5	5	18.7%	0.187
Slope	4	1	1	1	1	3	3	5	5	5	18.7%	0.187
Waterbody	5	1/3	1/3	1/3	1/3	1	1	1	1	1	7.7%	0.077
Built-up-area	6	1/3	1/3	1/3	1/3	1	1	3	3	3	7.7%	0.077
flooded area	7	1/5	1/5	1/5	1/5	1/3	1/3	1	1	1	3.3%	0.033
Wetland	8	1/5	1/5	1/5	1/5	1/3	1/3	1	1	1	3.3%	0.033
Roads	9	1/5	1/5	1/5	1/5	1/3	1/3	1	1	1	3.3%	0.033
	10	-	-	-	-	-	-	-	-	-	0.0%	1.00

Source: Saaty (1980) Adopted and Modified

Table 4.7: Eigenvector and Consistency Ratio

	Criterion	Comment	Weights	Rank
1	Landuse		18.7%	1
2	Geology		18.7%	1
3	Soils		18.7%	1
4	Slope		18.7%	1
5	Water body		7.7%	5
6	Built-up-area		7.7%	5
7	flooded area		3.3%	7
8	Wetland		3.3%	7
9	Roads		3.3%	7
10			0.0%	

Eigenvalue					lambda:	9.069		
Consistency Ratio	0.37	GCI:	0.03	RI:	1.32	CR:	1.0%	

Table 4.8: Explanation of the intensity Scale

Scale	Degree of Preference
1	Equal importance
3	Moderate importance of one factor over another
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values

Source: (Saaty and Vargas, 1991).

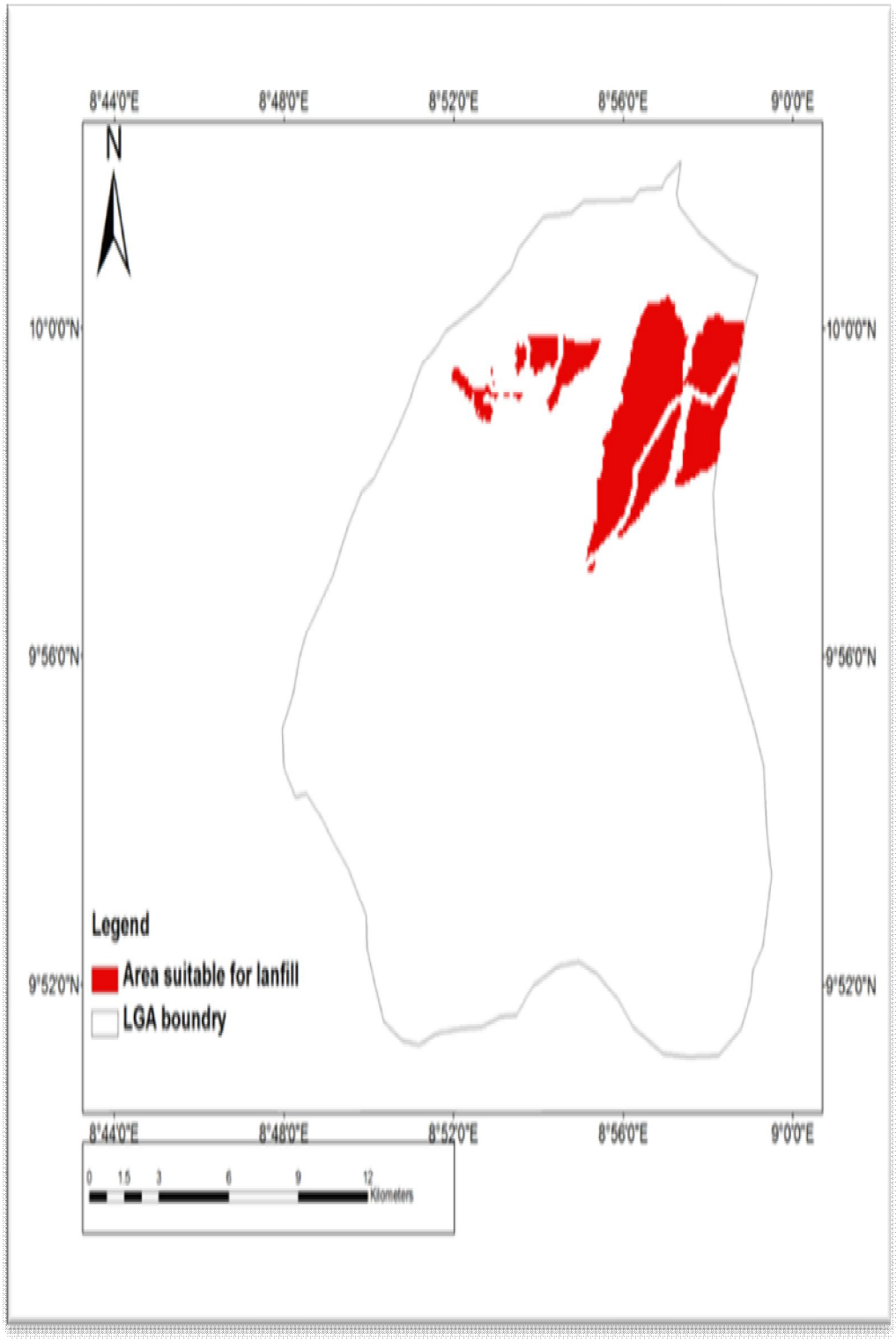


Figure 4.11 Suitability for landfill sites

Landuse, geology, slope and soil were assigned equal weight based on expert advice and previous works by Siddiqui *et al*. (1996), Bagchi (2004) and Babalola & Busu (2010). Each one of these factors is considered to have significant importance in the suitability frame. More to the point, the study aims to fill the gap reserved by Wuyep (2011), which failed to acknowledge the role of hydrogeologic factors in siting landfill. It is behind this reason that this study upholds these factors as most important in determining suitability for landfill siting.

Water body and built-up-area were assigned equal weight as well. Based on Siddiqui *et al.* (1996), Bagchi (2004), and Babalola & Busu (2010) these two factors/criteria were made to be moderately less important than the hydrogeologic criteria (slope and Surface permeability). See table 4.9. Similarly, Flood, wetland and roads were assigned the same weight and considered to have the least preference. Flood could have taken a more sensitive position but because most of the area accounted for as unsuitable by flood is adequately represented by the suitability frame for surface water.

Finally, out of 291km^2, the total landmass of the study area, only 20.8 km^2 is found to be suitable for siting landfill. Nine (9) constraint factors participated in the suitability frame, and it's especially important to note that 27.4% of the study area is covered by rocky outcrop; and such rocky outcrops are responsible for eliminating 80.3km^2 from the suitability frame.

4.4 Field check of suitable sites

In order to confirm the reliability of the results derived from the analysis, field checking was carried out to determine the accuracy and suitability of the available sites. This was achieved by overlying a transparent image of the study area from Google Earth to enable easy identification of features that will serve as guide during the field exercise.

Then, the selected sites were visited and the result of the field check confirms that areas that appeared to be suitable for siting landfill have really avoided the constraint factors. See figure 4.12

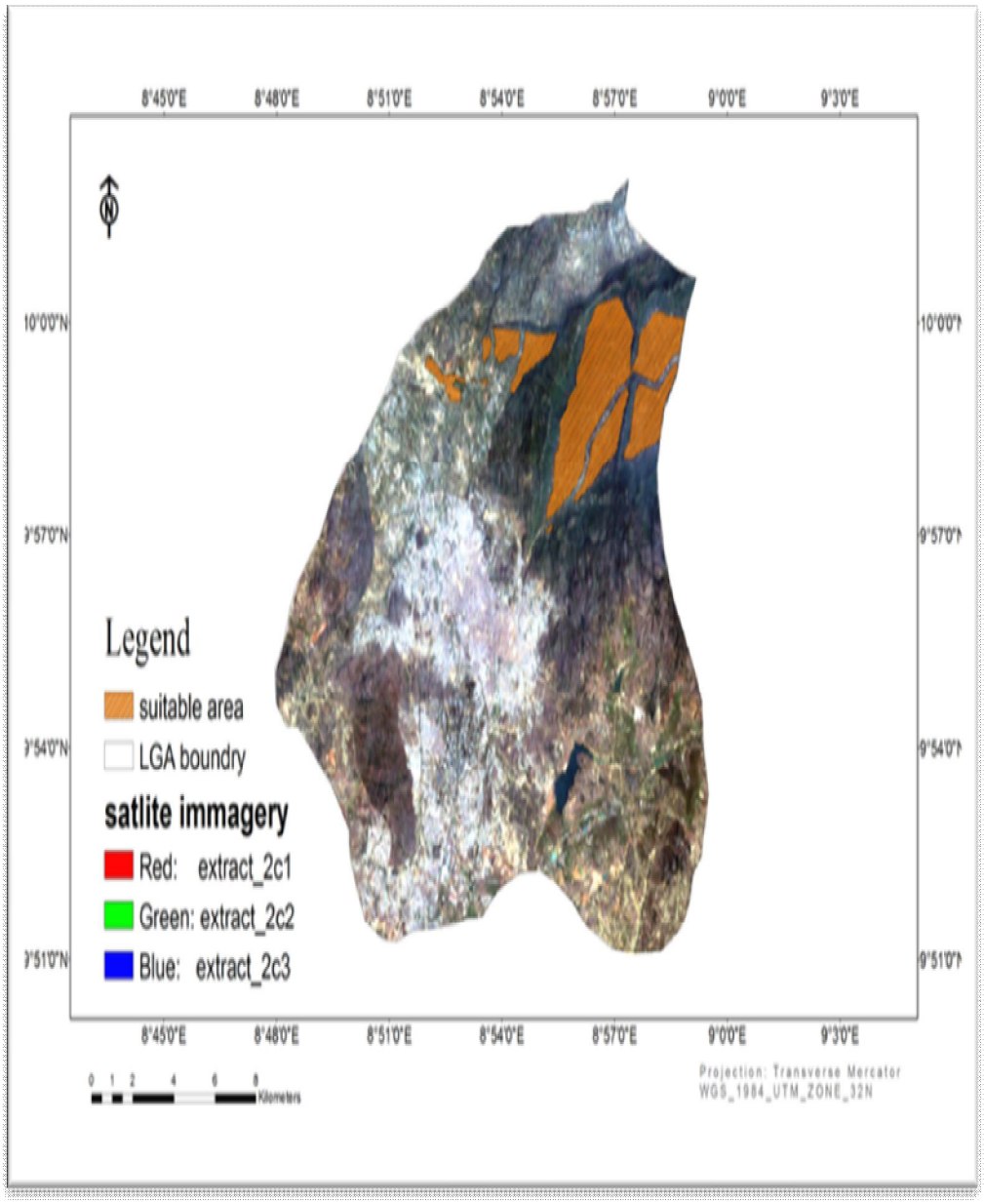


Figure 4.12 a satellite imagery confirming the suitability of landfill sites

During field checks, some interesting results were obtained. It is seen that additional parameters need to be included in the model which have not been thought before the

field work. Some of the parameters were given more credit than they actually deserve. One of the candidate sites is located at the plane surface of a hill top. Although the lithology, altitude and slope are suitable in terms of values, it is not practical to transport the wastes to this site. This shows that the slope layer needs to be defined to avoid such inconsistencies. In addition, some sites determined as suitable in the analysis have bedrock close to the surface, which is not convenient in terms of excavatability. The reason for this is that the geological map and the reports used in this study did not include sufficient data on surficial deposits. Thus, a special purpose geological map is needed, which takes surficial materials, their distributions and thickness into consideration.

It is important to realize that GIS analysis is not a substitute for field analysis; however, it does identify areas that are more suitable and directs efforts to these areas rather than areas that are unsuitable or restricted by regulations or constraints. The use of GIS during the study provides objective zone exclusion based on a set of screening criteria and effective graphical representation. At the end of the analyses, a number of candidate sites are identified. These sites generally satisfy the minimum requirements of the landfill sites. Among these candidate sites “potential landfill” sites are selected through careful field checks. The selection of the final site, however, requires further geotechnical and hydro-geological boring and testing.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary of Major Findings

It is important to acknowledge that this work has adequately satisfied academic demand on the research questions. The work is able to identify six (6) major landuse/landcover classes in Jos-North, as at 2012, with rocky outcrop, identified as a peculiar feature of the study area, covering 27% of the area; thus accounted for as ultimately unsuitable for siting landfill. Slope and surface permeability provide 58% and about 70% suitability respectively. But because other factors are also important and thus have a role to play in the suitability frame, the final suitability map provides for only 7.2% of the study area, equivalent to 20.8km^2 (out of 291km^2) as suitable area for siting landfill.

During the study, it is proved that GIS is a powerful tool in handling large amounts of data and narrowing areas of interest for potential landfill sites.

The map layers related with geology, hydrogeology, and land use are based on available data. Because they are not specifically prepared for landfill site selection purpose, the information provided from these maps were not quite satisfactory. It is understood that rather than general purpose lithological map, the maps showing distribution, thickness, and characteristics of the unconsolidated surficial deposits are more helpful.

5.2 Conclusion

Landfill site selection is a complex procedure which involves evaluating numerous factors like regulations, environmental, socio-cultural, engineering and economic factors. Using GIS for locating landfill sites is an economical and practical way as they have capabilities of producing useful, high quality maps for landfill site selection in a short period of time. The Multicriteria Decision Analysis is also a useful tool in making

landfill siting decisions in the area by supplying consistent ranking and weightings to the potential areas.

In this study, firstly the necessary criteria including regulations and constraints are gathered through literature review. According to data availability, 9 different criteria are defined to select a suitable site for a landfill and prepared as input map layers. A method which integrates both GIS and MCDA was used for the analysis (Analytic Hierarchy Process). The output map is divided into 2 classes: unsuitable and suitable areas. After the production of the final output map, field checks were carried out to ascertain for the real conformity of the candidate sites.

5.3 Recommendations

The slope layer needs to be refined to exclude those areas along the ridges and the hill tops; it is also observed that special purpose engineering geological and hydrogeological maps are required to achieve maximum and reliable protection of the underground water against contamination.

For future studies it is recommended to include excavability and construction material availability layer to the proposed model. It is also recommended that accessibility to suitable sites be given special consideration; thus providing prompt utilisation of the suitable sites.

It is also recommended that for further studies, the areal scope of the study be expanded to include Jos East and Bassa LGA to provide more opportunities for suitable sites.

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Appendix I

Guidance Published in May 1996 by the World Bank as an Urban Infrastructure Note, updated November 2004, identifies conventional criteria for siting landfill.

- Adequate land area and volume to provide sanitary landfill capacity to meet projected needs for at least 10 years. For siting purposes 2-4 hectares for the receiving area and additional 10% land for a landscaped buffer zone.
- Preferably, a site accessible within 30 minutes travel time (a function of road and traffic conditions) is to be sought.
- Accessible from a competent paved public road. To minimize landfill development costs, the requirement for new access road construction generally should be less than 10 km for large landfills serving metropolitan areas and less than 3 km for small landfills serving secondary cities.
- A gently sloped topography, preferably amenable to development of sanitary landfill by the Cell (Bund) method), with slopes which minimize the need for earthmoving to obtain the correct leachate drainage slope of about 20%.
- Groundwater's seasonally high table level (i.e., 10 year high) is at least 1.5 meters below the proposed base of any excavation or site preparation to enable landfill cell development.
- Availability on-site of suitable soil cover material to meet the needs for intermediate (minimum of 30 cm depth) and final cover (minimum of 60 cm depth).
- No private or public drinking, irrigation, or livestock water supply wells within 500 meters down-gradient of the landfill boundaries.
- No environmentally significant wetlands of important biodiversity or reproductive value are present within the potential area of the landfill cell development.
- No significant protected forests are within 500 meters of the landfill cell development area.
- No open areas of high winds, otherwise windblown litter will not be readily manageable
- No underlying limestone, carbonate, fissured or other porous rock formations which would be incompetent as barriers to leachate and gas migration
- No residential development within 250 meters from the perimeter of the proposed landfill cell development.

- No perennial stream within 300 meters down-gradient of the proposed landfill cell development, unless diversion, culverting or channeling is economically and environmentally feasible to protect the stream from potential contamination.

- No siting within 3 km of airport unless the aviation authority has provided written permission stating that it considers the location as not threatening to air safety.

- No siting within a floodplain subject to 10-year floods and, if within areas subject to a 100-year flood, must be amenable to an economic design which would eliminate the potential for washout.

- Avoid siting within 1 km of socio-politically sensitive sites where public acceptance might be unlikely (i.e., memorial sites, churches, schools) and avoid access roads which would pass by such culturally sensitive sites.