Bachelor's Thesis

Geographic Information System (GIS) as a Decision Support Tool for Selecting Potential Landfill Sites

Case study of Nigerian Municipalities

Emeka Amakihe

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Declaration

This work or any part thereof has not previously been submitted in any form to the University or any other body whether for the purpose of assessment or for any other purpose. I confirm that the intellectual content of the work is the result of my own efforts and no other person.

Signature…Emeka Amakihe ………………………

Date …4./05/11……………………………………

Abstract

Author: Emeka Amakihe

Supervisor: Romi Rancken

Title: Geographic Information System (GIS) as a Decision Support Tool for Selecting Potential Landfill Sites

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Summary

One of the growing potential problems of increased consumption is an escalation in the quantities of municipal solid wastes produced. Landfilling is now accepted as the most widely used method for environmentally safe disposal of solid waste. However, appropriate site selection for waste disposal is one of the major problems in waste management. Selection of suitable landfills can be extremely complex mainly due to the fact that the selection process involves many factors, criteria and regulations. In this study, attempts have been made to determine sites that are suitable for landfill siting in the Abuja municipalities and localities of Kaduna and Niger.

Geographical Information System (GIS) based methodology was applied in order to identify and select potential suitable sites. For this purpose, different criteria were examined in relation to landfill site selection. The initial step of the methodology comprises a GIS based operation and analysis that exclude all areas unsuitable for any waste disposal facility. Criteria were mapped using the GIS technique and spatial analytic tools, then different constraint map layers were overlaid to obtain a potential suitability map. The final map produced show areas that are suitable for landfill siting.

Finally, at the end of the analysis and result, an application model that incorporate sustainability in the application stage of landfill planning was developed for municipalities to adopt and follow. The analytical technique and model proposed here will help municipal authorities make the right and sustainable choice on the selection and planning of landfill sites without compromising human health, the environment or future uses of natural resources.

Keywords: Landfill, Geographical Information System (GIS), municipal solid wastes, analysis, suitability, sustainability.

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1 Introduction

Solid waste has become a major consequence of economic growth, development and rapid population growth, yet some of the greatest challenges to its management are most keenly felt in less developed countries of the world (Elizabeth, 1998). Waste has been recognized as one of the major problems confronting governments and city planners in Nigeria, thereby posing a serious threat to environmental quality and human health (Ogwueleka, 2009). In rural or urban areas in Nigeria, the volume of solid waste being generated continues to increase coupled with lack of infrastructure for adequate waste treatment and indiscriminate disposal of waste. Nigeria with a population growth rate of about 2.8% per annum and an urban growth rate of about 5.5 % per annum generates about 0.58 kg solid waste per person per day (Sridhar and Adeoye, 2003 in Babyemi and Dauda 2009).

Waste generation scenario in Nigeria has been of great concern. Of the different categories of wastes being generated, solid wastes had posed a problem beyond the scope of various solid waste management systems in Nigeria (Geoffrey, 2005). Solid wastes are unwanted heterogeneous materials and residue from domestic, commercial, industrial, and agricultural activities (Leton and Omotosho, 2003).

In today's Nigeria, Municipal Solid Waste (MSW) is assigned as anything that lacks utility or substance that the owner either voluntarily or involuntarily relinquishes. This encompasses refuse, garbage, as well as construction and demolition debris (Ossai, 2006). At present, MSW generated in local districts are creating serious environmental problems as a result of the poor state of proper waste disposal and in many of these localities, heaps of MWS have been found along major roads, stream channels, river banks and in open spaces (Ogbonna et al., 2007).

In recognition of these challenges and the increasing waste generation, the Government in Nigeria has attempted to tackle waste management issues through some approach such as consistent evacuation of waste, waste designation collection point, etc.(Ogbonna et al., 2007). But due to the lack of sustainable waste management system policies and techniques such as waste reduction, recycling, thermal treatment, and landfilling etc, the municipal solid waste management system has been inefficient (Ayo and Busu, 2010).

In many developing countries techniques such as waste reduction, recycling and reuse are widely used to manage solid waste. However, there is always residual matter left. The necessity to get rid of these residuals results in using the cheapest waste management option which is landfilling (Allen et al., 2001). And since this approach is economical, it is likely to be the dominant method for waste disposal for a foreseeable future.

Siting of landfills is a major environmental issue when considering that landfills have created various problems such as water contamination, health hazards, and damage to the biophysical environment, etc. (Mokhtar et al.,2008). But due to the continuing increase in waste generation, there will always be a need for new landfill sites every few years, which would eventually lead to more use of land space.

The availability of land for MSW disposal, environmental degradation has resulted in indifference about landfilling as an option for managing MSW, thereby creating difficulty in choosing suitable locations for landfills. Coupled with this issue, landfill sitting is also confronted with planning permits and siting requirements for operation, which could take months or years for approval of construction and operation, thereby leading to a waste management crisis (Allen et al., 2003).

Therefore, the selection of sites suitable for landfill is essential for managing waste sustainably. As a result, the disposal sites must not result in environmental degradation, ecological and social damage (Sener et al., 2010). It is therefore imperative to seek a suitable site that ensures environmental conservation and sustainability. However, the process is complicated and time consuming because it must combine environmental and social parameters.

Geographic Information System (GIS) is a method used for effectively selecting suitable landfill sites.GIS can be utilized in the search for suitable new landfill sites because it allows accurate processing of spatial data from a variety of sources, efficient storage, retrieval, analysis and visualization of information and enabling tailored solutions to be furnished. However, the capability of GIS can be hampered due to digital data availability.

Nowadays, GIS is used widely in many resource application areas. In landfill siting, Geographic Information System (GIS) can be used as a tool to aid the decision-making process. It can process large amounts of data in a short time and also help in storing the links between environmental issues and the elements and potential impact of the proposed project, thereby reducing time and resources spent in the screening and scoping process of landfill sitting (Mokhtar et al., 2008). In this study, landfill sitting has been carried out using GIS. The districts of Abuja (Federal capital territory) and the fringes of Niger and Kaduna are used as the case study area.

1.1 Statement of problem

In the early days of GIS, not much emphasize was put upon how users interact with GIS but only on collecting and presenting geographical data. But today, the use of geographical data is beginning to focus on how users interact with this data, thereby enabling tailored solutions for a whole series of applications. In today’s society, the selection of suitable landfill sites that combine social, economic and environmental factors for locating waste dump sites has been recognized as a major problem in planning and construction (Basak et al., 2005).

Over the last decade, many developing localities in Nigeria have grappled with the challenge of managing its solid waste as a result of increase in waste generation and improper disposal sites. MSW disposal in exterior localities of Abuja is still developing while the localities in Northern states are inefficient (Ayo and Busu, 2011). Due to this, solid waste disposal is of particular concern with indiscriminate dumping along roads, river banks and any open spaces (Ogbonna et al., 2007). Therefore, the siting of landfills has become a necessary issue for waste management in growing and developing areas of these states.

This project was therefore motivated by the need to find potential suitable landfill sites that would ensure that collected MSW are properly disposed of designated areas with the idea of incorporating sustainability into the project during the planning stage in order to reduce footprint of land area.

1.2 Aim

The purpose of this study is to use Geographic Information Systems (GIS) as a tool to aid the decision-making process in finding potential suitable sites for MSW disposal and probably propose an application model with the idea of sustainability.

1.3 Objectives

The objectives for the project are as follows:

- *To identify important criteria for locating a landfill site.* It is important to incorporate relevant criteria from environmental, social and spatial parameters in order to locate potential sites.
- *To identify possible suitable locations for a landfill site.*GIS would be utilized in the search for potential suitable landfill sites.

1.4 The Scope

Only data sets that are crucial for finding suitable sites are considered. The selected data sets cover environmental, social and demographic status. The project study area is restricted to districts of Abuja and fringes Niger and Kaduna State. Data was sourced from Nigeria and relevant international organizations.

1.5 Study Area

The study area consists of districts in parts of Abuja and fringes of Niger and Kaduna state. Abuja is the seat of Federal Capital Territory (FCT), Nigeria. It has an estimated land area of about 8 000 square kilometers. Abuja experiences two local climates (rainy and dry seasons) and temperature ranges from 19 o C to 37oC. With an estimated population of 590,400 (2006 census), waste generation is estimated at 60,338,880 kg/year (66,512 tons per year). The study area covers the part of the local government of Abuja and fringe parts of Niger state and Kaduna (see figure 1).

1.6 Significance of the study

The study will provide GIS techniques for the selection of suitable sites for the disposal of municipal solid wastes with a minimum or no risk for the environment. It is anticipated that the findings from this study will be a significant basis for application in other municipalities, this leading to environmental sustainability in MSW management.

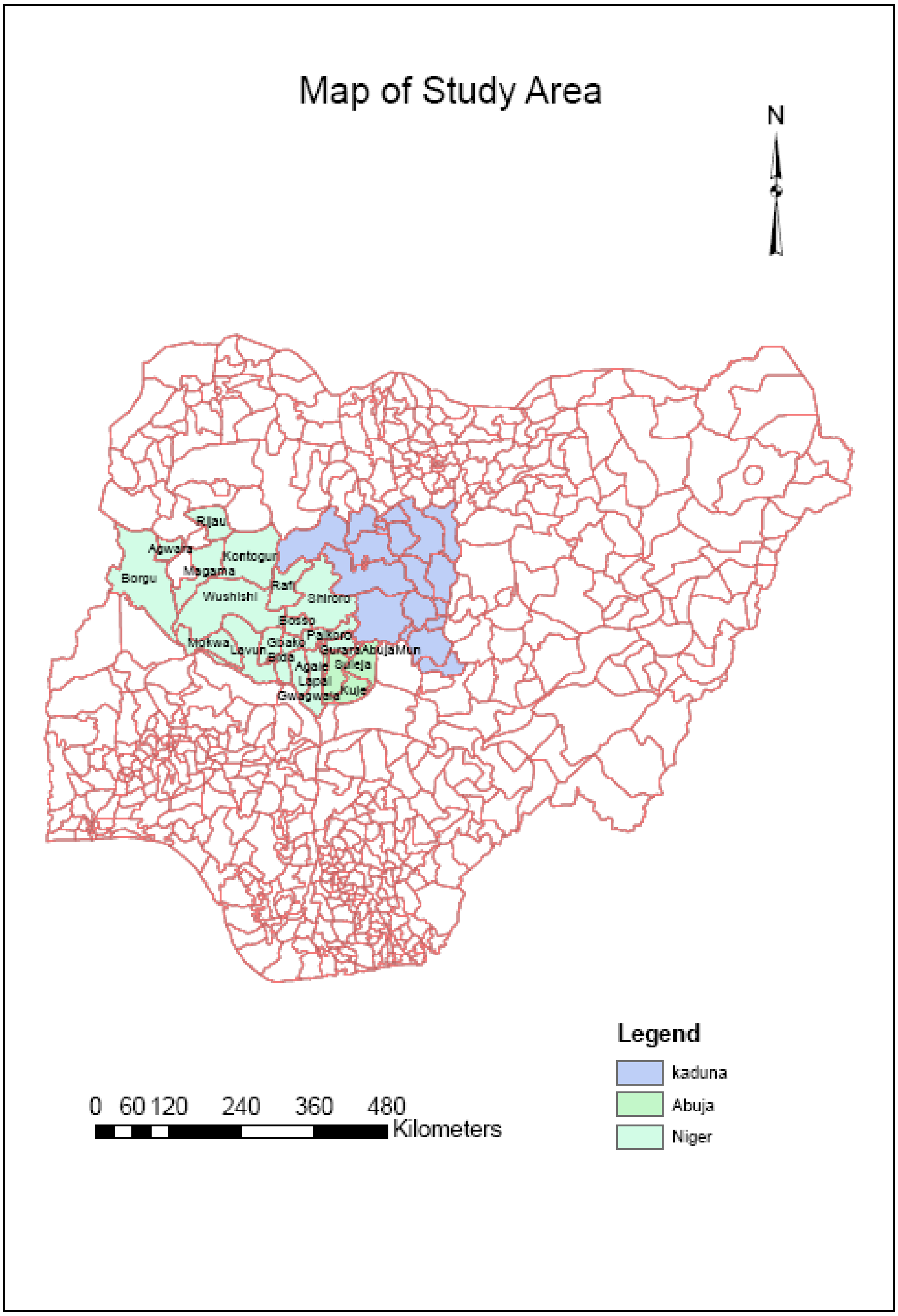

Figure 1. Map of Study Area

2 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. This difficulty has led to a strict definition to ensure proper handling and disposal of waste types in accordance with laws and regulation. (Hawkins and 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 (Adewole, 2009). According to their 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 the Department of Environment (DoE, 1994; Hawkins and 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 and Shaw, 2006).

2.1 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. (Sasikumar and Krishna, 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 and Uriarte, 2008). Solid waste generation has been of great concern in developing localities of Nigeria and of the different types of waste, solid waste has been difficult to manage. 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 (Babayemi and Dauda, 2009).

2.2 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. 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 (Sasikumar and Krishna,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 (Agunwamba, 1998).

2.3 Classification of municipal waste management

MSW is classified as hazardous and non-hazardous. ‘‘Hazardous waste is any waste, excluding domestic and radioactive wastes, which, because of the physical, chemical or infectious characteristics, can cause significant hazards to human health or the environment when improperly treated, stored, transported or disposed of” (WHO, 1987).

It is generated during activities by society. It poses potential health hazards to human and the environment. Examples include waste tarry residue arising from refining, and distillation. Non-hazardous waste consists of biodegradable and non-biodegradable waste that are not toxic, corrosive or reactive (Sasikumar and Krishna, 2009).

2.4 Municipal waste generation

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.

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 and Uriate, 2008). In Nigeria, the accelerated growth of population, increasing economic activities and change in consumption behavior has resulted in a quantum jump in solid waste generation. The waste generation rates ranged from 0.44 to 0.66 kg/capita/day (Ogwueleka, 2009). In Nigeria 25 million tonnes of municipal solid waste are generated annually (Ogwueleka, 2009). Table 1 shows the waste generation rates in some areas in Nigeria and the various agencies that are responsible for the state.

Table 2.Typical Waste Generation in Some Cities in Nigeria

City	Population	Agency	Tonnage per month	Density (kg/m3)	Kg/capit a/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	o.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
Markurdi	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	!4, 785	280	0.66

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

2.5 Waste composition

MSW consists of different category and types of material. The level of income largely determines the content of material in the waste composition, e.g. high income countries consume more of packaged products, which results to higher percentage of combustible materials and more inorganic material in their waste such as textile, plastics, etc, while low income areas have a higher percentage of materials suitable for compositing e.g.putrescible (Filemon and Uriate, 2008). Also the composition of waste varies depending on the source, life style, climate, market size for waste material, population size, reuse and reduction policy and effectiveness of recycling.

In Nigeria, the composition and characteristics of solid waste include paper, vegetable matter, plastics, metals, textile, rubber and glass. Table 2.1 shows the stream of solid waste composition in Nigeria. This table shows that wastes in Nigerian landfills are commingled.

Table 1.1.Typical Compositions of Municipal Solid Waste in Nigeria

Waste category in %							
Cateogry	Nsukka β	Lagos µ	Markudi ±	Kano µ	Onitsha ¥	Ibadan α	Maiduguri#
Putrescibe	56	56	52.2	43	30.7	76	25.8
plastics	8.4	4	8.2	4	9.2	4	18.1
paper	13.1	14	12.3	17	23.1	6.1	7.5
textile	3.1	-	2.5	7	6.2	1.4	3.9
metal	6.8	4	7.1	5	6.2	2.5	9.1
glass	2.5	3	3.6	2	9.2	0.6	4.3
others	9.4	19	14.0	22	15.4	8.9	31.3

Others = dust, ash, ceramics, rubber, soil, bones

Source: (α Diaz and Golueke ,1985, in Ogwueleka,2009) , (β Ogwueleka,2003, in Ogwueleka,2009) , (± Ogwueleka 2006, in Ogwueleka,2009), (¥ Agunwamba et al 1998, in Ogwueleka,2009), (µ Cointreau, 1982, in Ogwueleka,2009), (# Dauda and Osita 2003, in Ogwueleka,2009)

2.6 Waste handling practices

2.6.1 Waste reuse

In many of the developing municipalities in Africa, such as Abuja, the rate of reuse of waste is high due to the fact many households save and reuse materials such as plastic bags, bottles, paper for domestic purposes until it is no longer fit for reuse.

Some households sell this material in exchange for money or material contents. These wastes are then transferred to recycling industries or depots for recoverable domestic material or other things. In addition, there are also waste pickers that shred, clean, and reknit waste material for resale (AFDB, 2002).

2.6.2 Waste recovery and recycling

Recycling is an important factor in helping to reduce the demand for resources. In many of the African countries, waste recycling is often used to supplement income or when non-waste resources are unaffordable. Materials (empty bottles, plastic containers etc) from domestic use are kept away from the waste of the household, while commercial and industrial wastes, such as metal, glass, and paper, are recycled by industrial sectors (UNIDO, 2009).

Recovery and recycling of waste practices is used for conserving finite resources and reducing the amount of waste require disposal by landfilling. Despite these benefits, many of the African cities still have poor institutional framework for waste recycling, reuse and recovery. As a result waste management problems still prevail in these cities (AFDB, 2002).

2.6.3 Waste collection and waste transfer

Waste management infrastructure is largely non-existent in many cities in Sub Sahara Africa. Of concern is the poor state of infrastructure, constraints and inadequate waste management facilities for various waste streams. Currently, the MSW management situation is characterized by these concerns and has resulted in refuse being dumped in any open space. Only about 40 to 50% of waste is reportedly being collected (UNIDO, 2009). At present in Nigeria, waste collection and transportation is limited by inadequate equipment, personnel and financial resources

Across many cities, where collection service is limited, it is largely performed by non-mechanical means, which is often carried out by individuals and the community. However, the recent implementation of public private partnership in refuse clearing, collection and its disposal at designated landfill is gradually improving the efficiency of MSW, thereby resulting in affordable waste collection and disposal service (AFDB, 2002).

Finally, across the cities transfer stations are not common with regard to MSW management rather the collection vehicle goes directly from their pickup points to the disposal site.

2.6.4 Composting

Composting is a purposeful recycling or conversion of organic biodegradable waste materials. Basically, it considerably reduces the volume of wastes to be transported to sites designated for disposal, and increases the recovery rate of recyclable materials.

Across many African cities, the waste transported to a composting facility is with mixed municipal waste, which consists of plastics, glass, metals, and other household materials, instead of waste consisting primarily of organic matter. This has resulted in mechanical breakdowns and end products of poor quality. And at present, many composting facilities have failed as result of technical, financial, and institutional problems (AFDB, 2002). In most municipalities throughout Africa such as Abuja, small-scale composting practices are being promoted by NGOs and community based organizations. The compost produced is largely for self-consumption or for sale to households.

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).

2.8 Municipal Solid Waste Management in Sub-Saharan Africa (SSA)

In many of the municipalities of 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. 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.

2.9 Municipal 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. 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.

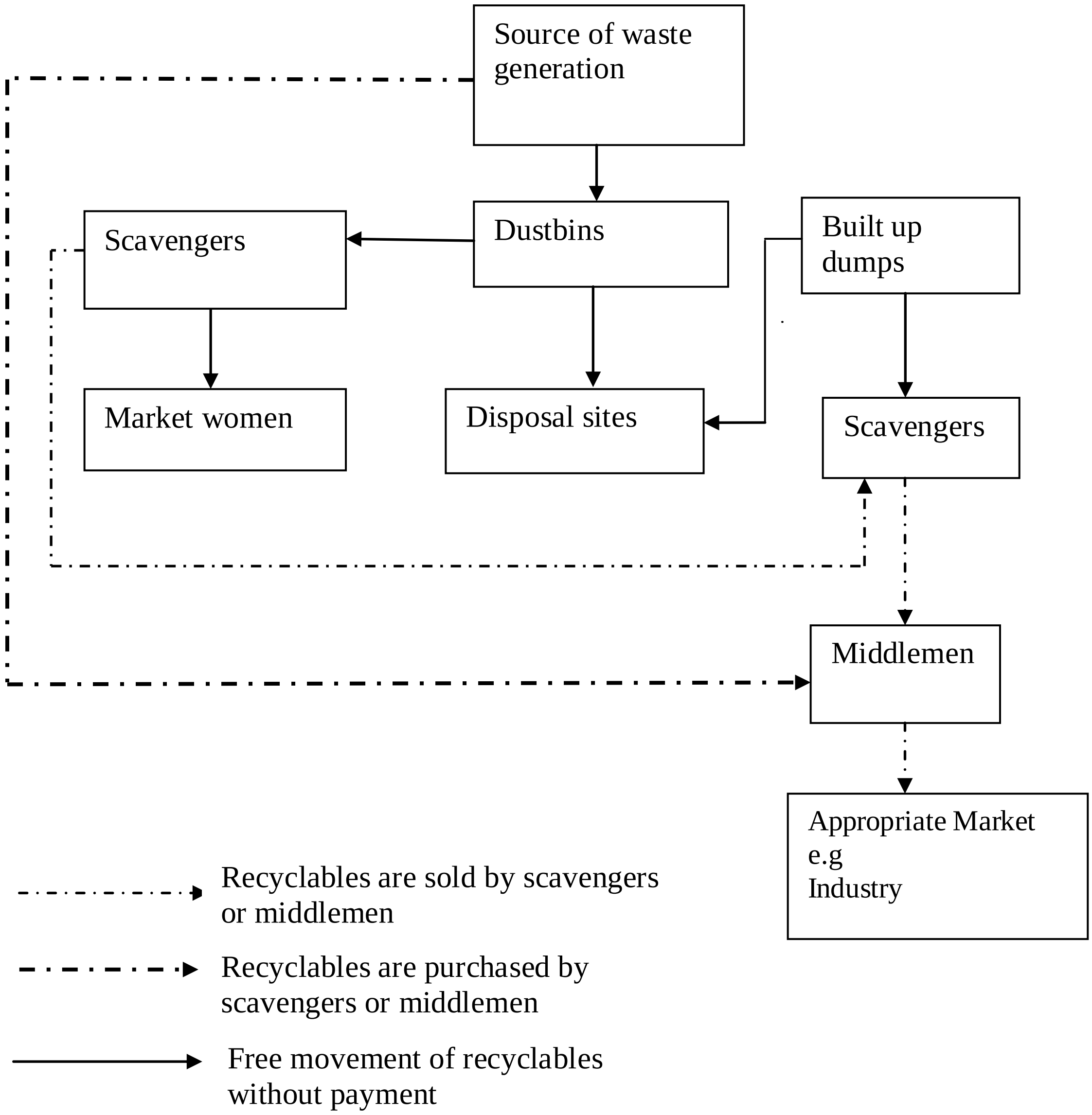

Figure 2.Illustration of informal sector activities in MSW management in Nigeria. (Agunwamba, 2003)

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.The specific roles of FEPA regarding solid waste management in Nigeria are:

- Study the most reliable systems that are appropriate for local, domestic and industrial Wastes.

- Specify waste disposal and treatment methods that take into consideration the geological and environmental setting and encourage recycling.
- Specify waste disposal sites that guarantee the safety of surface and underground water systems.
- Set up and enforce standards for adequate sanitary facilities for the disposal of human and other solid wastes in dwellings, housing estates and public facilities in both urban and rural areas.
- Establish monitoring programs including periodic surveillance of approved waste disposal sites and their surroundings and waste water systems.
- Establish monitoring stations for the control of the disposal of leachate from landfills into surface and groundwater systems. (Onibokun, 1999; Imam et al, 2007, in CPE,2010).

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.

2.10 Municipal solid waste management in Abuja

The Abuja Environmental Protection Board (AEPB) oversees the responsibility for the utilization and management process with regard to the solid waste stream. This involves public and private partnership in order to ensure different components of the management structure are functioning according to set objectives in terms of collection, recycling, transfer and waste disposal, etc. The board was established with the following aim and objectives for solid waste management (source: AEPB):

- Procurement and Distribution of Waste Receptacles to Tenement, Government Agencies etc.
- Prompt and efficient refuse collection, storage and disposal at least twice a week.
- Effective management of waste transfer stations [WTS] for separation of waste.
- Landfill site to secure the environment for present and future generations of FCT residents.
- Management of special waste [Hospital and Hazardous waste].
- Street Cleaning and Litter Control on a daily basis.

Ensuring that municipal solid waste management is managed properly is the main thrust of the board. Consequently, this will ensure effective waste management and culture of orderliness, cleanliness, and care of residents.

In Abuja, solid wastes are collected at household level and it is stored in plastic receptacles or bin bags. However, poor households residing in the informal settlements at the outer fringes use any available containers. At present there is no material recovery facility in Abuja, but material re-use and recycling activities are carried out by the households (Akoni 2007, in Ezeah 2009). It begins with the re-use of plastics, bottles, paper for domestic purposes until it is no longer usable. The non recoverable waste is disposed at solid waste dump sites.

Equipment used for waste collection, transfer and disposal includes side loaders, open tippers, pay loaders, etc. Primarily, wastes are collected from stationary containers placed within 500- 800 m apart (Ogwueleka, 2009). This method requires the delivery of waste by the residents to a storage container. Afterwards, it is collected and taken by collection vehicles directly to the disposal site. This process is driven by both private companies and government agencies.

2.10.1 Landfilling

Landfill is a system for solid waste disposal onto or into land, taking social, economic and environmental matters into account (Brandrup.1966). There are two extremes in waste disposal – crude or open dumping and sanitary landfilling, but there are also intermediate dumping which is referred to controlled dumping and engineered landfilling.

Landfilling includes monitoring of the incoming waste stream, placement and the compaction of waste, and installation of landfill environmental monitoring as well as control facilities. In developing countries, the implementation of improved land disposal practices is gradually progressing. At present, the accelerated population growth and the need to ensure environmental sustainability are forcing municipalities to plan towards better waste disposal practices. This implementation is largely dependent on the available resources and institutional framework for regulating solid waste management (Kreith and Tchobanoglous, 2002). Of concern is the location of landfill, considering that closeness of site to residential, river, water channel or other fragile ecosystem could lead to adverse environmental pollution and degradation as well as health hazards.

2.10.2 Open dumping

Open dumping is the disposal of solid waste at any location other than a facility permitted by the regulatory body. Although it is the most common disposal method in many countries it causes many problems that are detrimental to humans and the environment. For example, in most Nigerian cities, open dumping and open burning have been practised. And many of these open refuse dumps have consistently been emitting smoke due to fires set on them with the result that the environment is polluted and the leachate flows into streams and groundwater resources, contaminating water supplies (Mba 2004; UN-HABITAT, 2010).

2.10.3 Controlled dumping

No dump can be regarded as controlled unless it is run according to rules and regulation laid down by the relevant authority. It involves adequate sealing of the refuse with inert material. The first step in controlling a dumpsite is to stop burning the refuse on the site. The next step might be to improve access to the site by developing or upgrading the site roads and subsequently use inert materials to cover the waste in order to stem water population and other effects (AvCharles and Dixson 1981; UN-HABITAT, 2010).

2.10.4 Sanitary landfilling

"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" (Mba ,2004). In many developing countries such as Nigeria, open or controlled dumping is largely used as the disposal method. The benefit of sanitary landfill over the other approaches or methods cannot be overemphasized because it is pollution-free and prevents water infiltration. Thus it eliminates any health or environmental risk that may result from solid waste disposal.

Siting a sanitary or ordinary landfill requires an evaluation process in order to identify a potential suitable location. This location must comply with stipulated environmental regulations, and at the same time it must minimize economic and social costs (Mba, 2004; UN-HABITAT, 2010).

2. 11 Abuja waste disposal sites

With an estimated population of 590,400 (2006 census), waste generation is about 60,338,880 kg/year (66,512 tons per year) in Abuja (CPE, 2010). However, not all the wastes generated in the municipalities are disposed of at the dumpsites. According to CPE, 2010, it can be assumed that about 49,219 tons of wastes are disposed of at dumpsites yearly (CPE, 2010).

As regards waste disposal in the FCT, the AEPB currently has two landfill sites one in Gosa, and the other in Ajata, while the disposal site ,at Mpape and Karu have been closed because they are filled up (Daily trust, 2010).

2.11.1 Mpape dumpsite

The Mpape dumpsite is owned and operated by Abuja Environmental Protection Board (AEPB).It has an approximate area of 16 hectares and waste depth from 15 to 30 meters. The operation and usage of the site started in 1989 and it lasted for a period of 17 years before it was closed. Mpape dumpsite is the only site with intermediate cover soil over the waste. Still the dumpsite had regular problems with leachate being generated during rainy seasons (CPE, 2010).

2.11.2 Gosa sites

The Gosa dumpsite is owned and operated by Abuja Environmental Protection Board (AEPB).It has an approximate area of 90 hectares. The operation and usage of the site started in 2005 and is still open till date. It is the largest dump site for municipal solid wastes in Abuja (See appendix 1 for the estimated total waste tonnage information for all the sites in the FCT from 1998 to 2007). At present, AEPB is planning to upgrade the site into sanitary land filling (CPE, 2010).

2.12 Conceptual background of geographic information systems (GIS)

2.12.1 Geographic Information System (GIS)

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 (Fazal, 2008).

2.12.2 Geographic Information System: A Definition

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). Some selected definition of GIS is given in Table 2.2

Table2.2.Definition of GIS

Definitions of GIS
Aronoff (1989).Any manual or computer based set of procedures used to store and manipulate geographically referenced data
Parker (1988).An information technology which stores, analyses and displays both spatial and non-spatial data
Star and Estes (1990).An information system that is designed to work with data referenced by spatial or geographic coordinates
Burrough (1986).A powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world.
Devine and field (1986).A form of MIS (Management Information System) that allows map display of the general information

Source: Maguire, 1991)

2.12.3 GIS capabilities

The main purpose of a geographic information system is to process spatial information, which is then designed for data mapping, management and analysis. Moreover, it can be used to assist decision-making process. The processing functions consist of three functional areas: computer mapping, spatial database management and cartographic modeling. And with these functions, tremendous volumes of data are handled. The strength and power of GIS lie in:

- ability to integrate large spatial information and display the output
- manipulate data and present them in digital form
- ability to connect all activities to spatial entity, and
- allow for access to administrative data.

In GIS, the spatial element is seen as more important than the aspatial element and this is one of the key features which differentiate GIS from other information systems (Michael, 1993). And according to Galati, (2006), and Cromley and Mclafferty (2002), there are basic approaches to separating GIS from other types of information see Table 2.3, while Table 2.4 shows basic questions GIS can answer.

Table 2.3.Basic approaches of GIS

GIS Basic Approach	**Description**	**Example of Analytical Function**
Process	A system of handling information with advanced capabilities for storage, retrieval ,manipulation, and display of spatially referenced data	Spatial query Mapping
Application	Addresses problems based on information	Overlay, buffering and others.
Toolbox	Emphasizes the generic aspects of GIS which deals set of tools for performing spatial analytical functions	Network analysis
Database	Emphasizes referenced geographic features	Point in polygon

Table 2.4.Questions a GIS can answer

GIS Basic Questions	**Description**	**MSW Application**
Location	What is at?	Finding landfill site
Condition	Where does it exist?	Geographic characteristics
Trend	What has changed?	Land use change and others
Pattern	What patterns exist?	Patterns of environmental implications
Modeling	What if?	Depend on many criteria

(Source: Rhind 1990, in Maguire 1991)

2.13 Use 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.

GIS can add value to waste management applications by providing outputs for decision support and analysis of waste management databases (Singh, 2009).

2.13.1 Landfill site selection

One of the most critical needs that GIS can serve in solid waste management is siting landfills. With increasing land use pressure and impacts of landfill on the environment, finding potential sites for landfills can be complex and time consuming. Before the advent and widespread application of GIS in waste management, such as landfill siting, a special committee of professionals that consist of municipal planners, environmentalists, developers, public and other municipal board officials were mandated to investigate and find potential sites suitable for waste disposal. Many a time, the work has been cumbersome and time consuming due to conflict of needs within the large committee of legislated mandates. As a result, the outcome of the task may not be accepted by key groups in the approval process, thereby resulting in waste of money and time in investigating suitable sites for waste disposal.

With the application of GIS, the task of finding potential sites can be done efficiently and effectively. It also reduces time and costs and improves timelines of information. In locating a disposal facility, the process of selecting a site for landfill entails three major issues: data collection, criteria for location of disposal facility, and public participation.

In general, GIS is ideal for preliminary site selection because it can manage large volumes of spatially distributed data from a variety of sources, store, retrieve, analyze and display information for decision making. Therefore, the major goal of landfill site selection is to ensure that a disposal facility is located at a potential site with minimal environmental and social impact (Bagchi, 2004 ; Vasilios, 2004).

2.14 Criteria for landfill siting

2.14.1 Land use

Land use criteria are important in minimizing the conflicts associated with land use and site selection, it is useful delineating areas with zoning restrictions. For example, there may be restrictions on the use of agricultural land or proximity of landfills to protected area. These land use criteria are used to delineate possible sites that satisfy proximity and zoning criteria (Bagchi, 2004; Vasilios, 2004)

2.14.2 Distance to built area and restricted area

A new landfill should not be located within a distance of a housing area because of health effects associated with landfill. A safe distance necessary to locate a landfill site should be determined to prevent pollution and contamination hazards (Bagchi, 2004; Vasilios, 2004).

2.14.3 Proximity to water sources (river and water body)

The landfill site should not be placed within water resources areas in order to protect it from contamination .A safe distance should be maintained from all water sources such as surface water bodies, channels and rivers. A minimum distance between existing sources and a proposed site may be specified by the regulatory agency (Bagchi, 2004; Vasilios, 2004).

2.14.4 Infrastructural provisions

The location of the landfill must not interfere with existing infrastructural systems such as cables, underground pipeline or existing plans for drainage. Adequate consideration in terms of distance must be identified in order to minimize effects of landfill on existing infrastructure (Bagchi, 2004; Vasilios, 2004).

2.14.5 Proximity to existing road network

The landfill should be close to the existing road network for accessibility and cost related issues in transporting the waste from generation or transfer station to the site. Because of this, proximity of road network is an important factor in locating a landfill site (Bagchi, 2004 ; Vasilios, 2004).

2.14.6 Slope

It may be desirable to have a topographic surface that indicates the gradient of the area. Siting landfills on a less steep surface would reduce cost of locating the disposal facility. (Bagchi, 2004 ; Vasilios, 2004).

2.15.7 Soil

Soil spatial and attribute information is required for evaluating protective functions of soil layers for many environmental modeling and applications. For instance, soil information is useful in designing and implementing a landfill. It helps in determining the soil amendment needs and leaching requirements for sites suitable for landfill (Bagchi, 2004 ; Vasilios, 2004).

2.16 Sustainability Concept

‘‘Sustainability is a vision of the future that provides us with a road map and helps us focus our attention on a set of values and ethical and moral principles by which to guide our actions’’(definition by Viederman in Avnolberto, 2006). It is a process that involves people, institutions, natural resources, and the environment. Therefore, we must protect, maintain and preserve the environment and natural resources for future generations. This raises a question on how much resources we need to utilize for livelihood. Thus, the measure relates to the carrying capacity or footprint of our activities.

According to Wackernagel and Rees (1996), in Avnolberto, 2006: Carrying capacity or ecological footprint entails the ‘‘land area necessary to sustain current levels of resource consumption and waste discharge by a given population’’. Since the carrying capacity of the planet is limited, the idea of sustainability should be taken into account when using land area for waste disposal. We do not need to be futurologists to understand that in future we will not have as much suitable land as we have today (Avnolberto, 2006).

Thus, society needs to reduce its consumption of everything: water, land, etc. In general, we need to erase the idea of wasteful usage of natural resources in our activities. For example, large areas are acquired for dumping sites in Nigeria, which might never be used for the waste. Taking into account that there are a limited number of suitable sites available to manage our waste, we ought to reduce our footprint in order to ensure that the next generation would be able to cope with their needs with regard to waste disposal and management issues.

3 Methodology

3.1 Introduction

The primary objective of a site selection process is to assure that potential sites selected are suitable with regard to protection of public health and the environment. Application of GIS in landfill siting methodology is a relatively simple technique that is based on the overlaying of datasets and areas that satisfy certain suitability criteria. In this study, the GIS-based landfill site selection approach combines the spatial analysis tools provided by GIS to integrate and evaluate different datasets based on certain evaluation criteria in order to determine potential landfill sites.

The project relied on the existing spatial data of the study area. Data were extracted from land use maps, cadastral maps, and satellite imagery maps of the study area. The digitized datasets were interpolated with Arc GIS (Software) to generate operation of different dataset layers .The entity-relationship model was adopted for the conceptual design of the database and attribute data. Afterwards spatial analysis was carried out to identify potential sites. A final composite map was then produced, which presents all areas suitable for waste land filling.

3.2 Source of data

Both spatial and aspatial data were sourced from government and private agencies and the FAO Geoportal. Analogue maps of the study area were obtained from the Abuja municipalities planning office. The available data gathered for this project were:

- Administrative boundaries
- Road datasets
- River datasets
- Water body datasets
- Built up area datasets consist of housing, services, protected area

- Infrastructure datasets
- Social amenities datasets
- Population data published by National population Commission, Nigeria
- Solid waste data from published article
- Soil datasets and map from FAO Geoportal

3.3 Data Acquisition

Data acquisition is the process or method of acquiring the data required for the study area. It involves both geometric and attributes data. The data acquisition represents elementary properties of entities and relationships. Comprehensive information was collected and produced in a digital format.

3.4 Database design

Database design, also known as data modeling, is the process of defining features with the attributes and relationships, and their internal representations. In database design there is a need to organize a series of data themes that can be integrated using geographic location. Therefore, it makes sense that geodatabase design begins by identifying the data themes used for an application or group of application (Glenn et al, 1993).

The arrangements of entities into data layers mark the beginning of the database design and creation. The database design and creation passes through the following phases:

- Reality
- View of reality
- Conceptual design
- Logical design
- Physical design

- Database creation

The application of GIS in landfill site selection was subjected to the phases below as shown in figure 3

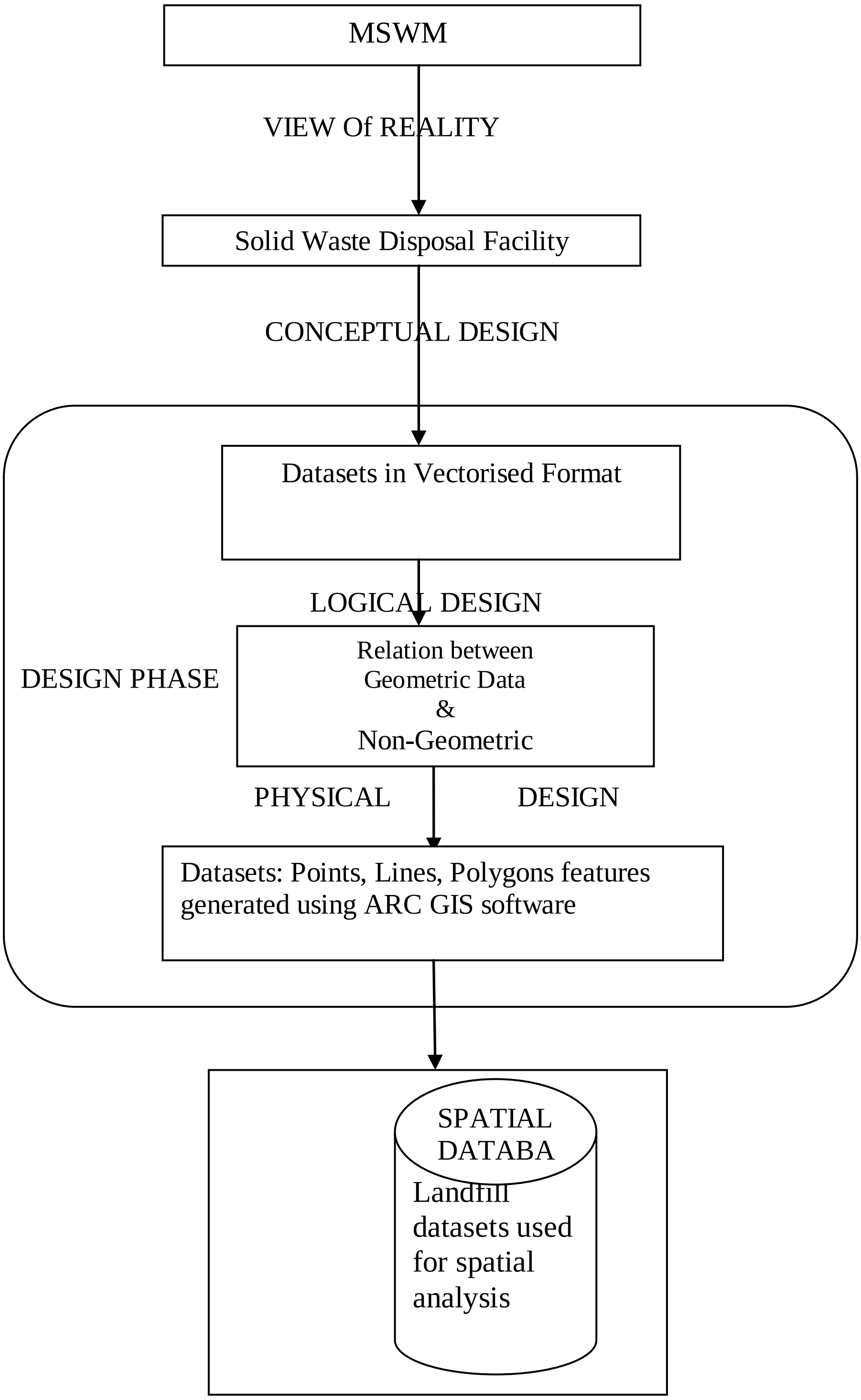

Figure 3.Design and construction phase of a spatial database for solid waste Disposal facility (Modified after Kufoniyi 1997, in Ogunbodede, 2007)

3.4.1 Conceptual database design

Conceptual database design involves formalization of objects of interest, processes and relationships in a non-redundant and simplified form to yield a conceptual model of an application. The main objective is to determine the basic entities, their spatial relationship and the entity of attributes (Avgleen et al, 1993).The entity relationships diagram in fig 3.2 illustrates the conceptual model of this project.

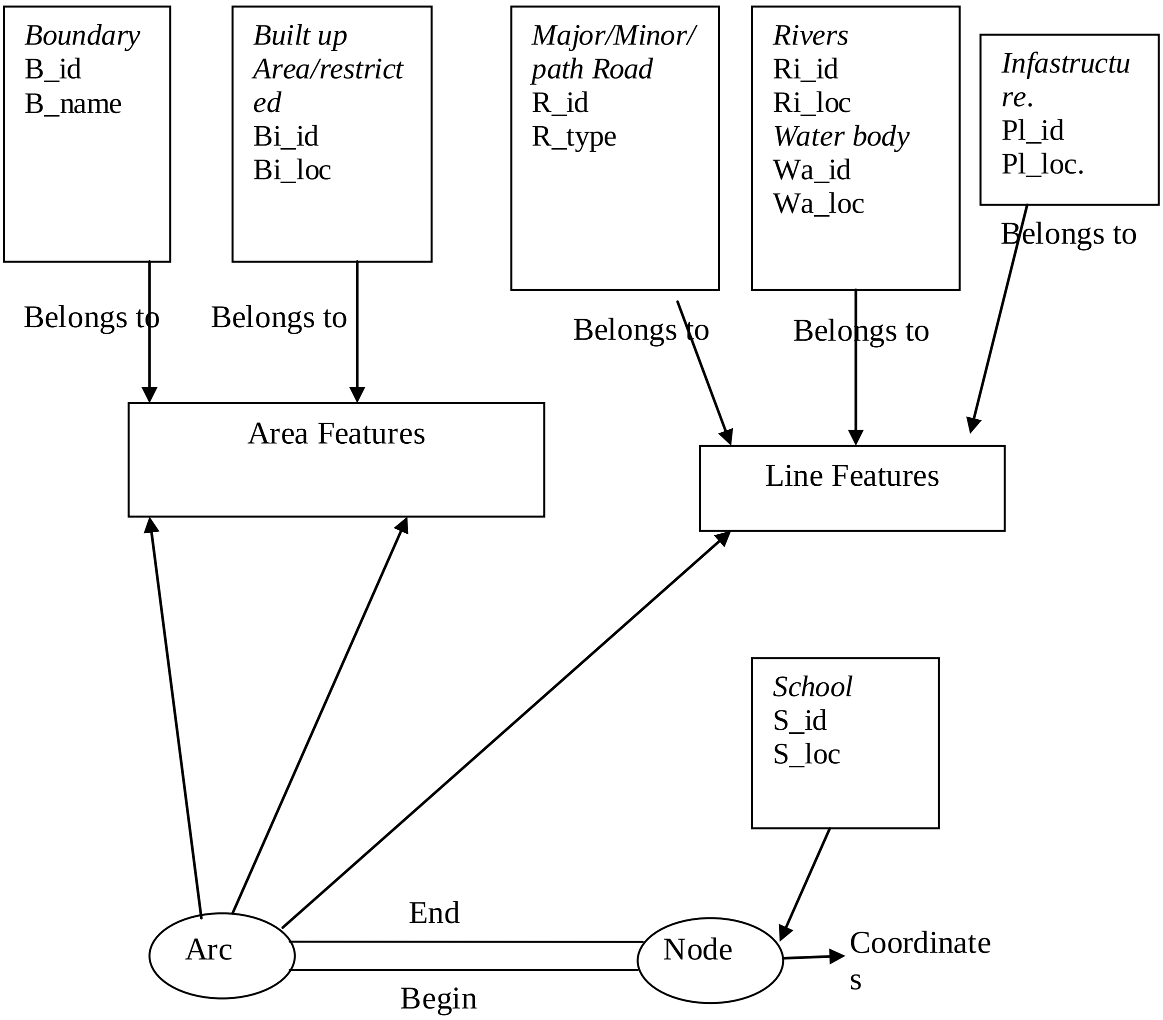

Figure 3.1.E_R Diagram showing the different feature classes and their attributes

3.4.2 Logical design

Logical design is the presentation of the data model. For this study, the relational data model type is used. In a relational database structure, data are presented in Tables. The conceptual data model in fig 3.2 was translated into relational data structure as below

Table3.Description of the Attributes of the Relational Structure

Identifier	Description
X-Coord	Position of a point in terms of its X-coordinates
Y-Coord	Position of a point in terms of its y-coordinates
MAJORRD_ID	Identification of major road entity.
BD_ID	Identification of boundary entity.
MINORRD_ID	Identification of minor road entity.
WA_ID	Identification of water body entity.
WA_Name	The name of the identified water body
RI_ID	Identification of river entity
RI_Name	The name of the identified river
PL_Name	The name of the identified infrastructure provision
SCH_ID	Identification of school entity.
SCH_Name	Name of identified school entity
RDPath_ID	Identification of road path entity.
BU_ID	Identification of built up/restricted area entity.
BU_Name	The name of the identified built up/restricted area

3.4.3 Physical design

Physical design is the stage where the choices of the software and hardware are determined. And at this stage, the internal storage structure and file organization for the database were specified. In this study, the field name, data type and data width were declared.

Table3.1. Showing the physical design feature

Field name	Data type	Data width
MAJORRD_ID	Number	6
BD_ID	Number	6
MINORRD_ID	Number	6
WA_ID	Number	6
WA_Name	String	6
RI_ID	Number	6
RI_Name	String	20
PL_Name	String	30
SCH_ID	Number	6
SCH_Name	String	35
RDPath_ID	Number	6
BU_ID	Number	6
BU_Name	String	50

3.5 System selection

The following system configurations were used regarding hardware and software:

- Hard drive capacity-250GB
- RAM-2.00GB
- Central Processing unit (CPU) with speed of 2.40GHZ,
- HP LaserJet P2055dn Printer
- Arc GIS software.

3.6 Data quality

The sourced data are of standard quality in terms of completeness, coverage, lineage, accuracy, reliability, validity, credibility, scale, resolution and logical consistency. The usefulness and efficiency of data depends on the viability of the data sources, the relevance of the data to the project, hardware and software selection, and accuracy of the geospatial data. The study area datasets were produced in Nigeria by Abuja Local Planning and Development Authority in partnership with private enterprise and while the soil datasets are produced by FAO.

3.7 Analyzing maps

GIS-based analyses were conducted using ArcGIS software. Spatial analyst functions were used to produce potential suitability areas derived from combined map layers based on established criteria. Analyzing maps involves setting the study area boundary, buffer zone maps, proximity, overlaying, dissolving, integrating soil map and producing suitability site maps and unsuitable areas as presented in Chapter 4.

3.8 Cartographic modeling

It is the graphical representation of data, analytical procedures and workflow. The figure below shows the cartographic model adopted for this project.

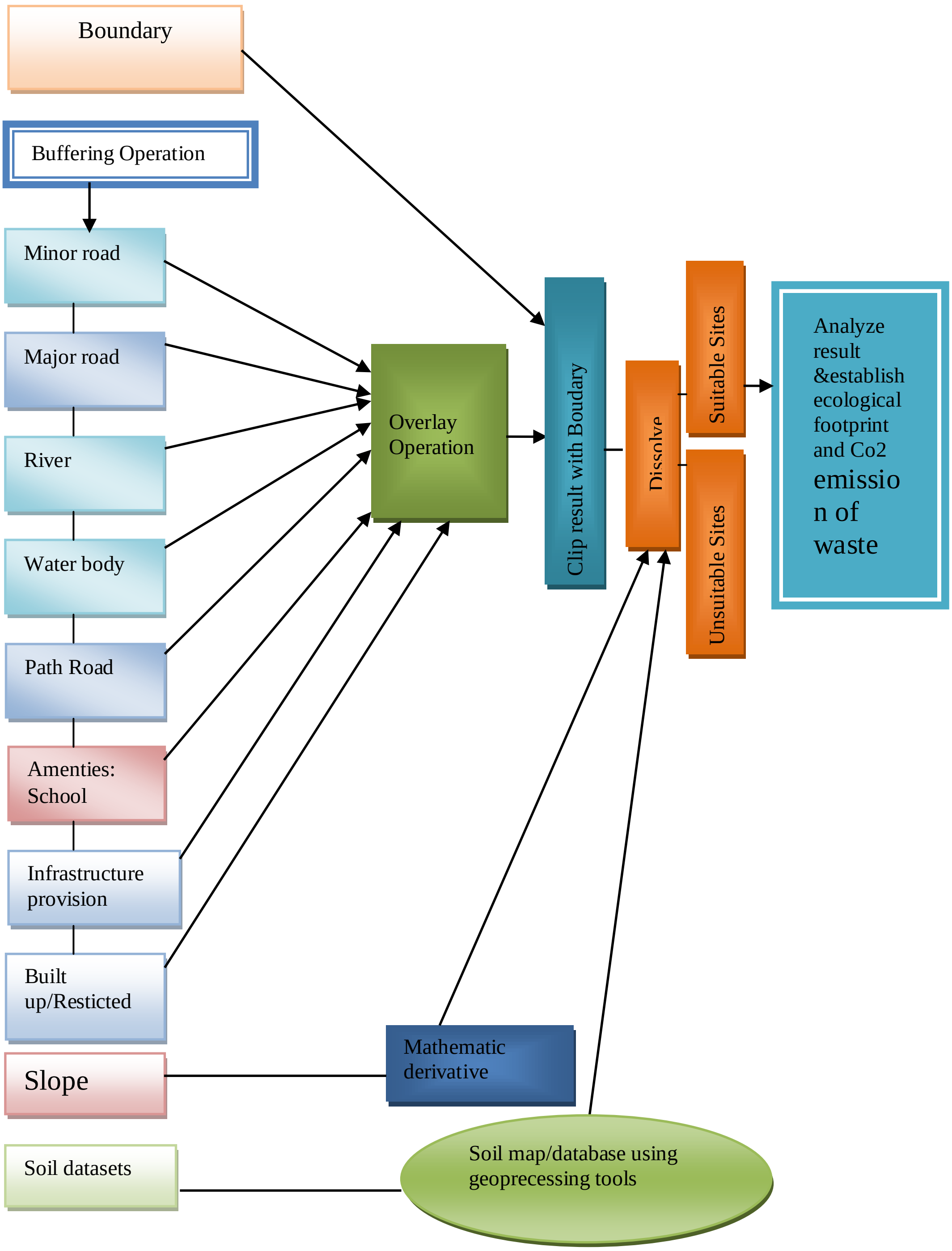

Figure3.2. Model applied for locating suitable land for landfill sites

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4 Analysis and Result

In many Nigerian urban areas, MSW is disposed on lands with water near surface, or open burning dumps. The waste is burned to reduce volume, but refuse does not burn well. The burnt refuse produces clouds of smoke and creates breeding grounds for rodents (Babayemi and Dauda, 2009).

The notion is, once the municipality acquires the land, dumping commences with no plan to utilize the waste for meeting the society need such as energy demand. The plan is that the site will be full, and it would be abandoned which has an ecological and social impact.

Landfilling is thought as a means of dumping waste on unutilized land. Landfills are not a favorable usage of land. Finding sustainable suitable sites for MSW waste disposal is becoming increasingly difficult and poses important challenges as result of land availability, developmental changes and population growth together with important factors such as environmental, economic and other social concerns. Of these, environmental concerns are perhaps the most important issues to be addressed during site selection (Baxter, 1992; Elliott, 1998 in Felix 2009).

Thus, the process of siting a waste disposal facility should explicitly address the issues of the community e.g. waste use for energy production, and well defined environmental boundaries should be a sought-after means of ensuring environmental sustainability.

Therefore, the use of a GIS as Decision Support Tool for Landfill Siting can be incredibly useful in locating potential sites for a landfill. GIS can use integration of spatial information to ensure the quality of location selected. Using GIS for landfill site selection is a cost-effective and time-saving tool compared to conventional methods.

4.1 Criteria

In finding a potential suitable site, a number of variables were taken into consideration, which includes environmentally sensitive areas, exclusive protected area distance to streams, distance to water body, proximity to settlement, and proximity to infrastructure provision and the distance from transportation routes (Vasiloglou, 2004; Hakan and Bulut, 2009).To arrive at the selection criteria for potential sites for landfill, relevant literature and opinion were sought from relevant local municipal offices.

4.2 Analysis

The capabilities of GIS for generating a set of alternative decisions are mainly based on the spatial relationships principles of connectivity, contiguity, and proximity and overlay methods. For example, overlay operations are often used for identifying suitable areas for proposed or new facilities, waste disposal, etc. Having acquired the datasets necessary for landfill siting, spatial analyses were carried out to locate potential sites.

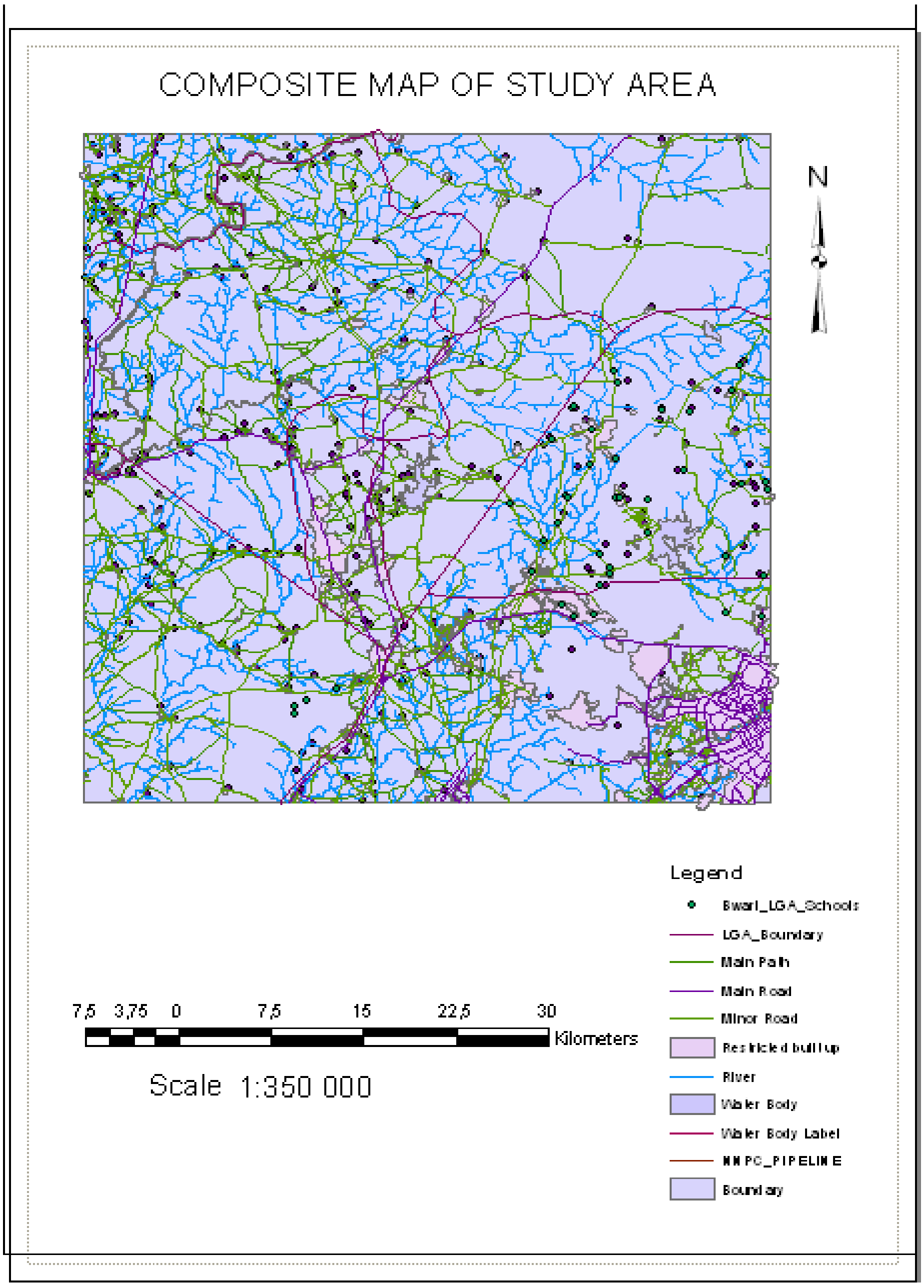


Figure 4.Composite map of study area

4.2.1 Built up and exclusive area

Parameters like nature reserves, recreational areas, and exclusive protected area, industrial and residential area have been taken into consideration. For this study, a buffer of three thousand meters is sufficient (see figure 4.2) to avoid pollution spread such as noise and air, social and ecological disturbance, with other health-related issues and concern.

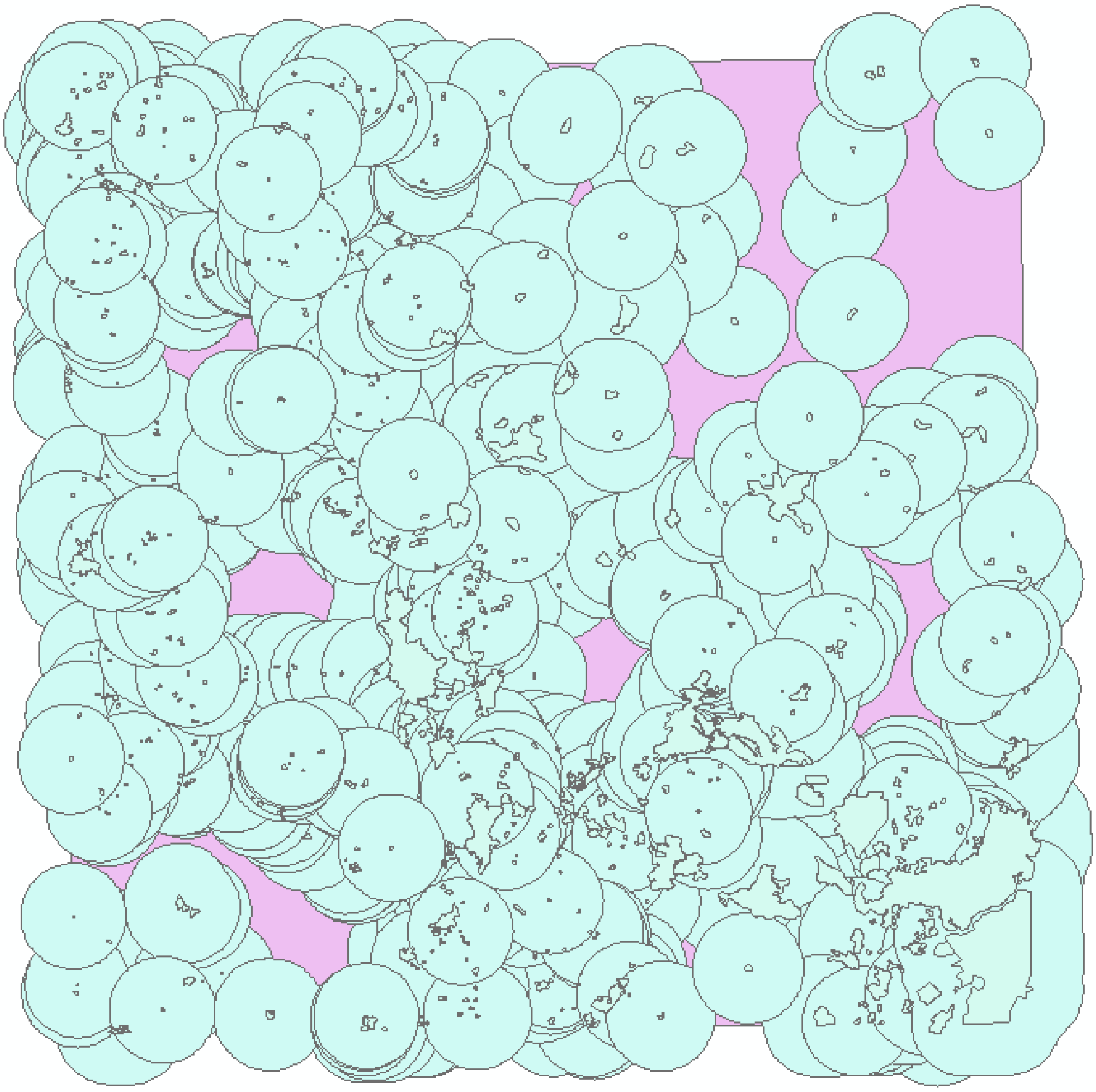


Figure 4.1.Result of Buffered Restricted area (built up, park, exclusive zone) at 3000 meters.

4.2.2 Proximity to road

Locating the landfill close to a road would help reduce costs related to transportation. To accomplish this, the major road layer (Figure 4.3) and a buffer zone around the major roads was created. For this study, it is found that a buffer of one meter is sufficient,to optimize possible sites for and aesthetic considerations .Landfills shall not be located within 100 meters of any major highways, city streets or other transportation routes. The 100 meters was chosen based on accessibility of sites and options sought.

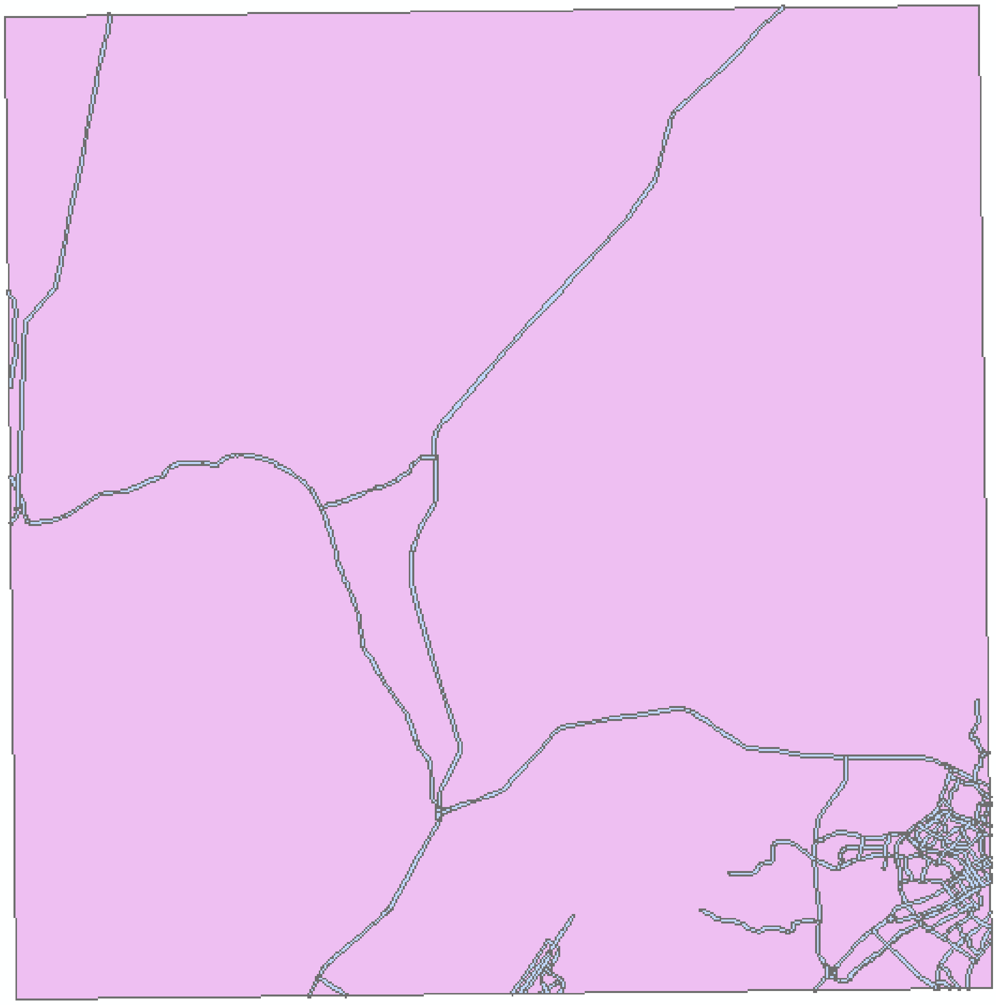


Figure 4.2. Result of Buffered Major road

4.2.3 Proximity to minor road

The Landfill is expected not to be located within 100 meters of any minor road or other transportation routes and paved pathways, and 100 meters is chosen because major roads and minor roads have similar features.

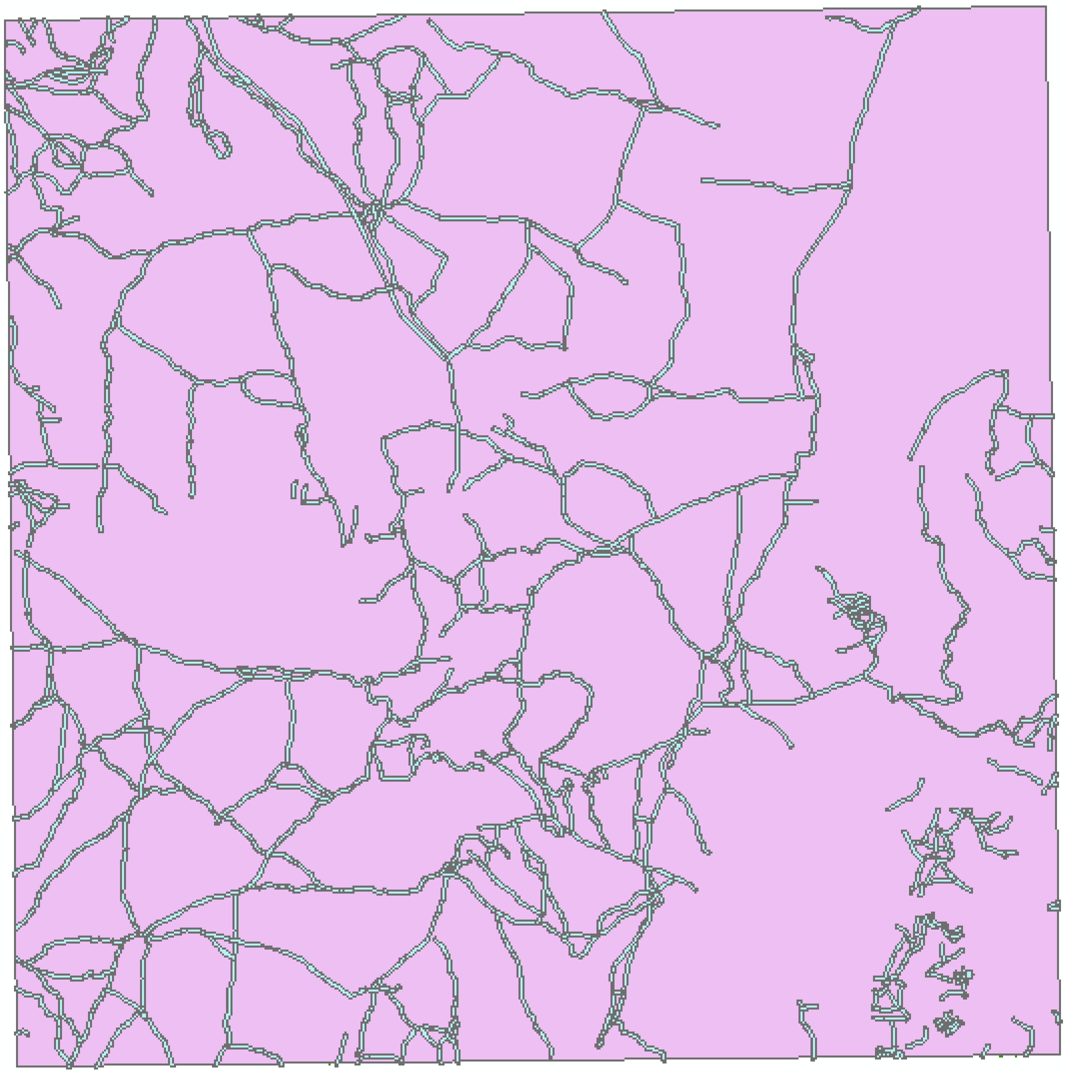


Figure 4.3. Result of Buffered Minor road

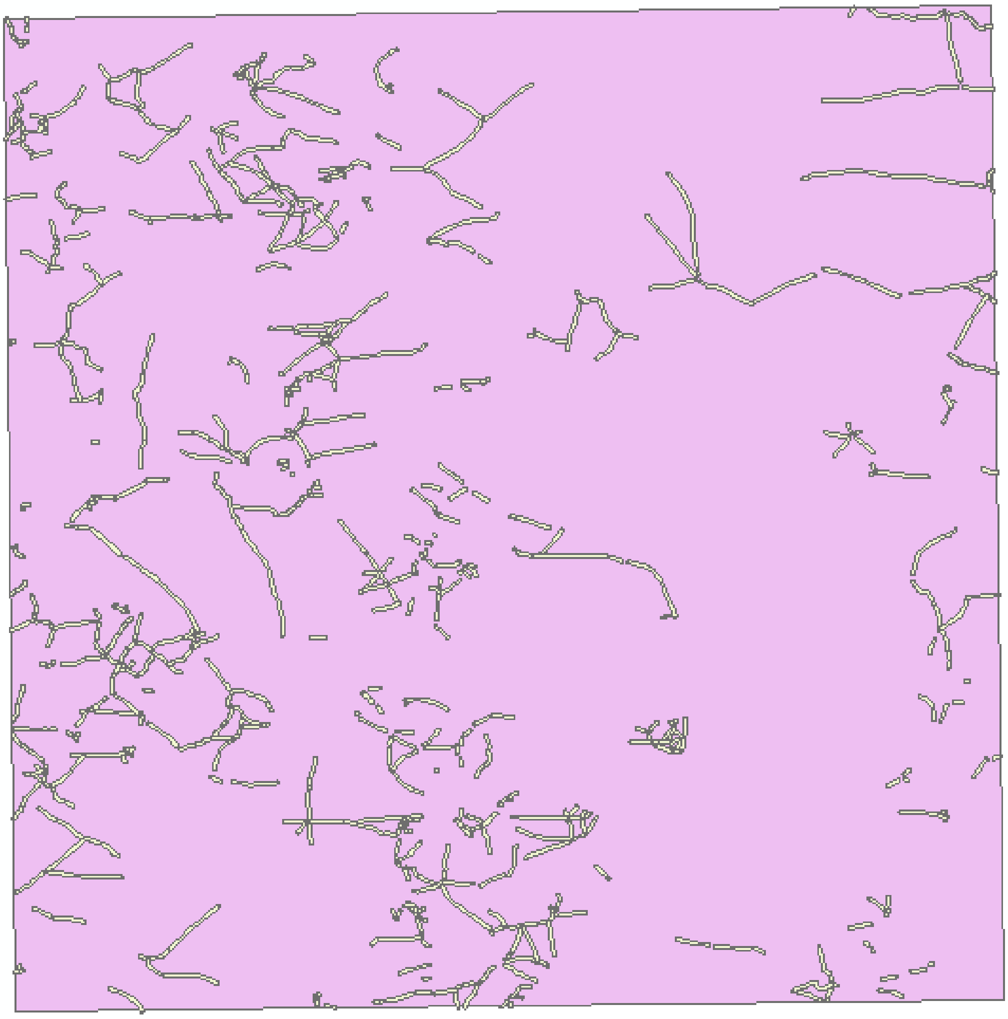


Figure 4.4. Result of Buffered Paved pathways

4.2.4 Proximity to river

Landfill must not be located near rivers. For this reason, a 200-meter buffer is used to generate the buffer around the entire river (see figure 4.6). The 200-meter buffer is in line with option sought.

Figure 4.5. Result of Buffered River

4.2.5 Proximity to water body

The water (streams, wetland) layer is constructed in order to generate a buffer zone around because it is unsuitable to place a landfill close. This is due to the possibility of contaminants flowing into streams. This is also primarily due to environmental concerns, where a location further away from a surface water source would be preferred. For this reason, a 100-meter buffer is used to generate the buffer around all the water bodies (see figure 4.7).

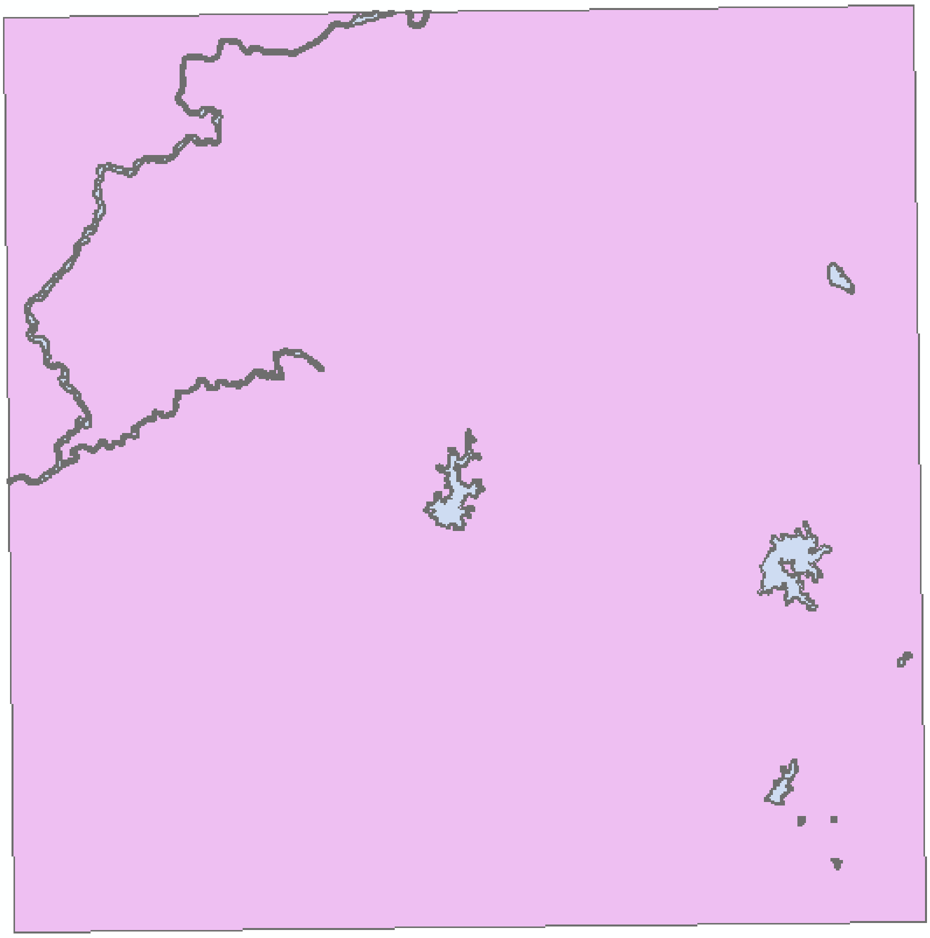


Figure 4.6. Result of buffered water bodies

4.2.6 Proximity to school

A buffer is created in order to define a limit around school areas that would protect the populace from landfill related problems. For this reason, a 500-meter buffer is used to generate the buffer around all the schools (see figure 4.8).The 500-meter buffer is in line with option sought.

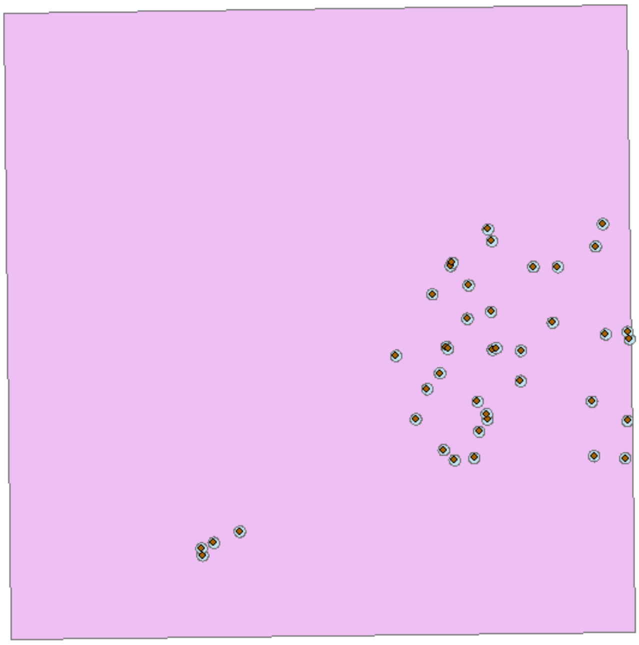


Figure 4.7. Result of Buffered schools (training schools)

4.2.7 Proximity to Infrastructure

A buffer is created to avoid landfill problem on existing infrastructure. For this reason, a 200-meter buffer is used to generate the buffer around all NNPC pipeline.

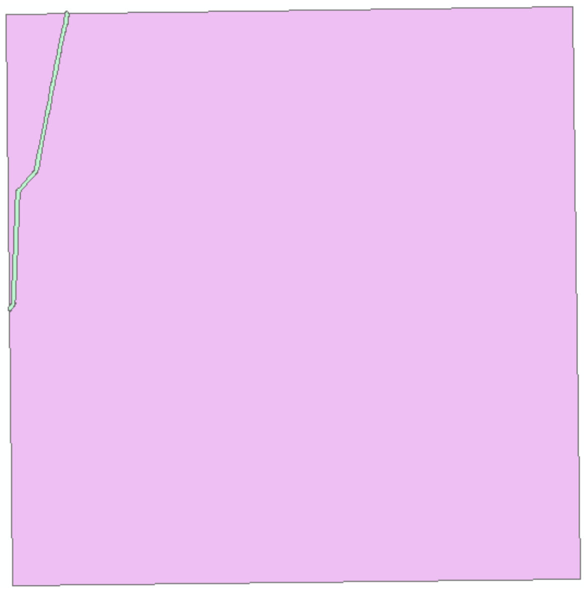


Figure 4.8. Buffered of infrastructure provision

4.2.8 General slope characteristics

In general, the slope map of the study area is not utilized because almost all parts of the study area comprise a gradient less than 10%. For example, the mathematical derivative of the slope of Site 3 will be:

Site 3: Elevation difference = 11 meters (0.011 km)

Distance = 19,000 meters (19 km)

Slope: $0.011/19= 5.78*10^{-4}$

Slope = $\tan^{-1}(5.78*10^{-4}) = 0.033$

Slope percentage = 3.3%

4.2.9 Overlay operation

In this project, the overlay function was performed to determine the suitability site map when all factor datasets were completely analysed. Based on this, a final analyzed composite site map was generated.

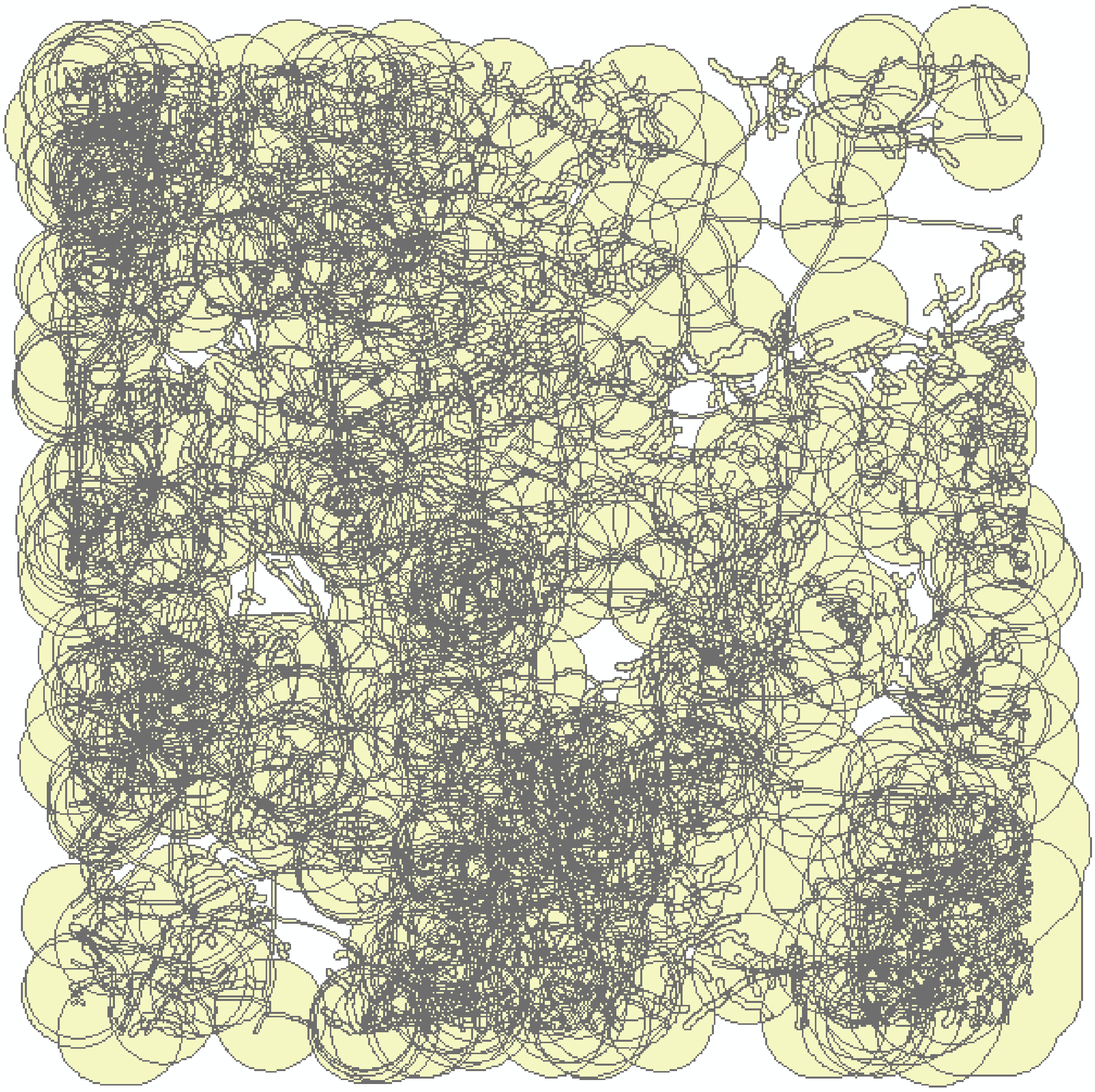


Figure 4.9.Result of overlay of themes.

4.2.10 Dissolve operation

A dissolve operation was performed to aggregate the attributes of the features of the themes generated by the overlay operations. This result in an output feature class of all the factor datasets.

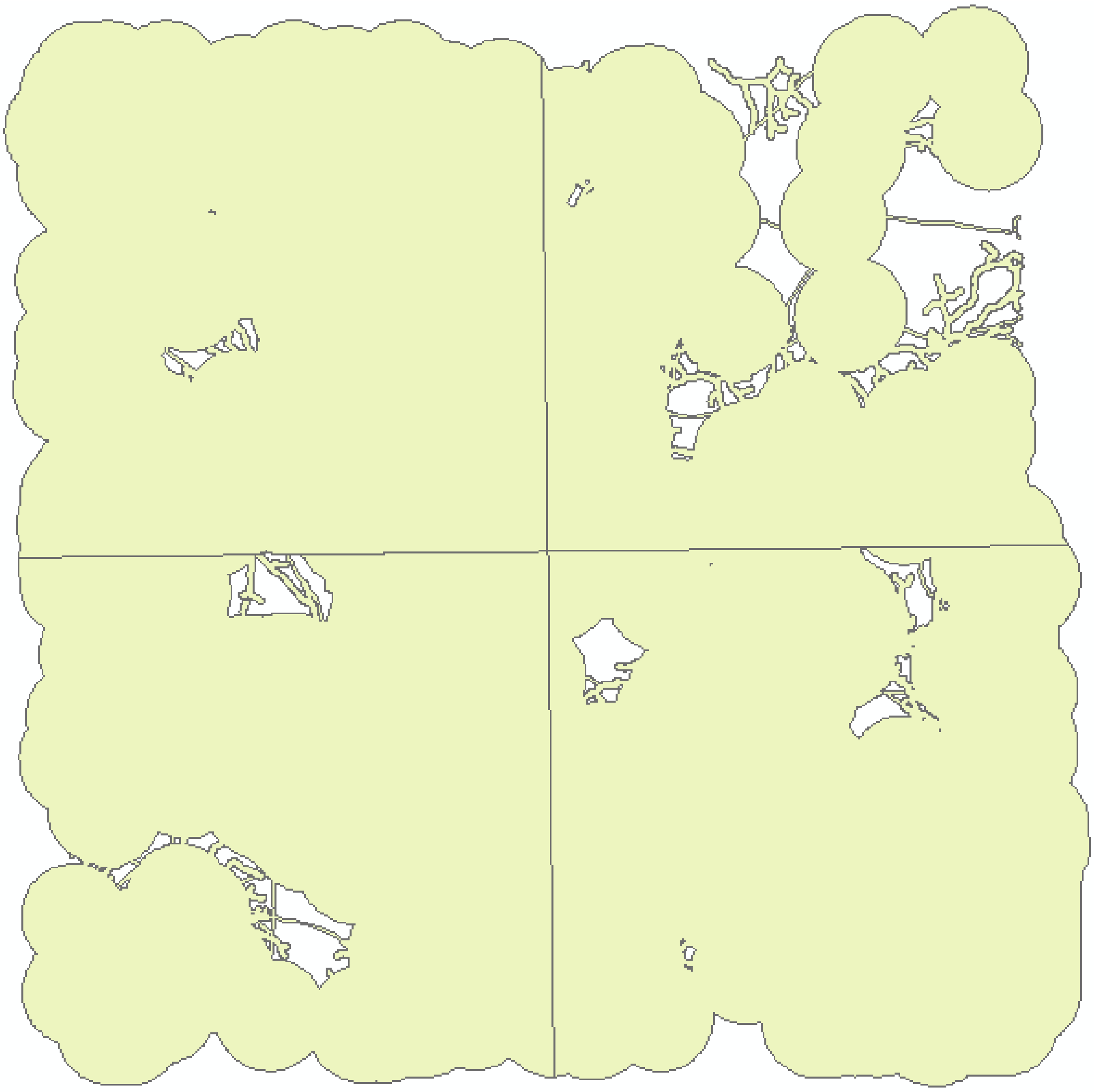


Figure 4.10. Result of dissolved themes

4.2.11 Clip operation

The clip operation was carried out in order to define the spatial extent of the study area. This was performed using the boundary layer with the final factor map layer.

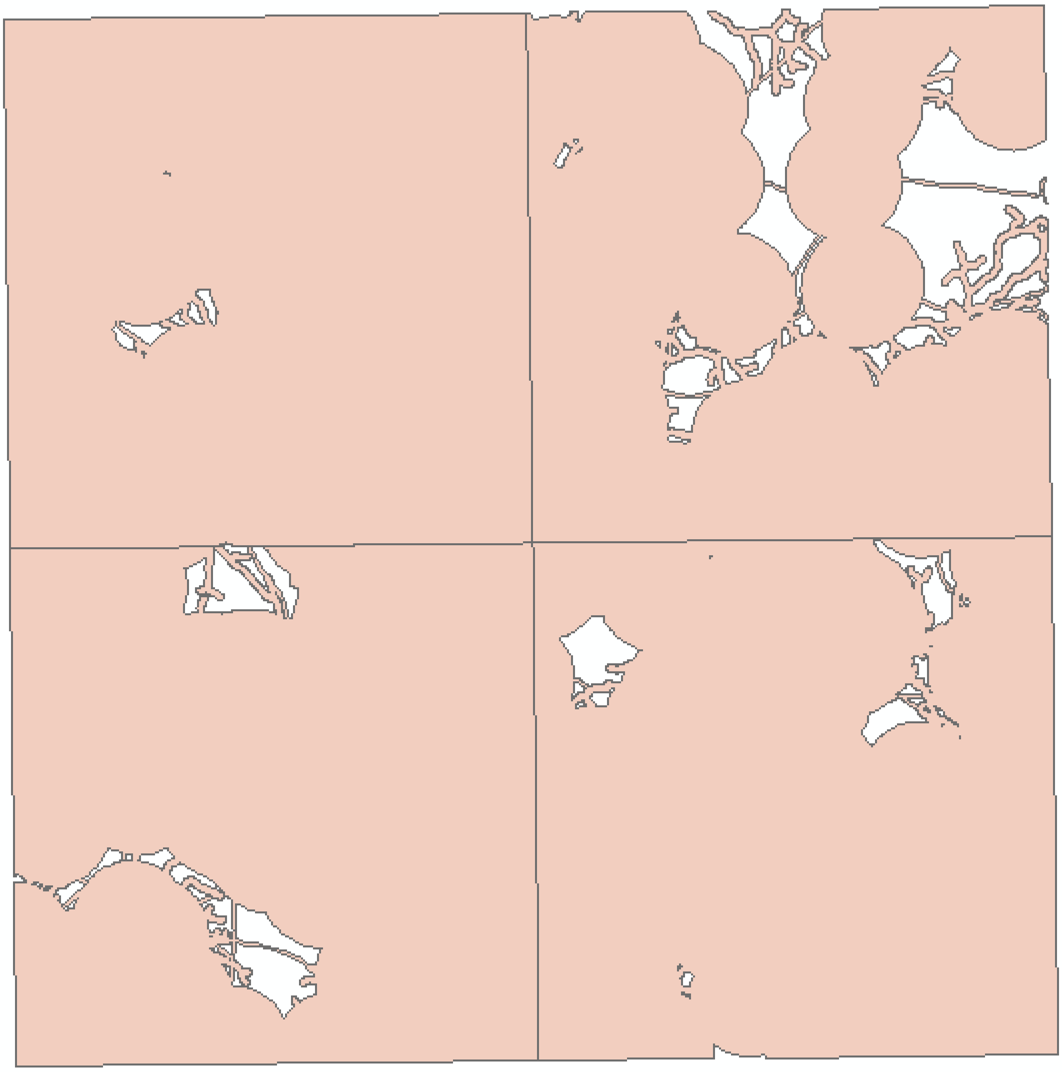


Figure 4.11. Result of clip operation

4.2.12 Soil characteristics

Soil properties that influence traffic ability and risk of pollution are the main considerations in evaluating the soils for areas of landfills. Thus soil should be of sufficiently low permeability to significantly reduce pollution and be suitable for construction activities. Thus, sites in clay-rich environments are preferable. The permeability for most soils which contain more than 25% clay, are in the range of 10^{-8}cm/sec to 10^{-5}cm/sec. (William and Robinson, 1986). And according to FAO soil permeability classes for civil engineering work; semi or low permeability and impermeability is within the range of $1x10^{-5}$cm/sec to $5x10^{-7}$ cm/sec.

The study area shows a general characteristic of more than 20 % clay sub soil. Thus, the area indicates that the soil is semi permeable, which is moderately good for landfill. However, when evaluating soil on site, several laboratory tests are usually performed to identify the soil strength. A further analysis of physicochemical characteristics such as PH, soil composition, moisture holding capacity and nutrients are needed. This is necessary in order to identify potential problems that may arise (AvErnest and Lehmann 2007).

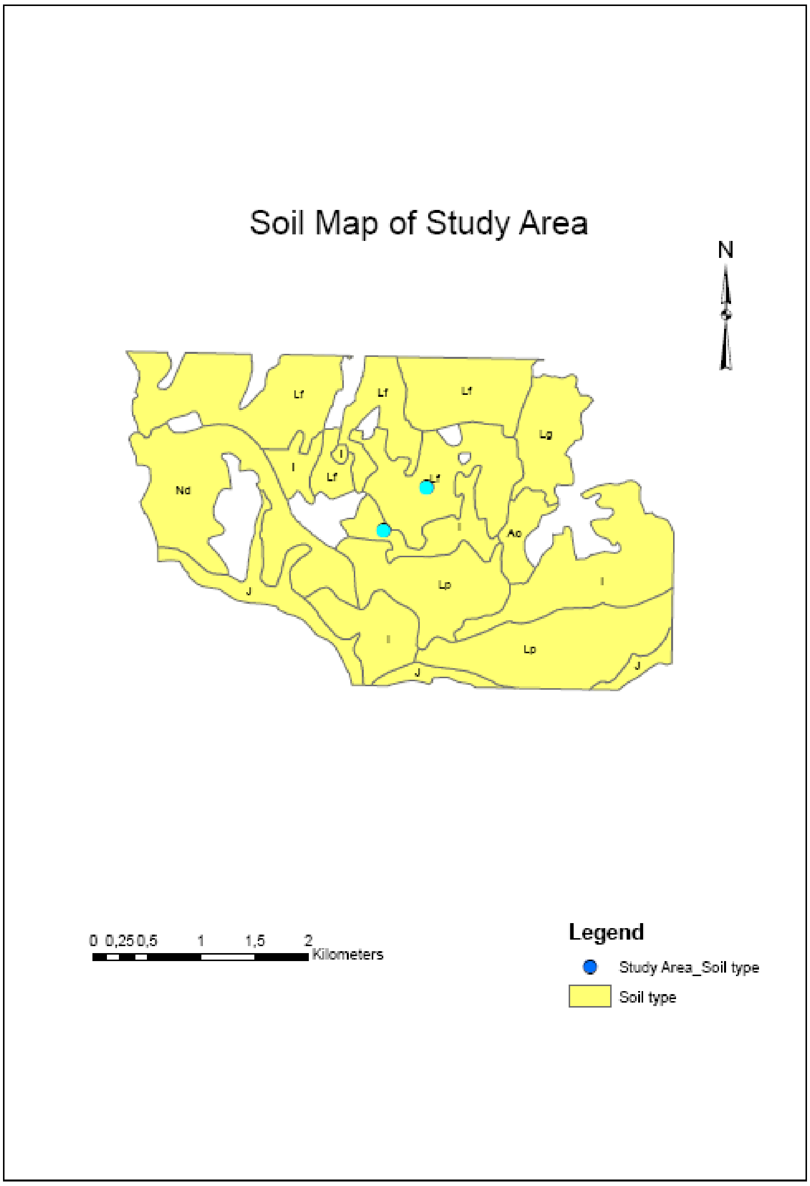
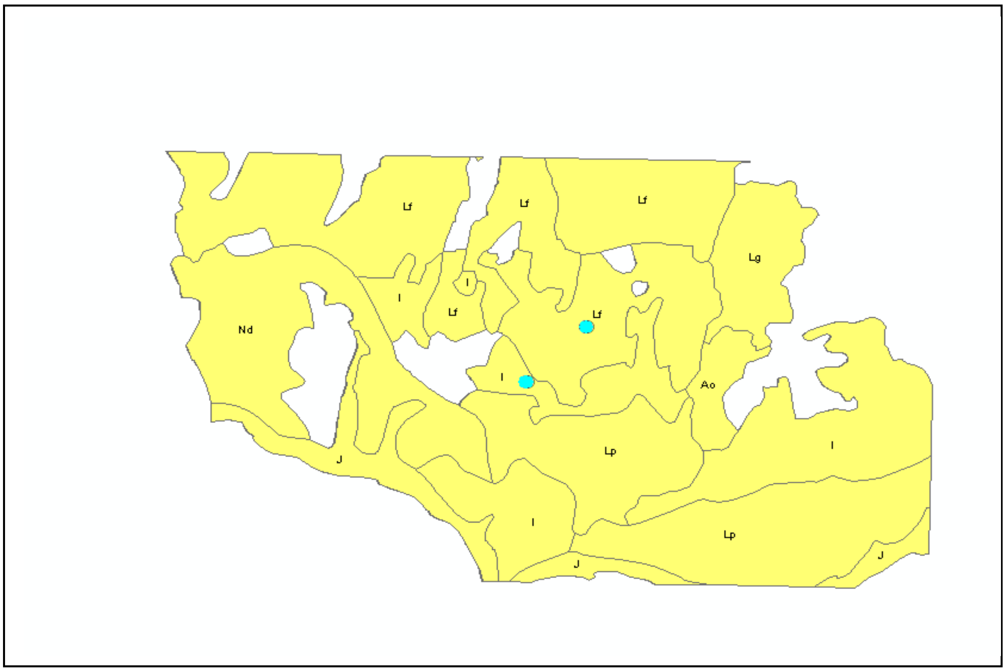


Figure 4.12. Soil map of study area



Field	Value
FID	0
Shape	Point
F1	
Soil_unit	I
soil_uni_1	
sand___top	58,9
sand___sub	56
silt___top	16,2
silt__subs	17
clay___top	24,9
clay___sub	27
pH_water_t	7,1
pH_water_s	7,2
OC___topso	0,97
OC___subso	0,4
N___topsoi	0,13
N___subsoi	0,02
BS___topso	69
BS___subso	90
CEC_topsoi	10,4
CEC_subsoi	8
CEC_clay_t	55
CEC_Clay_s	28
CaCO3___to	0,1
CaCO3___su	0,5
BD_topsoil	1,2
BD_subsoil	1,5
C_N_topsoi	11
C_N_subsoi	8

FID	1
Shape	Point
F1	
Soil_unit	LF
soil_uni_1	
sand___top	74,6
sand___sub	67,7
silt___top	9,6
silt__subs	8,9
clay___top	15,9
clay___sub	23,4
pH_water_t	6,4
pH_water_s	7
OC___topso	0,39
OC___subso	0,25
N___topsoi	0,05
N___subsoi	0,04
BS___topso	69
BS___subso	69
CEC_topsoi	5,3
CEC_subsoi	6,2
CEC_clay_t	33
CEC_Clay_s	27
CaCO3___to	0
CaCO3___su	0
BD_topsoil	1,5
BD_subsoil	1,5
C_N_topsoi	12
C_N_subsoi	9

Figure 4.13. Soil map attributes

4.2.13 Final map showing potential suitable sites

This approach consisted of finding appriopate sites that may present favorable conditions for solid waste disposal. The various datasets were analyzed based on environmental and social criteria .Based on the available data the final suitability map presented in Figure 4.8 is developed.

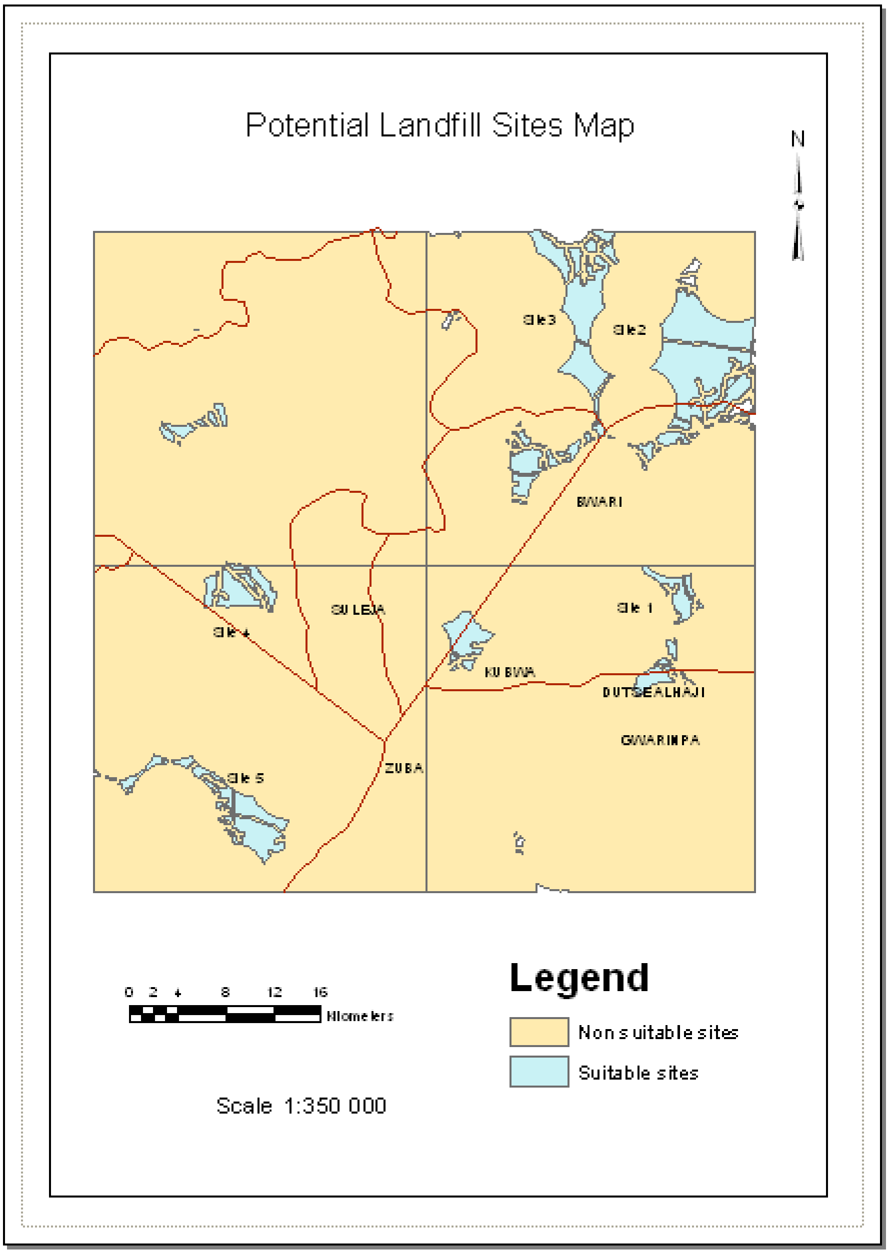


Figure 4.14. Result of suitable potential sites

4.3 Model application

When selecting a new site, the landfill footprint should provide adequate landfill capacity. In, Nigeria, many landfill sites are of large footprint with sizes in hectares (see photo1). Inspite of this land mass, waste is dumped indiscriminately with no control to contain and manage contaminants from the wastes (CPE, 2010). Investigations of studied sites show that most site are of shallow depth (see photo 2) which indicates lack of beneficial practices and sustainable management of solid waste, thereby resulting in environmental degradation (CPE, 2010).

In many cities, the idea of sustainability hardly comes into play when planning to select landfill sites and as a result many municipalities lack basic principles for siting landfill with small footprint or defining the capacity and $C0_2$ emission of waste disposed based on travel distance. Thus, in order to achieve or become a sustainable developed country, municipalities in Nigeria must incorporate the basic idea of the sustainability concept to managing solid waste. Using the result of these municipalities (Suleja and Bwari) as model, landfill sites can be built on substantial areas (small footprint), and the $C0_2$ emissions of disposed waste measured.

4.3.1 Establishing landfill footprint

Land fill space requirement can be determined from $VA= T (W/\rho w)$

Where VA = landfill volume required (yd^3 (M^3)

W =annual weight lb (kg) of waste generated

ρw = density of waste1100lb/ yd^3(650kg/ M^3)

T= operating life for landfill

*Site 1 area= 20,675*sqm

*Site 3 area= 38,862.5*sqm

*Site5 area=51,975*sqm

Suleja scenario for potential site 3

Estimate of population is 216,578 (census 2006)

Waste volume: 0.58 kg solid waste per person per day (Sridhar and Adeoye, 2003 in Babayemi and Dauda, 2009)

Waste volume per year:

216578 people *1.27lb/ day per person *365 days per year = 100394731 yd^3

Landfill area required:

100394731/ 1100 = 91267.9 yd^3

91267.9 yd^3 * 27 = 2464233.3 ft^3

2464233.3ft^3 /100ft = 24642.333 sqft

24642,333 sqft *2.2295* 10^-5= 0.54 acres

0.54 acres (2222.8 sqm) per year

For a 10-year life = 10* 2222.8= 22,228 sqm, Site 3 Area = 38,862.5 sqm.

The minimum recommended depth for landfill is 20ft (6m); minimum recommended life is 10 years. (Hicks and Hicks, 2007).In this arithmetic, 100 ft (30.6m) is used in order to conserve horizontal space (footprint)

4.3.2 Establishing unit of transportation measurement of MSW

In this section, a detailed estimate of MSW quantity with respect to haul distance is calculated and the $C0_2$ emission of MSW is measured

Waste generated in Bwari Municipality

Estimate of Bwari population is 227,216 (census 2006)

MSW volume of Bwari:

227 216 people * 0.58 kg/day per person *356 days per year = 48,101.6 tonnes (48,101, 627.2 kg

Method: Total capacity x per trip x distance x capacity utilization x effective use x number of days in a month (Jawaharlal, 2008)

Efficiency = 60% (Nkwocha et al, 2011; Ogwueleka, 2009)

Capacity = 9 tonnes per truck

Per trip = 1

Per km = 1

Capacity utilization = 40 % (Ogwueleka, 2009)

No of days per month = 30 days

Calculation: 9 x 1 x 1 x 40/100 x 60/100 x 30

Tonnes -per km = 64.8 tkm

C02 emission factor for 15 GMV vehicle = 77CO_2 [g/tkm] for full loaded (9t load)

CO_2 Emission = 64.8x 8.5x 2= 1101 CO_2 [g/tkm]

Photo 1: Dumping on disposal site

Photo 2: Shallow depth (Gosa site)

4.4 Discussion

In Nigeria, solid waste is mainly disposed of on open dumps, and water bodies. There has not been any systematic solid waste disposal strategy to this area. Provision of enabling a waste management system for successful implementation of a waste program is very important for the protection of the environment (Agunwamba, 1998).

Site selection should be performed for every municipality in Nigeria, but it is very cumbersome, time consuming and expensive. Therefore, the use of GIS as a support decision tool can effectively be employed in preliminary studies due to the ability of GIS to manage spatial and aspatial attributes from a variety of sources. This allows decision makers to combine environmental criteria with other constraints based on established guidelines for selecting suitable sites.

In the present study, a methodology for finding potential suitable sites for municipal solid waste landfill was developed using GIS. Based on this, suitable potential sites that require small footprint were determined .For this aim, there were several aspects of constraints taken into consideration using standard established criteria. The first was to analyze the datasets in the area. The selection concern was to find the environmental constraints of the location.

This was done by defining proximity distance from natural features, infrastructure provision and close proximity to sensitive land uses. The land uses were aggregated to contain protected areas, national park, residential areas, habitat reserves, and so on. Also, the soil layer was extracted and a map produced .GIS was used to perform analysis such as buffer, clip operation, extraction by selection, spatial join and overlay analysis with other functions. At the end of the analysis, potential sites were determined for all the municipalities. The analyses show that proximity to built-up areas (restricted area) was designated as the most important criteria.

Finally, based on the idea of sustainability, the ecological footprint and $C0_2$ emission of waste transportation are measured to help achieve optimal environmental sustainability in order to minimize environmental footprint and impact as much as possible.

5 Conclusion, Recommendation and Limitation

5.1 Conclusion

GIS as a decision support tool for landfill siting has been proven to be useful in finding suitable sites for landfill siting purposes. In this study, GIS software was used to locate landfill sites by creating maps according to the set criteria. A landfill siting process requires evaluating many criteria and processing much spatial information. Using GIS for locating landfill sites is an economical and practical way for the evaluation of and production of maps in a short time when there is a need for fast evaluation.

Through a literature review, the study has found that MSW production has emerged as one of the greatest challenges facing environmental protection in less developed countries such as Nigeria. During this study, the utilization of GIS as a tool in siting new landfills was employed and safe conclusions are arrived at concerning potential sites. Furthermore, the carrying capacity of the potential sites is defined with the utilization of waste volume based on the concept of sustainability.

Secondly, the result of the application of GIS-based models was based on environmental factors and constraints, potential sites were found based on these criteria. The proximity of the potential sites is not within the zone of environmental interest or natural features, and was located distances away from settlement, which minimizes social conflict, health hazards and environmental impacts. Also, the site is located close enough to transport routes, which ensures that economic costs of implementation are minimal. At the end of the analysis, appropriate MSW landfill sites are identified. These sites generally satisfy the minimum requirements of the landfill sites.

Finally, inappropriate landfill sites can become a problem in any municipal areas. Therefore planning for land use and deciding on the appropriate areas for waste disposal facilities demand spatial analysis and sound judgement. However, there are various deficiencies related to solid waste management (SWM) in most municipalities, such as lack of institutional capacity, inadequately formulated and poorly implemented environmental policy and so on.

It is hoped that relevant municipality authorities and agencies would cooperate and work together in acquiring spatial data with regards to the solid waste sector and implementing specific actions in disposal of solid waste in an environmentally safe manner.

5.2 Recommendation

Using GIS for the site selection process can make the selection of a potential site for a landfill facility more transparent, helping local authorities to adhere to environmental protection regulations and reduce public opposition, if the public can be reassured that site the selection is based on acceptable criteria. From the study carried out, the most realistic solution to sustainable environmental development in the country is to ensure that resources like solid waste offer the most environmental and social gain without compromising the ability of future generations. However, there are important issues that can be considered for future studies. For future study, here are some suggestions which can be adopted:

- Geotechnical analyses
- A detailed study can be carried out on the physicochemical characteristics of soil data.

5.3 Limitation

A landfill siting process requires evaluating criteria. Any GIS analysis is obviously limited to the data available. There were layers that were not available such as geological data. For future studies it would be useful to incorporate more layers into the GIS-based analysis. Concerning the municipalities, adequate spatial planning is non-existent for siting landfills Thus, through integrated management a system can be designed to foster environmental sustainability.

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Appendices

Appendix I: Total waste tonnage information for all the sites in the FCT

Waste quantity (tons)									
Year→	1998	2000	2001	2002	2003	2004	2005	2006	2007
Month↓									
Jan.	1,821	3,262	1,373	3,298	1,14	3,316	2,38	3,921	4,706
Feb.	1,821	3,262	1,013	3,071	9,71	4,279	2,289	3,654	4,782
Mar.	2,283	4,077	1,428	2,467	9,67	4,474	2,757	4,16	5,231
Apr.	2,283	2,262	1,227	2,873	1,268	3,549	3,316	4,844	5,567
May.	1,82	4,077	1,651	2,854	2,117	4,279	3,598	3,932	6,084
Jun.	2,283	3,262	1,699	2,626	2,099	4,677	4,293	5,365	6,724
Jul.	2,283	3,262	1,557	N/A	2,288	5,585	4,826	5,937	6,545
Aug.	1,821	4,077	1,751	N/A	2,194	6,948	5,719	6,333	6,536
Sep.	2,283	3,262	2,105	N/A	3,239	5,211	5,266	5,883	6,948
Oct.	2,283	3,262	2,33	N/A	3,129	5,825	5,109	6,333	6,31
Nov.	1,821	4,077	1,333	N/A	2,958	3,907	3,939	6,277	5,866
Dec.	2,283	3,262	4,869	N/A	2,016	3,663	4,165	5,811	5,607
Total.	25,085	41,404	22,336	17,189	24,386	55,708	47,657	62,45	70,906
TOTAL WASTE TONNAGE = 367,121									

Source: (Abuja Environmental Protection Board, in CPE, 2010)
*Waste data for 1999 (information not available).