APPLICATION OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) FOR SITING A SANITARY LAND FILL: A CASE OF FINLAY'S TEA (K) LIMITED KERICHO, KENYA

BY

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DECLARATION

I certify that although I may have conferred with others in writing this thesis and drawn upon a range of literature cited, the content of this thesis is my original work and has not been submitted for examination in fulfillment of a degree in any other university.

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DEDICATION

This work is dedicated to my beloved family members and lovers of the environment.

ABSTRACT

Solid waste disposal is one of the most troublesome challenges facing many developing countries including Kenya. Not only has the volume of solid waste increased rapidly in the past few years, but the available sites meeting stringent environmental requirements have been depleted. The study was carried at Finlay's Tea (K) Limited located in Kericho district in the Rift Valley province starting from October 2012 to April 2013. The main objective of the study is to assess the application of GIS and Remote Sensing technologies in locating a landfill. Solid waste was characterized by its nature as either organic or inorganic. Mode of solid waste management was determined using interview schedules with respective officers in charge of waste management. Spatial data for fitting in the regulatory and acceptance criteria processing model were collected using GPS (Gemini model). Constraint Mapping Techniques (CMT) and Geographical Information System (GIS) map analysis approaches were used to create new map layers. Once all the map layers satisfying the criteria were developed, an overlay map was generated representing the final landfill suitable areas. The study findings identified seven potential landfill sites that adequately satisfied the environmental and to some extent economic attributes. These sites are Cheptambas settlement, Chemamul, Cheptabes, Kaproret, Kapkoros, Kapsongoi, and Saosa respectively. Three most appropriate sites were picked basing on the constraints mapping techniques these sites are Kaproret, Chepgoiben and Chebitet respectively. Facility siting can affect the success or failure of a disposal facility in terms of the associated environmental, economic and social impacts. This study has outlined a siting methodology that is appropriate for siting a landfill facility within the context of the study area but is also flexible enough to be used in facility siting in other parts of the world. Recommendations are made for application of GIS in sitting landfills in the study area.

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DEFINITION OF TERMS

Built Environment: The part of the physical surrounding which is made up of structures such as buildings, roads and bridges.

Cell: Amount of waste deposited in a landfill in an operating period.

Census: An official enumeration or count of the population of animal, human beings and other things.

Central Business District (C.B.D): The nucleus of the urban area, which acts as a focus of commercial, social and civil life.

Collection System: Means a system for collecting refuse and or disposing off waste.

Composting: Biochemical degradation of the organic component of the solid waste material having its end product humus like substances that is used primarily for soil conditioning.

Constraints**:** Are conditions that make an area unsuitable for landfill construction, due to regulatory requirements.

GIS:May be defined as an organized collection of computer hardware, software, data and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information.

Incineration: A controlled combustion process for reducing waste.

Inorganic waste: The waste that cannot be broken down by bacteria

Land cover: Represents biophysical cover for instance woodland, forest and grasslands.

Land use*:* Refers to the human use of land for instance grazing and agriculture.

Landfills: Are the physical facilities used for disposal of solid wastes in the surface soils of the earth usually a natural or excavated depression.

Organic waste: The waste that can naturally be broken down by bacteria.

Pollutant: A substance introduced by man into the biosphere and which has adverse effects on the environments.

Reclamation: Implies physical and separation of a useful waste component such as ferrous metal from mixed waste.

Recycling: Is the processing of putting discarded material into a new useful product e.g. the old tyres can be shredded into rubberized road surfacing material or plastic materials are re-made into new useful products, e.g. pipes etc.

Refuse management: Refers to full range of activities that involve handling of refuse from the point of generation to the point of final disposal.

Refuse: Refers to all petresible solid wastes. It includes combustible thrash and non-combustible waste.

Re-use: It means using the material again without undergoing any physical or chemical change instead of dumping e.g. beverage bottles, plastic containers they are only cleaned.

Sample: A part of the sub-set of a given total quantity or statistical population.

Sanitary landfills: Engineered facility for disposal of the solid waste designed and operated to minimize public health and environmental impact.

Solid waste: is the term used to describe non-liquid waste materials arising from domestic, trade, commercial, agricultural, industrial activities and from public services.

Waste shrinking: Reduction of waste in terms of quantity.

Waste stream: Is a term that describes the steady flow of variable waste from their sources.

Waste: Is any substance deemed to be of no economic value by the owner and therefore needs to be disposed off

ACRONYMS

CMT: Constraint Mapping Techniques

EIA: Environmental Impact Assessment

EMCA: Environmental Managements and coordination Act

EPA: Environmental Protection Act

GIS: Geographic Information Systems

ISWM: Integrated Solid Waste Management

NEMA: National Environment Management Authority

NIMBY: Not in My Back Yard syndrome

UNCED: United Nations Commission for Education

UNHCS: United Nations High Commission for Settlement

WHO: World Health Organization

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Solid waste is the term used to describe non-liquid waste materials arising from domestic, trade, commercial, agricultural, industrial activities and from public services. Wastes are either a by-product of initial production process or they arise when objects or materials are discarded after they have been used and they are an inevitable part of human activity just as they are an inevitable part of the natural ecosystem. Life from development is also a production system for living materials, which produces wastes as a by-product.

Naturally, when all living organisms die they ultimately become waste. Despite this, nature appears to be able to deal with its own waste very effectively. The natural world is also however the recipient of human waste material which is apparently different from the natural material. It would appear the most environmental problems arise because the natural world cannot cope with these novel substances. In the waste management hierarchy waste disposal is last option, it occurs when no further recovery and recycling of materials can be done (Ross C.M 2000)

A sanitary landfill is a site where waste is isolated from the environment until it is safe after it has completely degraded biologically, chemically and physically. All wastes disposed in a sanitary landfill is compacted at the end of each day's operation and covered with a layer of soil. A sanitary landfill is constructed and the walls well are plastered with impermeable materials to avoid leachate getting into the underground water bodies. The landfill is also designed with a vent to let out gases generated from decomposition processes. In a larger landfill, the gases are collected for the production of energy. A landfill therefore is a place where all unavoidable waste is placed with no more potential for recovering or salvaging the materials (Thurgood,Maggie 1999).

Geographic Information Systems (GIS) are computer based systems for the collection, storage, manipulation and presentation of spatial (geographical data)(Kemper M 2000).The field of GIS is rapidly expanding aspect of information technology which has greatly contributed to site selection for waste disposal and treatment facilities. GIS can be used to enhance the process of data integration and spatial analysis, in terms of both time and accuracy. Furthermore, GIS can be used to facilitate the process of “what if” questioning as it is relatively easy to change the search criteria and keep running the model to find the optimal site (Kao et al 1997)

1.2 Statement of the problem

Siting of a waste treatment facility requires careful consideration of several interacting factors such as enhancement of collection and waste management, efficiency and general pollution control. The potential environmental impact of uncollected or improper solid waste disposal is widely acknowledged by environmentalists, health authorities and the public (NEMA, 2004). The problem of disposal of solid waste in Kenya in general and the study area in particular is compounded by large volumes of waste generated and scarce space available for locating dumpsite since most areas are settled and or are near water bodies. This study is aimed to assessing the application of GIS to properly site a appropropriate location for dumpsite in the study area.

1.3 Research Objectives

The main objective of the study is to assess the application of GIS and Remote Sensing technologies in locating a landfill. This is done under the following specific objectives.

1. To characterize the waste generated in the study area as either organic or inorganic.
2. To assess the current capacity of the company to manage the waste generated.
3. To identify suitable sites for solid waste disposal using GIS techniques.

1.4 Justification of the Study

Wastes can be characterized basing on their chemical and physical characteristics. This is important because it is from their characteristics that a method and where to dispose them is determined. The amount of waste generated can be used to determine the design and area of the disposal site. GIS is a tool that not only reduces time and cost of the site selection, but also provide a digital data bank for future monitoring program of the site, GIS therefore is very appropriate in locating the facility so as to avoid pollution of ground water and other resources. With the growing amounts of solid waste, it’s hoped that the findings of this study will be available to enable the company plan and design an appropriate landfill facility both now and in the future.

1.5 Scope and Limitations of the Study

1.5.1. Scope

The subject of solid waste management is very wide in scope and cannot be covered within a single study given the time and financial limitations. The study therefore was designed to cover a landfill location for solid waste generated by the company. Other types of wastes such as liquid waste are not covered.

1.5.2. Limitations

Due consideration must be given to key environmental issues associated with a specific project either by quantitative or qualitative ranking systems so that the best site can be designated for landfill site. The landfills site selection guidelines produced by the above process can identify a preferred landfill site; its selections however cannot be confirmed prior to completion of the feasibility study and the Environmental Impact Assessment (EIA) studies. This particular research will only cover the first step of the said guideline.

1.6 Study area.

1.6.1. Location and Size

The study was carried at Finlay's (K) Limited located in Kericho County in the Rift Valley province. It lies between latitudes 0^{o}29' and 1^{o} 23' South of the equator and between longitudes 35^{0}05'and 0^{o}35'East. The study area covers an area of 10,972 ha. Finlays (K) Limited was established in 1926; it is basically a tea growing and manufacturing industry and consists of five manufacturing factories.

The company also grows flowers for export in an area of 69ha with over 144 Greenhouses which produce 92,300,000 stems annually. It has over 18,000 employees with over 55,000 dependants. Housing is provided and the company maintains 12 primary schools, 3 secondary schools and medical facilities. These are the main waste generating sources.

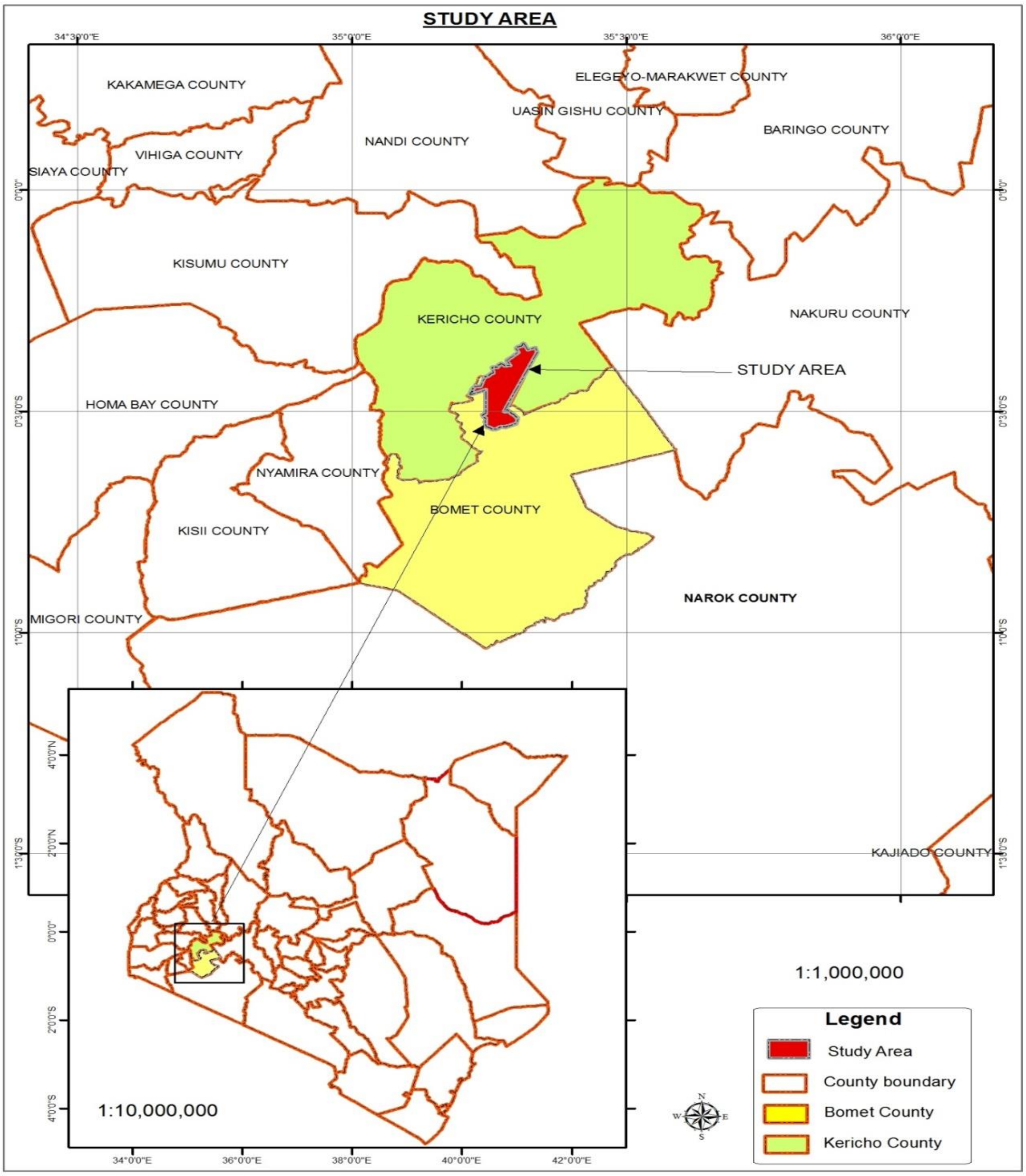

Fig 1.0 Map of the study Area derived from topographic map sheet of kericho Source survey of Kenya 1989(Topographic map kericho scale 1:250,000)

(Survey of Kenya, Kericho 1989)

1.6.2 Geology, hydrology and climate

The landscape of the area is characterized by undulating topography. The overall slope of the land is towards the West. The geology of the area is characterized by volcanic as well as igneous and metamorphic complexes. The region is also underlain by tertiary lavas (phonlites) and intermediate igneous rocks and some parts dominated by undifferentiated sanitary landfill should located in an area with a slope of less than 5% and the rocks should be impermeable so as not to allow leachate to contaminate the ground water sources(UNEP 1994). The area receives rainfall throughout the year with peaks in March-May (long rains) and August-October (short rains). The mean monthly rainfall is 125mm. The area is classified under ecological zone two the vegetation cover mainly consists of moorland, upland grassland and high rainfall forests (Ministry of Environment and Natural Resources 2013).

The mean monthly temperature is 17.6^0C. Cold months are July and August with mean monthly temperatures of 16.6^0C and 16.9^0C respectively. The study area is well drained with rivers. Some of the main rivers flowing through the area include Changana, Dimbilil, Maramara, Chemosit and Koruma.Climate has an implication on solid waste management for example during the wet season frequency of waste biodegradation is slow (Kiplagat, 1999). A place that experiences high rainfall amounts also means that leachate can be easily transported by runoff and leachate production is higher compared to an area that experiences low rainfall amounts.

During the dry season rate of biodegradation is higher because the temperatures favor this process. Warm conditions also encourage or attract flies to dumpsite in large numbers and at high rates. Thus knowing mean monthly temperatures and rainfall of an area is important so as to come up with an option that is functional during all periods (Kiplagat, 1999). At present, the company has one open dumpsite to dispose off the wastes generated. The garbage from residential places and restaurants in the company is mainly reused to feed the domestic animals and some is composted to form organic manure to be used in the gardens. Due to public health concerns and aesthetic concerns, open dumpsites are not the best for waste disposal(UNCED 2001). Basing on this, the study will focus on the use of a sanitary landfill instead of an open dumpsite.

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of Proper Waste Management

According to (Ross, 2000), solid waste management may be defined as the discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid wast es in a manner that is in accordance with the best principals of public health, economics, engineering, conservation, aesthetics and other environmental considerations and is also responsive to public attitudes. In its scope, solid waste management includes all administrative, financial, legal planning and engineering functions involved in solutions to all problems of solid wastes(Ross 2000).

The solutions may involve complex inter disciplinary relationships among such fields as political science, city and regional planning, geography, economics, public health, sociology, demography, communications and conservation as well as engineering and material science. The activities that are involved with the management of solid wastes from the point of generation to final disposal can be grouped into six functional elements namely waste generation, on-site handling, storage and processing, collection, transfer and transport, processing and recovery and disposal. The functional elements are described in the table below:

Table 1.0: Elements of a solid waste management system

Functional element	Description
Waste generation	Those activities in which materials are identified as no longer being of value and either thrown away or gathered together for disposal
On-site handling, and storage	Those activities associated with the handling of solid wastes at or near the generation point.
Collection	Those activities associated with the gathering of solid wastes and the hauling of wastes after collection to the location where the collection vehicle is emptied
Transfer and transport	Those activities associated with (1) the transfer of wastes from the smaller collection vehicle to the larger transport equipment and (2) the subsequent transport of wastes, usually over long distance, to the disposal site.
Processing and recovery	Those techniques, equipment and facilities used both to improve the efficiency of the other functional elements and to recover usable materials, conversion of products, or energy from the solid wastes.
Disposal	Those activities associated with ultimate disposal of solid wastes, including those wastes collected and transported directly to a landfill site, semisolid wastes (sludge) from wastewater treatment plants, incinerator residue, compost or other substances, from the various solid-waste processing plants that are of no further use

Source:Peavy *et al.* (1985)

A remarkable amount of work has been done, written and published on the issue of waste management in both the developing and the developed world. More effective and efficient management has been difficult to achieve in the developing countries and this can be attributed to wholesale adoption of technology from the developed world (UNHCS, 2000). For many years, refuse and waste management problems enhanced by an industrialized societies was characterized by the maxim ‘out of sight out of mind’ principle (WHO, 1999).

With time this attitude has begun to change and much progress has been made over the past decades. The problem of waste management is of global nature and its increasingly being recognized that the goal to form a cleaner environment can only be achieved by integrated control of all types of pollution and of all wastes whether they are discharged to air, water or to land. The state of Environment Report, 2000 stresses the need to address municipal wastes, plastics recycling and waste reduction from the source (NEMA 2000). This can be made possible within the framework of the existing physical, socio economic and ideal environments (UNCED, 2001).

Waste management is a global environmental issue which concerns about a very significant problem in today’s world. There is a considerable amount of disposal of waste without proper segregation which has led to both economic and environmental sufferings. It is better to segregate the waste at the initial stages when it is generated, rather than going for a later option which is inconvenient and expensive. There has to be appropriate planning for proper waste management by means of analysis of the waste situation of the area. Solid waste management can be bifurcated into mainly two phases. One is the waste management in the area where it is generated and second is the management of waste at dumping grounds.

These include the issues related to the waste generation, their storage, collection and removal from the collection points (Assad, 1995). There are many drawbacks in the existing waste management system. For example, allocation of waste bins at improper location, multiple and manual handling of the waste, no separate bins for recyclable waste, and pollution of natural water streams due to waste bin proximity. Source reduction, recycling and waste transformation are methods widely used to manage solid waste, however, in all these methods there is always a residual matter even after the recovery process to disposal.

The waste management issues are considered to solve some of the present situation problems like proper allocation and relocation of waste bins, check for unsuitability and proximity convenience due to waste bin to the users, proposal of recyclable waste bins for the required areas and future suggestions. Geographical Information System can be used as a decision support tool for planning waste management (Antunes, 1999).

The necessity of getting rid of these waste yields in an economic approach which is called as land filling (Tchobanoglous and Kreith, 2002).Landfill siting is an extremely difficult task to accomplish because the site selection process depends on different factors and regulations. It is becoming increasingly difficult due to growing environmental awareness, decreased amount of funding with extreme political and social opposition. The increasing population densities, public health concerns, and less land available for landfill construction are also the difficulties to overcome (Kao and Lin, 1996).

Environmental factors are very important because the landfill may affect the biophysical environment and the ecology of the surrounding area (Siddiqui*et al.*, 1996; Erkut and Moran, 1991; Lober, 1995). Economic factors must be considered in the siting of landfills, which include the costs associated with acquisition, development, and operation of the site (Erkut and Moran, 1991).

In Kenya the environmental impact assessment exercise in the case of waste treatment and disposal facilities like sanitary landfill, composting facilities has to be done at is at developmental stages.Environmental legislation pertaining to the submission of an environmental impact assessment report for landfills has been enacted by the National Environment Management Authority. Any municipal authority or designated agency engaged in the management of municipal solid waste anywhere in the country must perform an environmental impact assessment of the proposed site for a sanitary landfill operation. Landfill projects must comply with the standards for air, water (ground and surface), pollution, and other environmental norms (NEMA, 2003).

2.2 Risk of Poorly Sited Solid Waste Disposal Facilities

Site selection criteria for waste disposal facilities have been developed over the years by many institutions. Criteria for site selection commonly address issues such as proximity of the site to residential areas, the likely hood of leachate reaching an underground source of drinking water, based on soil permeability and other geologic factors, the possibility of a flood and or earthquake, the safety of transport routes, the protection of the environmentally sensitive land, other related safety issues and the availability of services, access and markets.

While addressing similar issues, the nature of their classification and presentations varies widely. The criteria recommended by the WHO for the siting of all solid waste disposal facilities are defined in broad terms and include both physical factors and the criterion of inequity (EPA, 1999).Open dump disposal facilities of solid wastes in third world thrives because of mistaken belief that it is the cheapest disposal method. Mexico City the largest city in the world generates some 10,000 tons of thrash most of which is left in giant piles exposed to the wind, rain as well as rodents(Tchobanoglous and Kreith, 2002).

Deposition of solid wastes along roads and riverbanks or in abandoned quarries with hope that the waste will disappear is both naïve and dangerous to human health and the environment. Solid waste disposal activities should be environmentally sound with regard to economy, aesthetics, energy and conservation. (Otieno, 2000) noted that improper disposal of waste was and is still a major environmental problem especially in developing countries. The main problem however is that our societies have not been educated on the need for a clean environment (Pugh, 1999).

Solid waste has emerged as one of the leading public policy issues of the 1990s. The solid waste issue has exploded around the siting of new landfills and particularly landfills which are being developed to take in out-of-state garbage. Eighty percent of the world's waste is disposed off in landfills (WHO 1999). As the production of garbage increases each year, landfill sites are diminishing. The shrinkage of landfills is most severe in the densely populated states. In addition, closure of existing landfills is, at best, problematic because of the lack of alternative waste disposal methods, this may lead to poor disposal of wastes and hence a lot of health problems (UNCED, 2001).

Fears that landfills will pollute groundwater and contaminate the drinking water are the overwhelming concerns with regard to landfill impacts on the environment and public health. Of particular concern is the long-term impact on future generations. The public distrusts the ability of government agencies to properly regulate the kinds of wastes disposed of in landfills or to monitor performance of landfills adequately (WHO, 1999). Numerous cases of groundwater contamination from landfills have been cited in the literature (EPA, 1988).

Consequences of the contamination of the drinking water have been well documented and include such problem areas as health, emotional stress, and inability to sell houses, disruption of family and social life, and emergence of psychological problems. How people perceive the contamination has a great deal to do with the resulting impact. One study found those who lived closer to the landfill and families with young children were more vulnerable to all of the possible adverse effects of contamination (Carla and Greg, 2000).

The public's concerns over increased truck traffic focuses on greater congestion, stray litter on the highways and in towns, and safety problems with trucks. Many land fill designers may not consider the road network of an area, if roads are narrow or two-lane highways that are perceived to be inadequate to handle the increased traffic then increased truck traffic during the hours of transporting are feared. This creates a possible increase in the number of road accidents .Some citizens have documented frequent violations of safety and driving codes by garbage trucks. Similarly, fears of increased accidents from rail transportation of solid waste may directly threaten water quality and safety (EPA 2001)

Many of the negative influences of transporting solid waste can be mitigated by strict enforcement of driving and safety regulations, restricting transportation of solid waste during school transportation hours, requiring covered vehicles to prevent stray litter and, if necessary, requiring a landfill developer to build a separate access road to the landfill (Kemper, 2002).

All sanitary landfills receive some degree of hazardous wastes. In fact, normal household garbage contains some hazardous wastes for example old batteries and fabric dyes. Small generators of hazardous wastes have been allowed to dispose of certain amounts into sanitary landfills (WHO, 1999). There is evidence of considerable illegal activity in the solid waste industry, and of illegal disposal of industrial hazardous wastes in sanitary landfills. The regulatory system is designed to have a check on all shipments of hazardous waste through what are called "manifests" which identify the type and source of waste. Manifests can be falsified despite penalties.

The ability to regulate what comes into a landfill, therefore, is only as good as the existing monitoring systems. Even if a landfill is carefully monitored, it is not possible to check every barrel of waste (EPA, 2001).One tonne of biodegradable waste produces between 200 and 400m^3 of landfill gas. Landfills released 25% of the UK's methane emissions in 2001, about 2% of greenhouse gas emissions (in terms of carbon equivalents). About a third of the 500 landfill sites taking significant amounts of biodegradable waste have gas controls and many sites extract the gas for energy recovery (Kemper, 2002).

About 48% of renewable gas and electricity now comes from landfill gas in Great Britain. Burning the methane produces carbon dioxide, which has a much weaker global warming effect (Bhardwaj& Singh, 1997). Extending these measures will reduce methane emissions over the next 10 years. There is a need for a better landfill site design and management to prevent pollution from organic acids, ammonia and other hazardous substances. Older sites relied on natural dilution to disperse the effects of the liquid that landfill produces (leachate). New landfills usually use liners to contain leachate. The leachate is collected and treated before being discharged or returned to the landfill site (EPA, 2001).

A number of experts point to potential problems with the state-of-the-art technology. Synthetic and clay liners are fallible; leachate collection systems require constant oversight; and covers are vulnerable to erosion, penetration by the roots of shrubs and by animals, reptiles and insects, and by the sun. Solid waste experts, including those at the Environmental Protection Agency, hold that eventually all landfills will leak due to natural entropic forces that take place once a landfill is no longer maintained. The risks for landfills, even state-of-the-art landfills, are uncertain. (EPA 2001)

The public's perception of risk is grounded on experiences of contamination in the past and the opinion of some experts that even modern landfills will eventually lead to environmental problems. Poor landfill siting would affect wildlife preservation this affects not only the tourism industry, but also recreational opportunities in a given place. The actual landfill site, road construction and increased traffic, and potential contamination of air and water could potentially disturb wildlife habitats and affect the recreation industry. Such a case was reported when a solid waste accident occurred, in the summer of 1988, when garbage washed up on New Jersey beaches (Rush Brook 1999).

Various ecosystems were also tampered with by the accident. If a landfill ends up polluting the environment, it will not only detract from the economic development potential of an area, but cleanup costs could be substantial (Carla and Greg, 2004).The documented cases of contamination are seen by landfill developers as resulting from what is now considered outdated technology. The landfill industry argues that much has been learned about disposal technology and that present technology and monitoring systems will prevent contamination from occurring in the future. In fact, it is argued, modern landfills actually enhance the overall environment, and the public health and safety (Antunes, 1999)

2.3 Inconvenience of Conventional methods of siting Landfills

Vigil (2000) in his argument puts an important consideration in the final disposal of wastes and the effects of disposal itself on the characteristics of the waste being disposed. Factors to be considered in the disposal of solid wastes include the effects of disposal on the environment, the disposal method to be used, the location of the disposal site and public health aesthetics.

Food and other organic wastes placed in a dumpsite will almost immediately start to undergo microbiological decomposition (often called putrefaction) as a result of growth of bacteria and fungi. If wastes are left in an open dump, flies can start to breed and odorous compounds can develop. Because the components that comprise solid wastes have differing initial moisture contents, re equilibrium takes place as wastes are disposed off. Where mixed wastes are stored together, paper will absorb moisture from food wastes and fresh garden trimmings. The major waste components may be contaminated by small amounts of wastes such as motor oils, household cleaners and paints (Otieno 2000).

The effects of this contamination are to reduce the value of the individual components for recycling. In conventional methods of citing a landfill, the various underlying factors like soil characteristics may not be considered. This often leads to contamination of ground water and other resources by leachate. Most of the papers written about the siting of a solid waste management facility refer to the siting of a landfill. Compost facilities are associated with somewhat different environmental concerns. The operation of the facilities themselves is of concern because of odors, dust, litter and noise (MOE, 1998).

These will differ depending on the method of composting used and may be reduced with certain mitigating measures. A compost facility may also be a source of water contamination as the water used to maintain the desired moisture content in the organic material can often leach contaminants (MOE, 1998). Transportation issues are important for compost operations as trucking of wastes is not only costly but can also have negative environmental impacts. This is particularly important when siting the facility, as the location of the facility determines the amount of transportation needed.

In the past, land filling in wet areas was considered acceptable if reasonably adequate drainage was provided and if nuisance conditions did not develop (McNally, 2002). The usual practice was to divide the area into cells or lagoons and to schedule the filling operations so that one individual cell or lagoon would be filled each year. Often, solid wastes were placed directly in the water in areas with high ground water levels. As an alternative, clean fill material was added up to or slightly above the water levels before waste filling operations were started o withstand mud waves and to increase structural stability, dykes used to divide the cells or lagoons were constructed with riprap, trees, tree limbs, umber demolition wastes and related materials in addition to clean fill material. In some cases, to prevent the movement of malodorous leachate and gases from completed cells or lagoons, clay and lightweight interlocking steel or wood sheet pilling have been used (Rushbrook, 1999).

More recently, because of concern over the possibility of ground water contamination by both leachate and gases from landfills and the development of odors, the direct filling of wet areas is no longer considered acceptable (MOE, 1998). If wet areas are to be used as landfill sites, special provisions must be made to contain or eliminate the movement of leachate and gases from completed cells. Usually this is accomplished by first draining the site and then lining the side and bottom with clay liner or other appropriate sealants. If clay liner is used, it is important to continue operation of the drainage facility until the site is filled in order to avoid the creation of uplift pressures that could cause the liner to rupture from heaving (EPA 2001).

According to Rushbrook, (1999) among many alternatives, some countries especially those that boarder the sea coasts have resorted to ocean dumping. The immediate obvious merit of this suggestion is removal of waste from many inhabited area. One immediate obvious disadvantage is the need for complex political negotiation to legitimize such use of international waters. Every year some 25,000 metric tons of packaging materials including half a million bottles, cans and packaging materials are dumped in the ocean. Until 1988, many cities in the U.S.A dumped municipal refuse, sewage sludge and industrial waste into the ocean.

However, several unhappy incidents have shown that toxic materials added to coastal waters can remain undispersed long enough to being ingested by microorganisms and then concentrated as it passes along the food chain into the higher organisms (W.H.O, 1999). The plastics also remain at the shore making the beaches look so ugly. Recently, geographical information system (GIS) has been used to facilitation landfill siting. GIS can be used to convert geo-referenced data into computerized maps and map analysis tools can be used to manipulate maps in an efficient way (Kao et al., 1997). This is especially useful when dealing with large amounts of data, which is typical in landfill siting. The outcome of this step is a long list of potential candidate sites.

Typical constraints relating to water resource protection are:

- Landfills should not be constructed in areas with fractured bedrock, karst topography, etc. to ensure groundwater protection.

- Water bodies (lakes, streams, wetlands, etc.) are not suitable for landfill development.
- Areas with complex geology are not suitable as it will be difficult to monitor and remediate in the event of groundwater contamination.
- Landfills should not be sited in protected areas such as forests, wetlands, and endangered species habitats.
- Landfill should not be constructed in the floodplain of a river or other areas susceptible to frequent flooding.

2.4 Application of GIS

A GIS may be defined as an organized collection of computer hardware, software, data and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information (Burrough, 1986). GIS is a specific information system applied to geographic data and is mainly referred to as a system of hardware, software, data , people and procedures designed to support the capture, management, manipulation, analysis, modelling and display of spatially-referenced data for solving complex planning and management problems, GIS has following advantages:

a) Complex techniques requiring a large number of map overlays and calculations become feasible.

b) It is Possible to improve models by evaluating their results and adjusting the input variables.

c) Input maps derived from field observations can be updated easily when new data is collected. Also, after completion of project others can use the data in an effective manner.

d) Integrate different data sets acquired from library, laboratory, and fieldwork with remotely sensed data.

e) Helps in decision making.

f) It also helps in change detection.

The applications of GIS are heavily dependent on both timeliness, and accuracy of the data they contain, as well as the geographic coverage of the database. For a variety of applications, Remote Sensing can provide timely data at scales appropriate to a variety of applications. Therefore, it appears that the collective use of remote sensing and GIS techniques can enhance the operational capabilities of these techniques in decision making and optimal use of natural resources. Merging these two technologies can result in a tremendous increase in information for a variety of users.

Site selection criteria for waste disposal facilities have been developed over the years by many institutions. Criteria commonly address issues such as proximity of the site to residential areas, the likely hood of contaminants reaching an underground source of drinking water, based on soil permeability and other geologic factors, the possibility of a flood and or earthquake, the safety of transport routes, the protection of environmentally sensitive land, other related safety issues and the availability of services, access and markets. However, while addressing similar issues, the nature of their classification and presentations varies widely. The criteria recommended by the WHO for the siting of all solid waste disposal facilities are defined in broad terms and include both physical factors and the criterion of inequity (EPA, 1999).

Site selection is a spatial problem that requires inputs of large volumes of biophysical, environmental, and sociopolitical data. A geographic information system GIS) is a tool for entering, storing, manipulating, analyzing and displaying large volumes of spatial data (Congalton and Green, 1992). Recent advancements in GIS have developed techniques to select, rank and map sites that are suitable (or unsuitable) for a specific purpose (Davis, 1996). A GIS-based site-selection procedure is potentially useful to manage solid wastes Pollution through the identification and mapping of sites where the construction of a landfill is less likely to produce pollution of riverine flows and underground water. Site suitability analysis involves overlaying graphically (or combining databases) of more than one coverage to locate suitable spatial (or attribute) conditions (Davis, 1996).Vector-based methods are most commonly applied to identify suitable sites for various purposes. For example, vector GIS has been used to identify dump sites in Malaysia (Yagoub and Buyon1998), landfill sites in the United States (Herzog, 1999) and Turkey (Basagaoglu*et al*,. 1997), solid waste disposal sites in the Philippines (Cruz 1993), and animal waste application sites in Australia (Basnet*et al*., 2000).

Manual methods adopted for analysis of many factors would be a lengthy and tedious work. Also there are possibilities of errors while merging the spatial and non-spatial data. But in GIS, as the work is carried in layers, there are least chances of confusion or error and the system is capable enough to coordinate between spatial and non-spatial data. There are several areas where the municipal bodies are striving hard to provide best of their services for the betterment of the city. This can be achieved with the help of GIS which can handle different data forms like spatial as well attribute data simultaneously. Solid Waste management can be handled efficiently in several ways like Identification of exact location of waste bins, either with GPS or surveys and demarcating on the base map. Secondly maintaining a record of the waste bins, identification of existing waste lifting pattern and Location of the waste dumping ground/landfill site and lastly allocating a unique number to all the waste bins so it can be easily and quickly located in case of any complaint registered or planning and maintenance and maintaining a record about the amount of waste being dumped at the landfill site. The field of GIS is a rapidly expanding aspect of information technology which can potentially contribute a great deal to site selection for waste disposal facilities.

GIS can be used to enhance the processes of data integration and spatial analysis, in terms of both time and accuracy. Furthermore GIS can be used to facilitate the process of what if questions as it is relatively easy to change the search criteria and keep running the model to find the optimal site. It has been argued that GIS can provide a basis for justifying eventual siting decision which could be stronger than that provided by ad hoc methods (Carver and Open Shaw, 1992) GIS has been used by major waste contractors to identify the potential landfill sites within a country. The Midlands Regional Research Laboratory at the University of Leicester has investigated the role of GIS in this purpose.

The data from various sources are incorporated into a GIS as a collection of data on one characteristics or criteria. The data layers have to be converted into digital format from the maps using a table digitizer which collects x and y coordinates of points, lines and areas. The GIS is the used to carry out the following operations:

- Map transformations-to bring the data layers onto a single map projection
- Proximity analysis-to locate buffers around certain features (e.g. land within 500 meter of housing)
- Extraction to select appropriate location from the maps
- Overlay to compare maps and locate areas which conform to location criteria.
- Presentation-to annotate the maps for easy and clear presentation

The Geographic Information Systems (GIS) model can be used as a tool to assist local authorities in the selection of suitable sites for landfill. In Ireland, GIS has widespread use in issues dealt with by local authorities. Its full potential, to become an integral part of the planning process has been fully exploited within local authorities (O'Sullivan, B., Cork County Council, pers. comm., 2001). The landfill GIS models have been designed so that non-GIS experts, but those with a basic knowledge of GIS, can run the models. In this way, it will provide a user-friendly tool to aid decision-making where a broad array of complex criteria must be considered.

The study site and methods used for the landfill location are described below.

1. Exclusion of areas unsuitable for landfill

2. Weighting of residual areas

Table 2.0 Exclusion of areas unsuitable for a sanitary landfill

Exclusion areas

1.Non geological (anthropogenic) factors	**2.Geological and correlated factors**
Built areas ▪ Urban & Hi-Tech Industrial Areas: (major/minor administrative centers, areas with more than 10 houses per hectare) ▪ Industrial Areas: (hazardous, manufacturing, food/agricultural) ▪ Airports: (national, local, flight paths) ▪ Roads: (highways, motorways, municipal, other etc.) ▪ Railways ▪ Water Supply: (reservoirs, wells, boreholes, springs) ▪ Military Areas ▪ Public Buildings/ Infrastructures: (hospitals, schools, gas stations, treatment plants) ▪ Linear Infrastructures: (cables, pipelines, etc.) ▪ Nature Reserves: (ecological, biogenetic, etc.) ▪ Agricultural and Game Reserves ▪ Geological and Archaeological Reserves ▪ Mining Areas not Suitable for Landfill ▪ Leisure Areas: (speleological, parks etc.)	**Hydrological and geomorphological** ▪ Rivers/Canals (permanent / temporary) ▪ Floodplains ▪ Lakes, Swamps ▪ Coastline ▪ Steep Slopes ▪ Major Geological Faults:(active and potentially active, prone to surface rupture) ▪ Regionally important aquifers with extreme vulnerability

2.5. Theoretical Framework

2.5.1. Integrated solid waste management

Integrated solid waste management (ISWM) can be defined as the selection and application of suitable techniques and management programs to achieve specific waste management objectives and goals. ISWM is evolving in response to the regulations developed to implement the various laws on waste management. A hierarchy in waste management can be used to rank actions to implement programs within the community. The ISWM hierarchy developed by the US Environmental Protection Agency (EPA) and is composed of the following elements: source reduction, recycling, transformation and land filling.

Source reduction: Is the highest rank of the ISWM hierarchy. It involves reducing the amount and or toxicity of the wastes that are generated .It's the most effective way to reduce the quantity of waste generated, costs associated with its handling and environmental impacts.

Recycling: It's the second highest rank in the hierarchy; it involves the separation and collection of waste materials, the preparation of these materials for re-use, reprocessing and manufacture. Recycling is an important factor in helping to reduce the demand on resources and the amount of wastes requiring disposal by land filling.

Waste transformation: It involves physical, chemical and biological transformation s that can be applied to solid wastes.

Land filling: Ultimately something must be done with solid wastes that cannot be recycled, re used and the residual wastes remaining after then recovery of conversion products or energy.Landfilling is the lowest rank in the hierarchy of ISWM because it represents the least desirable means of dealing with society's waste.

An important consideration in the final disposal of wastes and the effects of disposal itself on the environment based on the characteristics of the waste being disposed have to be considered. The disposal method to be used, the location of the disposal site and public health and aesthetics are also factored in. In regard to solid waste management, sustainability should involve:

- A system that does not pollute or overuse the waste absorbing capacity of the system leading to breakdown of a system
- It should have minimum environmental impact
- The activity does not damage the natural resources
- It should last for a substantial period of time

2.6. Conceptual Framework.

2.6.1 GIS and the concept of sustainability

In some cases sustainability is simply used to mean the practical long term results of some action or set of actions that is consistent with desired out comes. It involves a continuation over a long period of time of an activity that is in progress. Sustainability is a complex concept referring to interactions of major critical environments. These environments include; the physical, the economic, the institutional, political and the social environments. Within each environmental system, there are subsystems, which interact together and function as a whole.

The physical environment comprises of natural resources used by man for the purpose of development. In this context it is land that is needed for the present and future sanitary landfills. The present use of land as dumpsite has a bearing to the future need of land for the same purpose.

The economic environment can be viewed as consisting of all the activities which deal with the extraction of natural resources, processing, distribution and maintenance of capital of which all are governed by market systems where the overriding factors is profit. To get desired profits a system will try to minimize costs through reduction of wastes, maximization of income through sales and revenue collection and effective planning system. Political environments concerned with policy formulation. For it to do this, it utilizes data on physical environment, social environment, institutional arrangements, technology in use, stakeholder needs, costs, income and planning requirements. Policy tries to harmonize all the other facets of the environment in order to achieve desired goal and minimize negative impacts.

Institutional environment takes care of the structural arrangements, stakeholder, technology and planning aspects. Effective planning Makes use of information derived from other systems (physical, economic, political and social). In conventional methods of siting a landfill, the various underlying factors like soil characteristics may not be considered. This often leads to contamination of ground water and other resources by leachate.

Recent advancements in GIS have developed techniques to select, rank and map sites that are suitable or unsuitable for specific purposes. A GIS-based site-selection procedure is potentially useful to manage solid wastes Pollution through the identification and mapping of sites where the construction of a landfill is less likely to produce pollution of riverine flows and underground water. Site suitability analysis involves overlaying graphically or combining databases of more than one coverage to locate suitable spatial or attribute conditions .Vector-based methods are most commonly applied to identify suitable sites for various purposes. Data availability is of prime importance when using GIS. In the current study, a comprehensive body of information related to environmental (groundwater protection area, stream network, flood plain, etc.), socio-cultural (municipal development planning area, historic and important cultural sites, population, etc.), and engineering-economic factors (road network, land slope, digital elevation, soil cover, geology, faults, etc.) are factored in order to come up with the most appropriate site for a landfill

Constraint mapping is a method that applies constraints over a large area. The constraints are plotted onto a series of maps by blocking out areas that do not meet the constraint. These maps are then overlaid on one another essentially leaving only areas that meet all constraints

uncovered. The blank areas become the candidate sites and go on to be evaluated in more

detail. The map overlays can be done physically with areas blocked off on transparent layers of the map. All the geographical information available is converted into Geographical

Information System (GIS)-compatible format, such a system is used to perform constraint mapping. If the areas identified are too large or too plentiful, more constraints

may need to be added to generate a suitable number of candidate sites. If no areas meet

all of the constraints either the search area must be enlarged or one or more of the

Constraints must be relaxed in order to find suitable sites. This information is presented in a flow chart as follows:

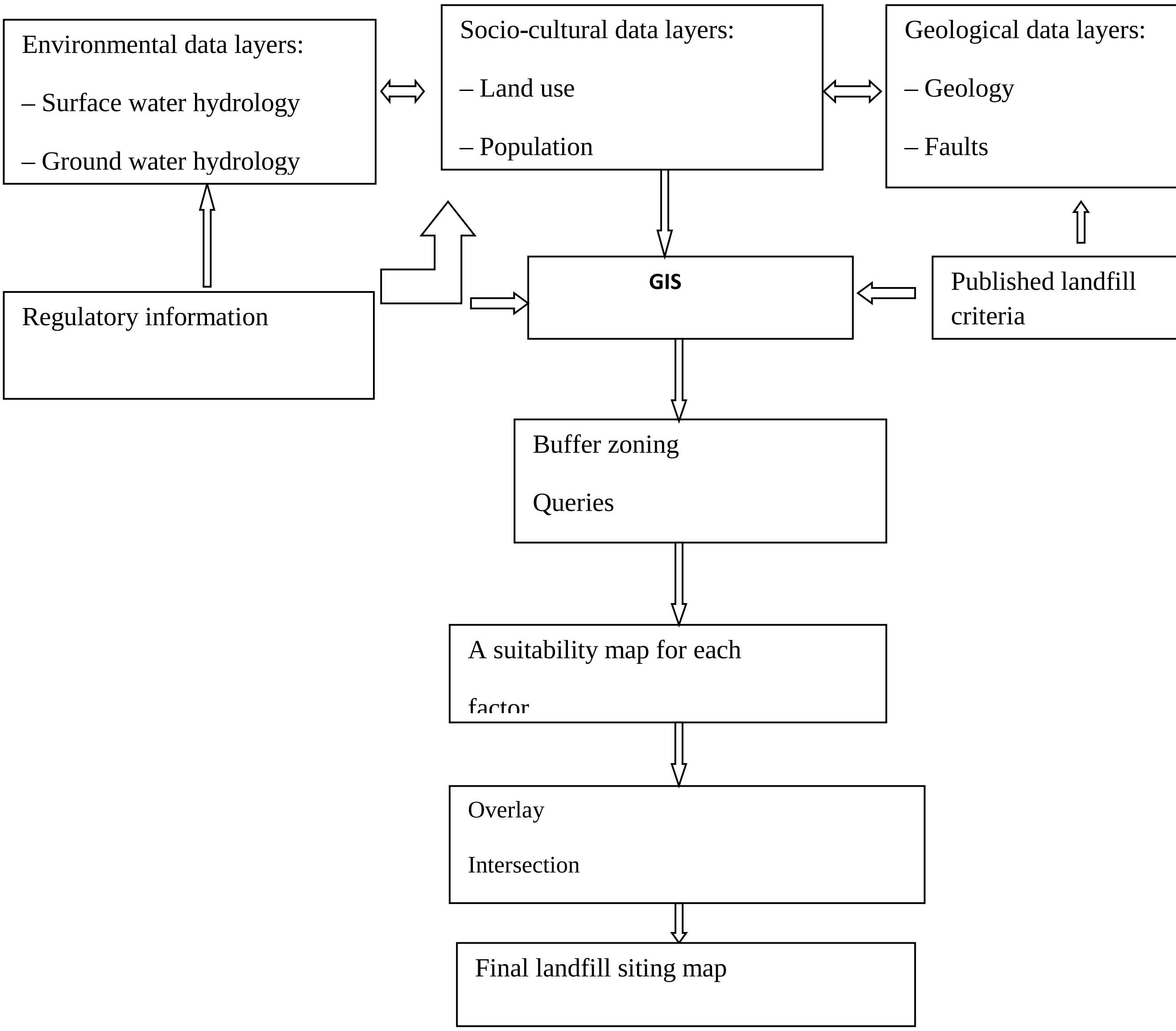

Figure 2.0: Conceptual Framework

CHAPTER THREE

METHODOLOGY

3.1. Introduction

The landfill sitting process is a complex operation requiring a number of steps before reaching the final outcome. The site selection process can be broken down into several distinct tasks where by each task is designed to narrow a list of possible locations to a few, which can be passed on to the final stage of investigation. This particular research applied Constraint Mapping Technique to reduce the search area over vast land coverage and to leave only those areas that are suitable for siting a landfill.

3.2. Data sources

Table 3.0 Data Source: (Modified from Dubertret (1996) and Bedran (1997)

Coverage	Description	Attributes
Company Boundary	This coverage was digitized from a map of the study area scaled at 1:20,000. A larger scale was not needed because it does not reveal additional detailed features this was generated from an aerial photograph flown over the study in the month of December 2012.	The study area is bordered by Unilliver tea estates to the north, South west mau forest to the East, kipsigis land units to the south George Williamson tea estates to the west.
Geology	The geological map of Kericho was digitized at a scale of 1:20,000. Data for building this coverage was obtained from previous work and recent observations drawn from an aerial	Name of geological formations, their age, type, and origin

	photograph flown over the study area.	
Soil	The available soil cover maps (scale 1:20,000) were digitized and prepared for the study area.	Name and general classification of the soil types
Rivers	A coverage representing temporary and permanent rivers was developed on a scale of 1:20,000.	Name, length, and type
Topography contour	The scale of 1:20,000 was adopted for digitizing the topography resulting in 50m contour lines. In areas where more precise information was available, closer contours were possible (20m).Point elevation coverage was derived from the elevation contour lines coverage. Then a digital terrain model was constructed. This enabled the creation of a slope map of the study area	Length and elevations
Land use	The land use map was created based on a scale of 1:20,000.It includes land use types that were regrouped into the following categories: settlement, forest and agricultural. The land use map was derived from an aerial photograph flown over the study area in the month of December 2013.	Area, perimeter, and Land use/land cover category
Population	In this coverage population densities were introduced to every inhabited village. The population census of the area was obtained from The Kenya National Bureau of Statistics(2009 Census)	Every inhabited village has a population of 1000 people.
Major roads	In this coverage, roads were classified into major and minor, roads, The coverage was digitized from the scale 1:50,000 and was transformed to the Lambert Conformal Conic Projection.	Length and category

3.3 Data capture

Data availability is of prime importance when using GIS. In the current study, a comprehensive body of information related to environmental (groundwater protection area, stream network, flood plain, etc.), socio-cultural (municipal development planning area, historic and important cultural sites, population, etc.), and engineering-economic factors (road network, land slope, digital elevation, soil cover, geology, faults, etc.) was collected and produced in a digital format .The database requirements were set as one of the objectives of the project at hand. These included a definition of the study area boundary, the required data layers or coverage, the features needed in each coverage, the attribute data for each feature type and how to code and organize these attributes scale and base map projections was adopted for the whole data set. The study area is an agricultural production zone and most of the waste generated is organic originating from flower stems and tea leaves. The company employees and their dependants also generate most of the organic wastes which are mainly kitchen wastes, garden wastes and yard trimmings. The inorganic waste generated consists mainly of industrial wastes which are: packing materials, steel and beverage containers, old electric appliances, old furniture and packaging plus office papers. Measurements of all wastes generated were taken at the at the disposal wastes based the nature of the waste that is organic or inorganic.

To avoid problems associated with poor waste management the company has tried its best to reduce waste through: source reduction, composting, reuse and recycling most of the wastes generated.

3.4 Constraint Mapping Techniques (CMT).

Constraint Mapping Techniques (CMT) was used to designate areas, which have unsuitable physical and other environmental characteristics.

Constraint mapping is a method that applies constraints over a large area (Sumanthi 2008). The constraints are plotted onto a series of maps by blocking out areas that do not meet the constraint. These maps are then overlaid on one another essentially leaving only areas that meet all constraints uncovered. The blank areas become the candidate sites and go on to be evaluated in more detail. The map overlays can be done physically with areas blocked off on transparent layers of the map. If the areas identified are too large or too plentiful, more constraints may need to be added to generate a suitable number of candidate sites. If no areas meet all of the constraints either the search area must be enlarged or one or more of the constraints must be relaxed in order to find suitable sites(Natesan 2008).

Central to this is a control file which lists the “rules” used for the constraints mapping. Each rule can be defined by a number of parameters.

- Rule type – Query, buffer or wait (omit from the analysis)
- Input dataset name
- Query
- Buffer distance (m)
- Output dataset name

With unsuitable areas excluded, potential sites were simply selected based on the remaining areas. According to the technique, sites can be selected based on performance basis, on ability and on economic grounds. Potential sites were then subjected to rapid preliminary screening to narrow down numbers to more desirable sites which would then be subjected to detailed evaluation studies.

The second step suggested by the guideline is to further screen the potential sites. A minimum of 3 sites should be selected in order to allow a reasonable comparison and allow the retention of alternate sites if the preferred site proved unworkable (Davis 1996). Screening is conducted based on conceptual design and costing for the sites in question in addition to a selected specific set of critical environmental criteria (EPA 1999).

3.5 General Site Selection Criteria

Criteria used to determine the most suitable site for landfills have been identified based on the guideline produced by the Ministry of Environment, Kenya and also in collaboration with the other environment bodies and physical planning groups (NEMA 2003). The criteria are both constraints and factors for an ideal siting of landfills. The constraints were related to roads, open water, protected areas, urban, rural residential areas, soil permeability and soil type, land use/land cover and distance to transportation routes. The above criteria are then refined according to the existing and established guidelines in Kenya and also in agreement with the Physical Planning Department, which are briefly explained in table 3.1

3.5.1 Proximity to surface water

A landfill must not be located near any surface streams, lakes, rivers or wetlands. For this reason, a 100-meter buffer would be placed using the function in GIS software, which will be used to generate the buffer around all surface waters such as streams, lakes and wetlands. The 100-meter buffer is in line with riparian reserve guidelines produced by the Ministry of Water and Irrigation, Kenya

3.5.2 Distance from transportation routes

Aesthetic considerations would be of good practice for good planning and based on this principle, 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 the current practice provided under supplementary guidelines for development of residential, industrial and commercial sites under the Ministry of Urban and Regional Planning, Kenya.

3.5.3 Distance from environmentally sensitive or protected areas

The location of a landfill in close proximity to sensitive areas such as fish sanctuaries must be avoided, and mangrove areas and areas gazette for special protection would be excluded. Apart from the area being excluded, a 3,000 meters buffer would also be created surrounding the environmentally sensitive area. The 3,000-meter buffer is in line with the guidelines produced by the Ministry of Environment and Natural Resources, Kenya.

3.5.4 Distance from urban areas

Landfills should not be placed too close to high-density urban areas in order to mitigate conflicts relating to the Not in My Back Yard syndrome (NIMBY). This guard against health problems, noise complaints, odour complaints, decreased property values and mischief due to scavenging animals. For this reason, population density was then generated based on the settlement patterns in the villages and the population statistics Census in GIS ready format produced by the Applied Research Department Finlay's (K) limited.

3.5.5 Distance from rural settlements areas

Due to the same conflicts relating to the NIMBY syndrome, development of landfills shall be prohibited within 3000 meters from village settlements. The rural settlement area was designated either by point location or by polygons in the Kericho District map and a 3000-metre buffer shall be created around it. There is no pre-qualification of the use of 3,000-metre buffer but such a distance should be sufficient to guard the interests of the rural settlement area around the company.

3.5.6. Landform and Soil Type

The permeability of the underlying soils and bedrock will greatly influence how much leachate is escaping a landfill site; therefore, preference is given to a landform that is somewhat located in flat or undulating land the soils should be impermeable so as not to allow leachate to escape to the water bodies and the surrounding environment. The soil below and adjacent to the landfill must be firm to allow for construction of roads and other structures. The ideal soils are silt and clay soils.

3.5.7. Land use/land cover

The Land use and Land cover must be known in order to determine which areas are more suitable for a landfill. Land use types such as grassland, forests and cultivated land would be considered and assigned an appropriate index of land use suitability. The Applied Research Department, Finlay's has identified several classes of land cover and for the purpose of this research three (3) classes were used, natural forests, rivers and other natural water bodies and grasslands.

3.5.8. Haul distance

Whilst a landfill should not be located within 100 meters of a road it would be more cost efficient for landfills to be located not too far away in order to avoid high transportation costs.

3.6. Screening criteria

A spatial analysis was performed to identify potential landfill sites, objective criteria and factors were set and evaluated for their suitability of the study area given the related legislation, restrictions, rules, experiences, and local expertise. Criteria may be defined as rules that prohibit a landfill from being placed within a specific area, whereas factors are important attributes that should be used to evaluate the suitability of a site. Other than assessing and comparing the suitability of a candidate site, the criteria and factors presented in Table 3.1 were used to screen out unsuitable areas and define a model objective for implementation in landfill siting practices**.**

Table 3.1: Selection criteria used in landfill siting procedure

Factor type	Feature	Criteria
Environmental	Surface water	Landfill at least 50 m away from temporary rivers Landfill at least 100 m away from permanent rivers and lakes
	Ground water	Landfill area should have a minimal depth to groundwater of 60 m
Socio-cultural	Land use	Avoid agricultural and residential land use areas
	Population	Avoid towns and villages Landfill should be at a minimal distance of 500 m from areas of population larger than 2000

	Cultural environment	Avoid historical landmarks
Geological Data	Geology and faults	Avoid karst topography The site should be located at a minimal distance of 100m from existing faults.
	Topography	Site slope should be less than 5 % (UNEP, 1994)
Road Network	Soils	The most suitable kind of soils is soil mixtures and clay rich soils.
	Roads	The site should be located at a maximum distance of 100m from a major road.

Source: UNEP 1994

3.7 Siting procedure

Once the needed data was collected, it was converted into a raster format to produce various map layers that spatially represent various factors contributing to the selection process. Numerous intermediate or analysis map layers were created using GIS map analysis approaches. The latter included buffer zoning, neighboring computation, and geo-processing tools (overlay, intersection, union, clipping, etc.). While the intermediate map analysis allowed the exclusion of areas not satisfying the specific siting criteria, the geo-processing tools constituted the most commonly used GIS function in selecting the sites satisfying all the required conditions.

Values of cell features are expressed with numbers in various geo-referenced map layers. With logical or arithmetical operations, this overlay function performed arithmetical expressions on existing map layers to create a new map layer. Of these expressions, each map layer was treated as a single variable, and a new value of each cell was computed based on the expressions from values of the cell at the same geo-referenced location of map layers included in the computation. Accordingly, all the map layers satisfying the criteria were developed and an overlay map was obtained representing the final landfill suitable areas.

CHAPTER FOUR

RESULTS

4.1.1 Amount and source of waste generated

The rate at which waste is generated and their compositions are the principal parameters essential for the planning of any disposal facility. Waste is generated from different sources: residential areas, industrial activities, agricultural activities, construction activities and offices as outlined in Table 4.1

The amount of wastes generated at the study area was weighed basing on the source and the composition of the waste. The total amount of waste generated per day in the study area is approximately 5 tonnes of which 3 tonnes are salvaged through recycling; reuse and composting the other 2 tonnes end up in the open dumpsites used by the company. The results are presented as follows:

Table 4.1. Source of waste generated.

Source of waste	Waste composition
Household waste	-Organic kitchen waste -sweepings, rags, paper -plastics, rubber, glass, leather, bones and metals -Ashes -Garden wastes, yard trimming. -textiles: cotton, curtains, used clothes -sanitary waste: disposable nappies
Agricultural wastes	-flower cuttings -yard trimming

	-wasted tea leaves
Office waste and institutional wastes	-paper from stores, offices, schools, warehouses and hotels -wood: furniture pencils, lollipop sticks. -Food remains
construction waste	Gravel, sand and rocks
Industrial waste	-Packaging material -Discarded waste products -Steel cans and packaging bags
Special waste	-old electric appliances, batteries, car parts, leather, (purses, clothes, shoes)

Source: Field Research

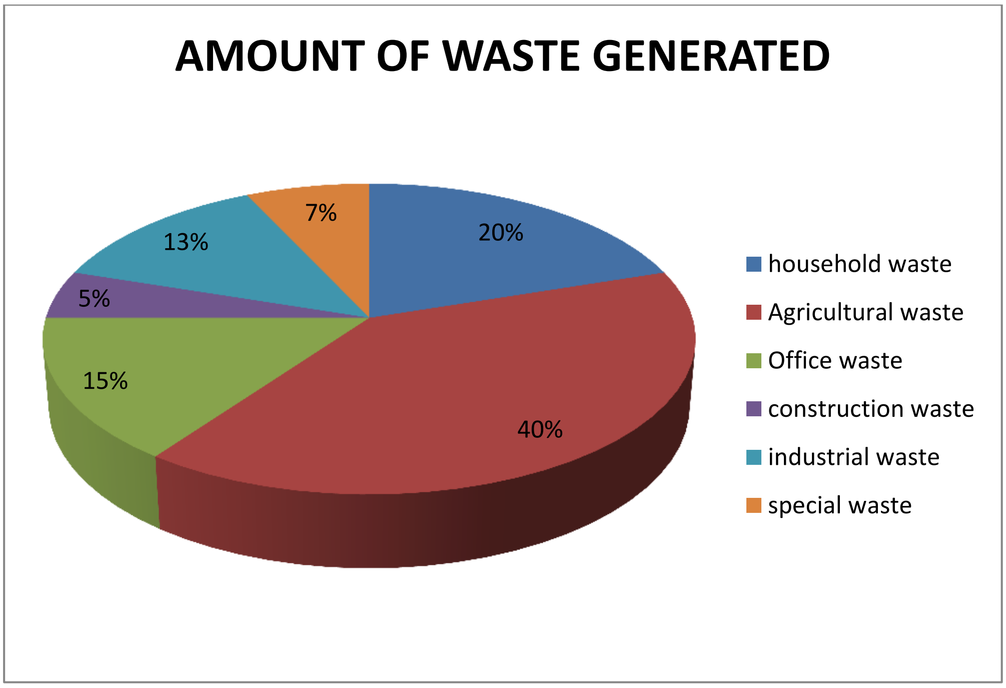

Fig: 4.0.Amount of waste generated in percentage (Source: Author, 2012)

The spatial operations for constraint mapping began by identifying the criteria or conditions for constraint mapping and after that the criteria was converted into GIS layers. From the GIS layers the spatial operation was performed. The spatial operation is normally performed in conjunction with GIS functionality found in most GIS software. This particular study used the query functionality to a create buffer surrounding the theme such as river, road and others. In particular, spatial operation to produce the buffer was conducted for the following 5 themes:

1. Create 100 meters buffer from surface water and water sources,
2. Create 100 meters buffer from transportation routes.
3. Create 100 meters buffer from historical landmarks.
4. Create a buffer on residential areas basing on the population on the enumeration blocks of available census,
5. Create 100 meters buffer from agricultural land use areas.

   Analysis employed was descriptive and quantitative. Data is represented in form of text, charts, figures and maps,

4.2. Map presentations

4.2.1 Land use map

The Land use type must be known in order to determine which areas are more suitable for a landfill. Land use types such as, forests and cultivated land would be considered and assigned an appropriate index of land use suitability. The Applied Research Department at Finlay's has identified several classes of land cover and for the purpose of this research seven (7) classes were used i.e. cultivated land, eucalyptus plantation and manmade forests, tea plantation, natural forest, settlement areas, recreational areas, factories, manufacturing and packaging areas(see Fig 4.1).

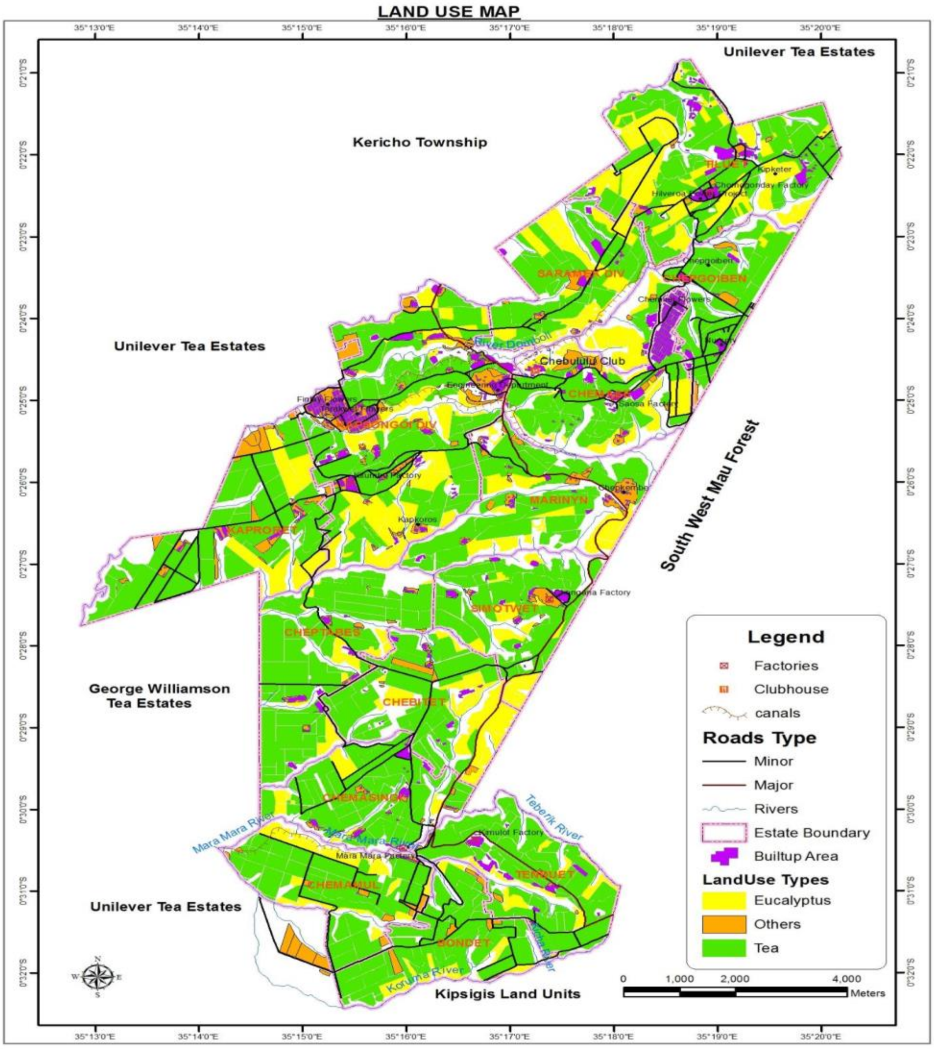

Figure 4. 1: Land Use map   (Author, 2015)

4.2.2 Rivers and drainage pattern

A landfill must not be located near any surface streams, lakes, rivers or wetlands. In this case a landfill should be located at least 50 m away from temporary rivers and at least 100m away from permanent rivers and land. Fig 4.2 shows the drainage pattern in the study area

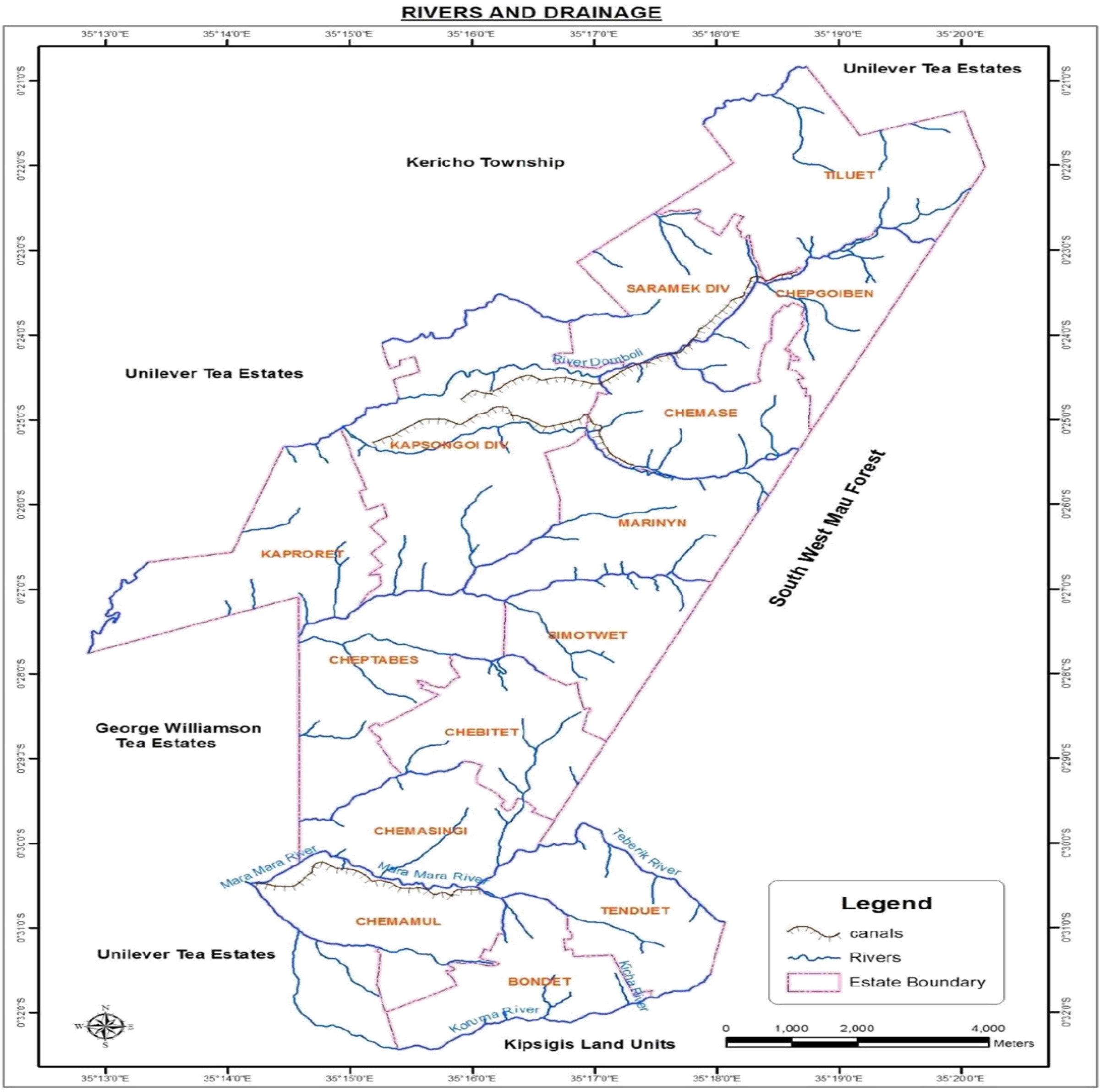

Fig 4.2: Rivers and drainage map (Author, 2015)

4.2.3 Road network

Whilst a landfill should not be located within 100 meters of a road it would be more cost efficient for landfills to be located not too far away in order to avoid high transportation costs. The roads should be easily accessible by solid waste vehicles in all weather conditions. Fig 4.3 shows the road network in the study area.

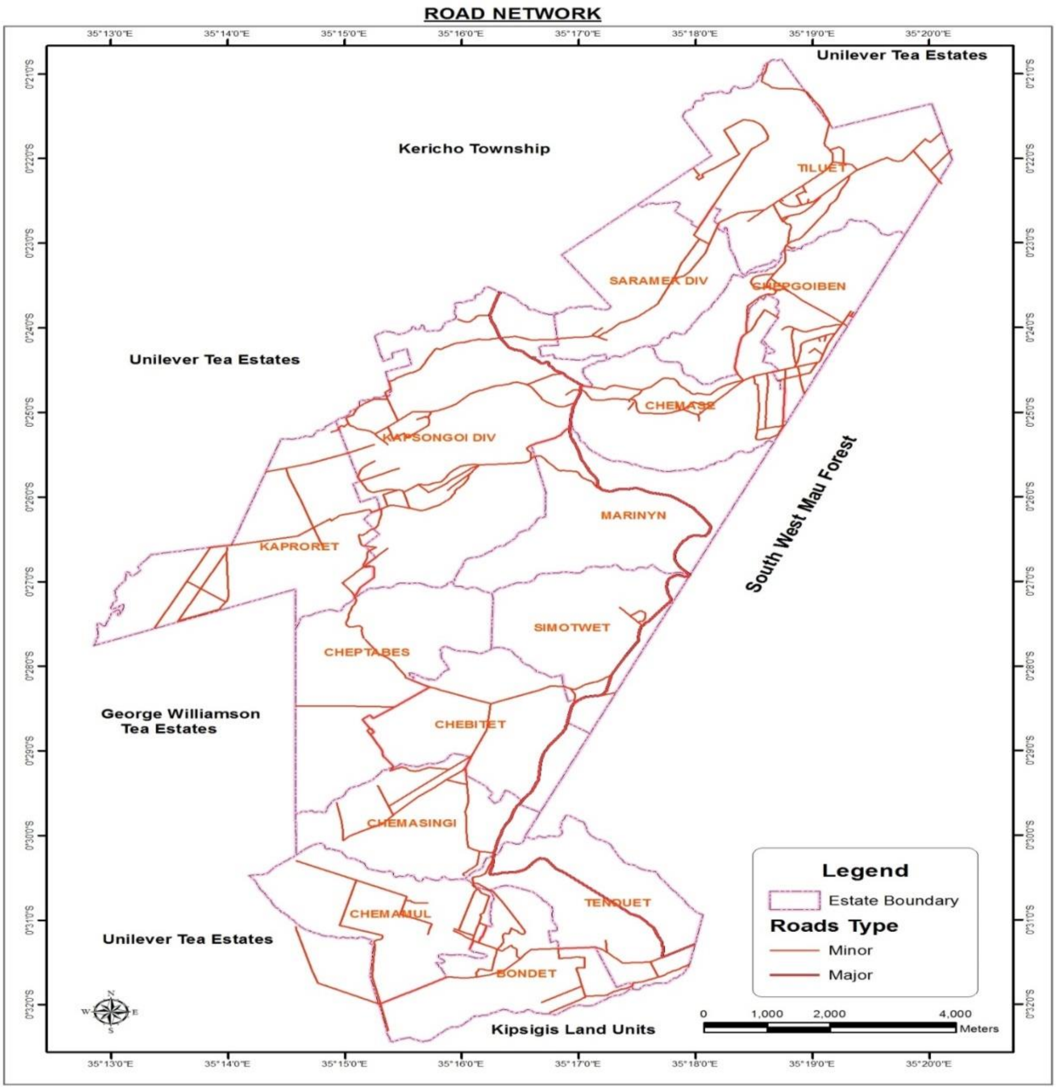

Fig.4.3 Road Network map (Author, 2015)

4.2.4. Built up areas

Landfills should not be placed too close to high-density settlement areas in order to mitigate conflicts relating to the Not in My Back Yard syndrome (NIMBY). This also guards against health problems, noise complaints, odour complaints, decreased property values and mischief due to scavenging animals.

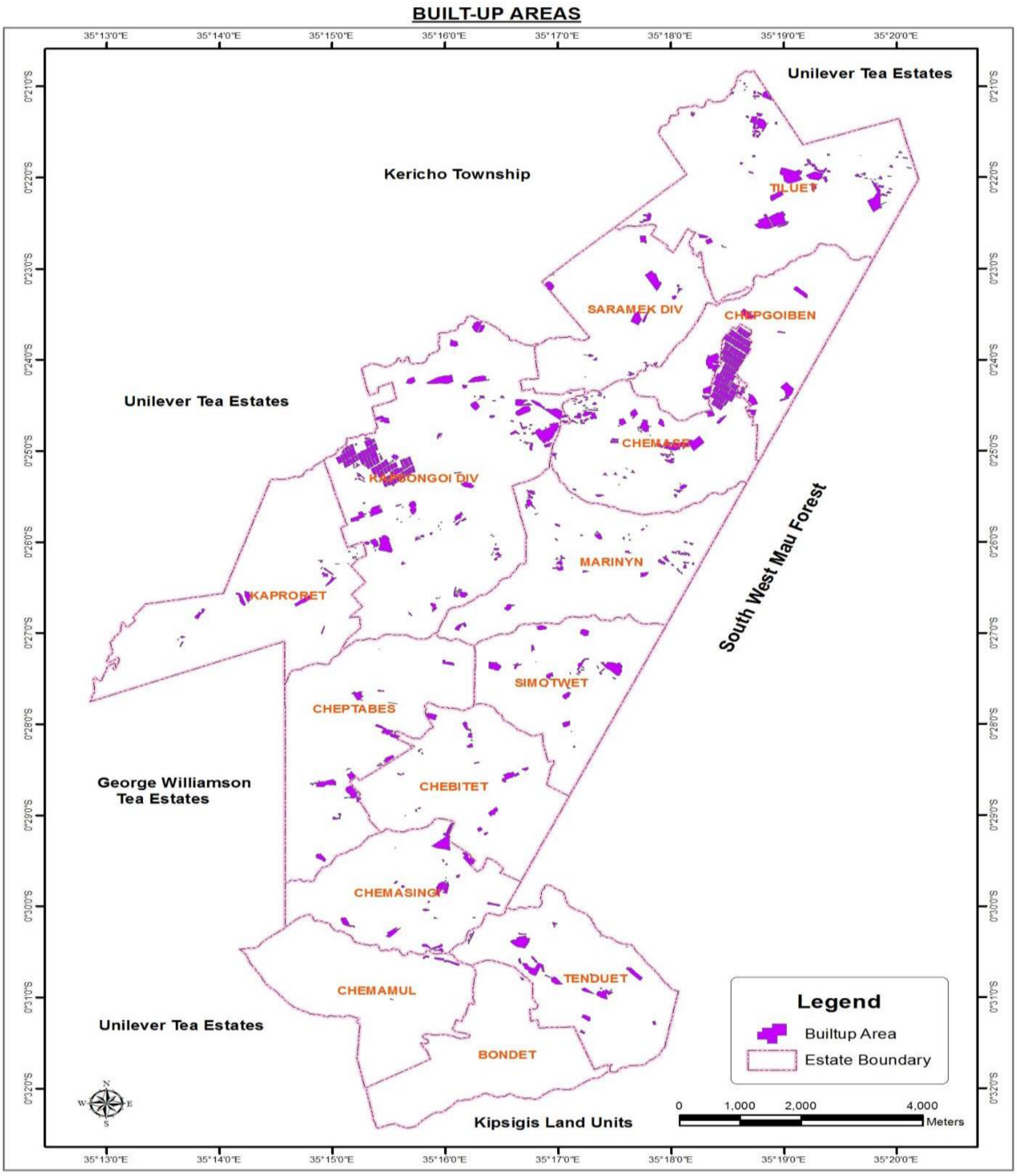

Fig 4.4 Built up areas4.3.Analysed map presentations (Author, 2015)

4.3.1. Environmental Data

a) Surface water

A coverage representing temporary and permanent rivers was developed on a scale of 1:20,000. A buffer of at 50 m around temporary rivers was created and another buffer of100 m around permanent rivers was also generated. These buffers ensure that all then water bodies are not contaminated by leachate from the landfill site. The 100-meter buffer is in line with riparian reserve guidelines produced by the Ministry of Water and Irrigation, Kenya

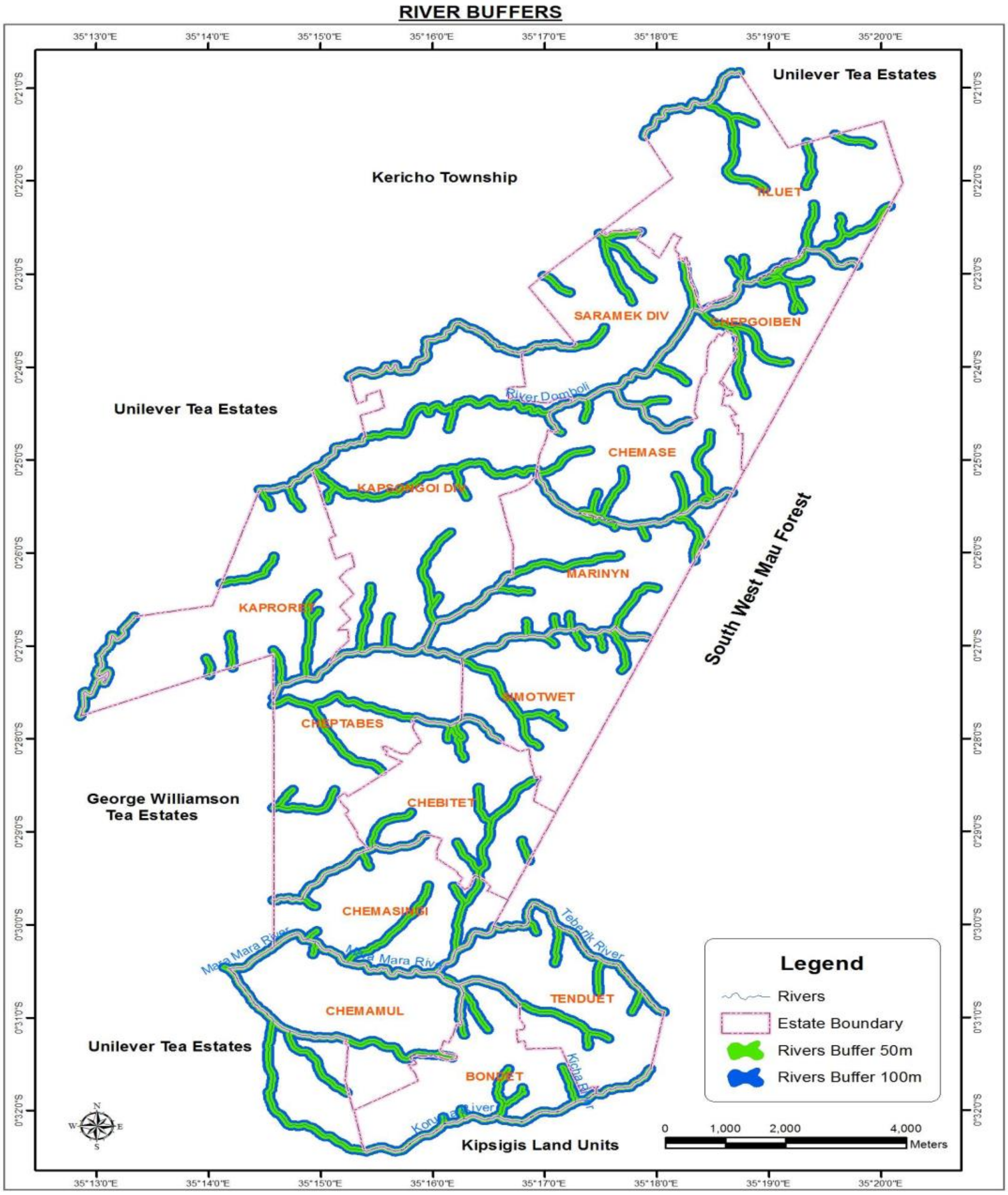

Fig 4.5: Buffer around permanent and temporary rivers (Author, 2015)

4.3.2. Socio-cultural Data

4.3.2.1. Agricultural land use Map

The land use map was created based on a scale of 1:20,000. It includes land use types that were regrouped into the following categories: settlement, forest and agricultural. The land use map was derived from an Ariel photograph flown over the study area in the month of December 2013.

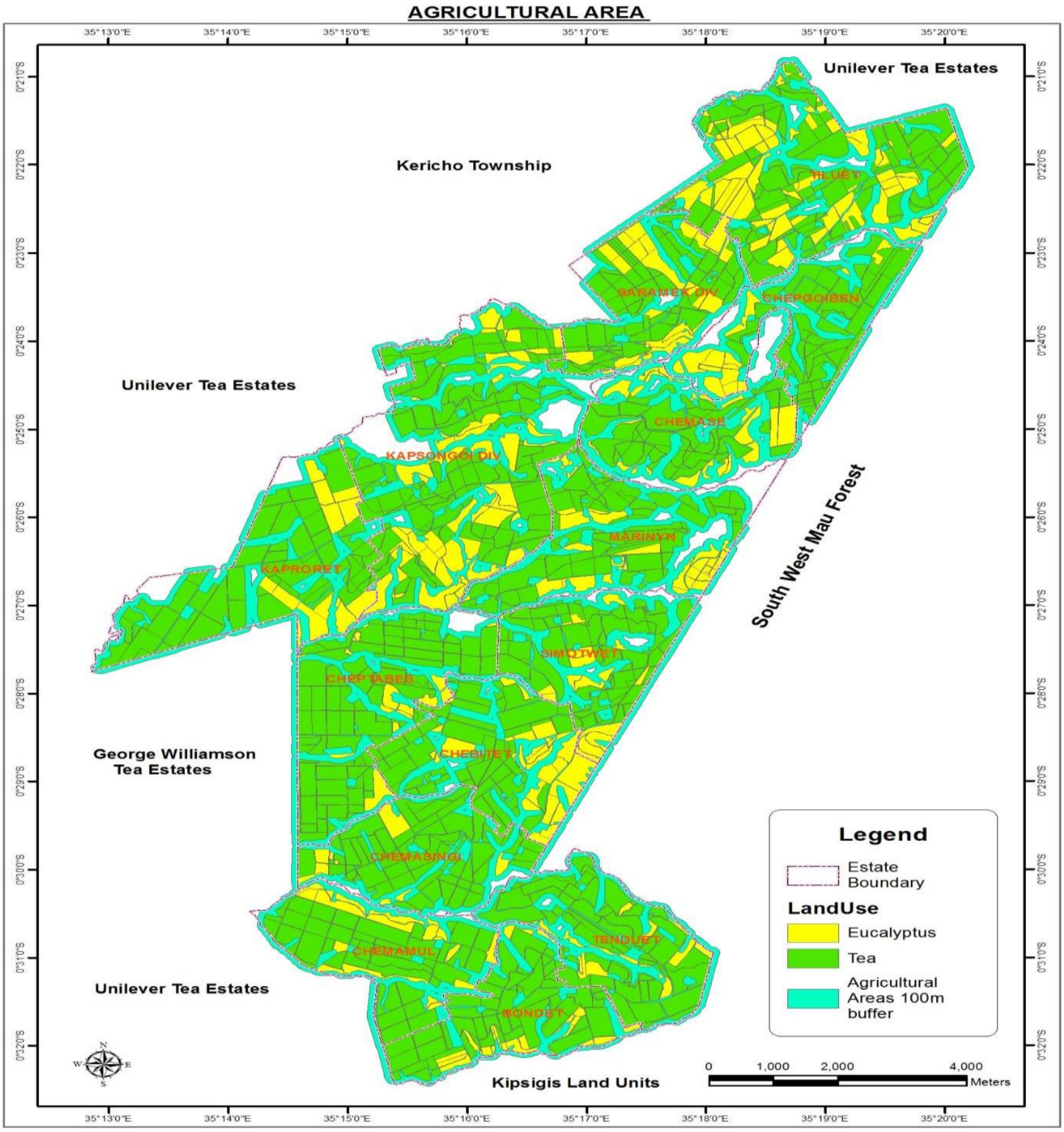

Fig 4.6 Buffer on agricultural land use areas. (Author, 2015)

4.3.2.2. Residential Areas

In this coverage population densities were introduced to every inhabited village. The population census of the area was obtained from The Kenya National Bureau of Statistics (2009 Census)Landfill should be at a minimal distance of 500 m from areas of population larger than 2000.Landfills should not be placed too close to high-density settlement areas in order to mitigate conflicts relating to the Not in My Back Yard syndrome (NIMBY). This also guards against health problems, noise complaints, odor complaints, decreased property values and mischief due to scavenging animals.

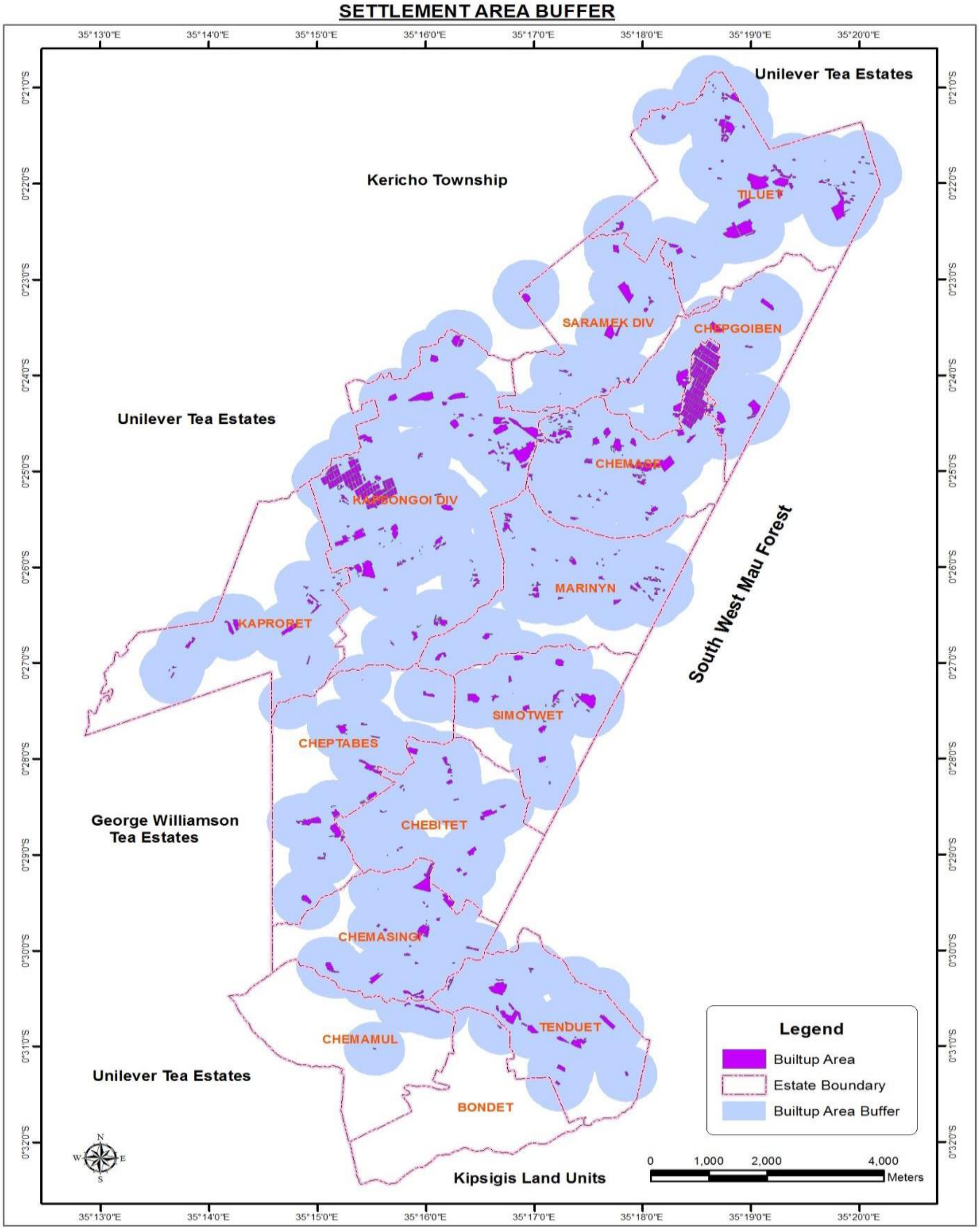

Fig 4.7 Buffer on residential areas. (Author 2015)

4.3.2.3 Road Network map

In this coverage, roads were classified into major and minor, roads, the coverage was digitized from the scale 1:50,000 and was transformed to the Lambert Conformal Conic Projection. Whilst a landfill should not be located within 100 meters of a road it would be more cost efficient for landfills to be located not too far away in order to avoid high transportation costs. The roads should be easily accessible by solid waste vehicles in all weather conditions, in this study a buffer of 100m was created around all the roads as shown in Fig.4.8

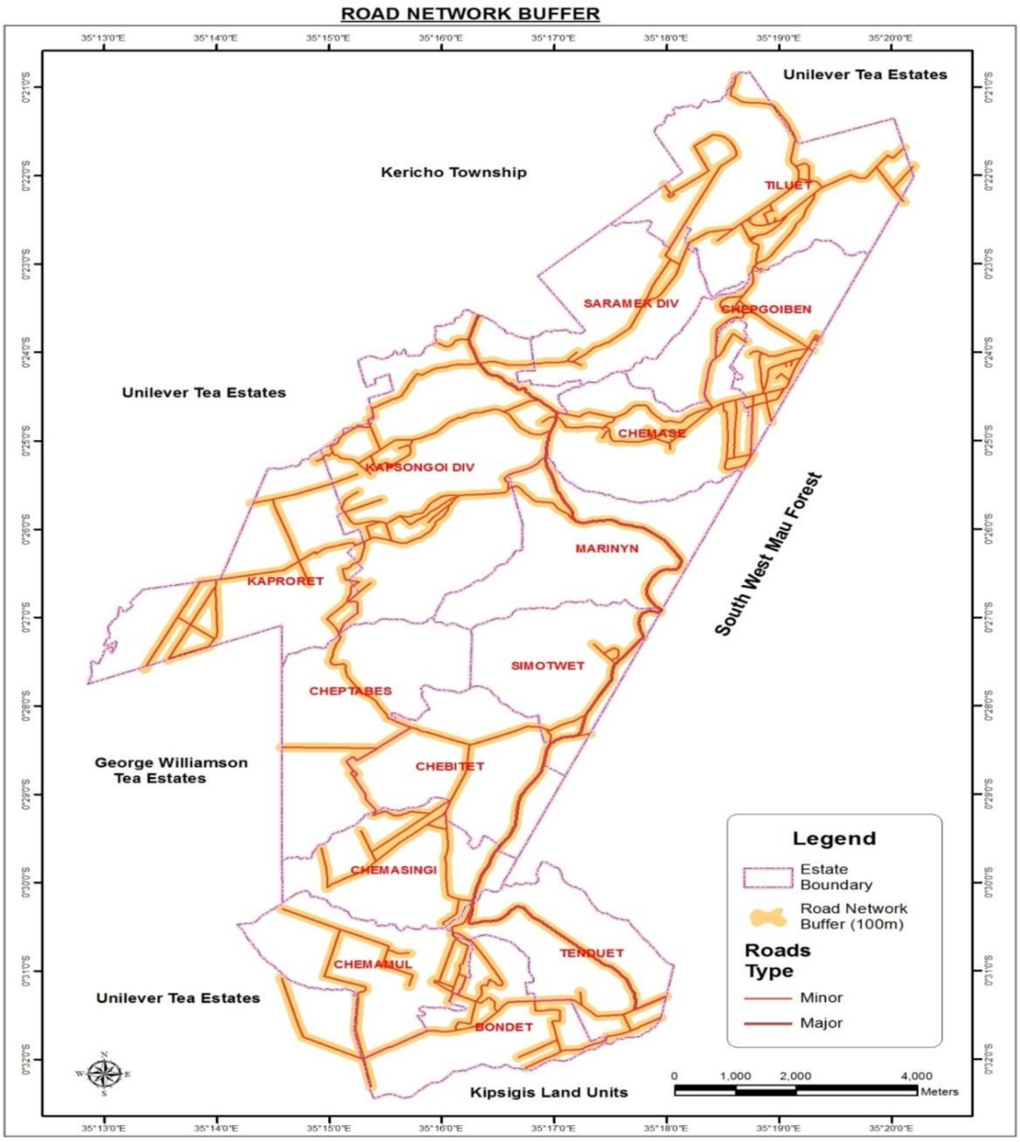

Fig 4.8 Road network buffer. (Author, 2015)

4.3.2.4. Topography Map

The scale of 1:20,000 was adopted for digitizing the topography resulting in 50m contour lines. In areas where more precise information was available, closer contours were possible (20m). A point elevation coverage was derived from the elevation contour lines coverage this is shown in Fig 4.9

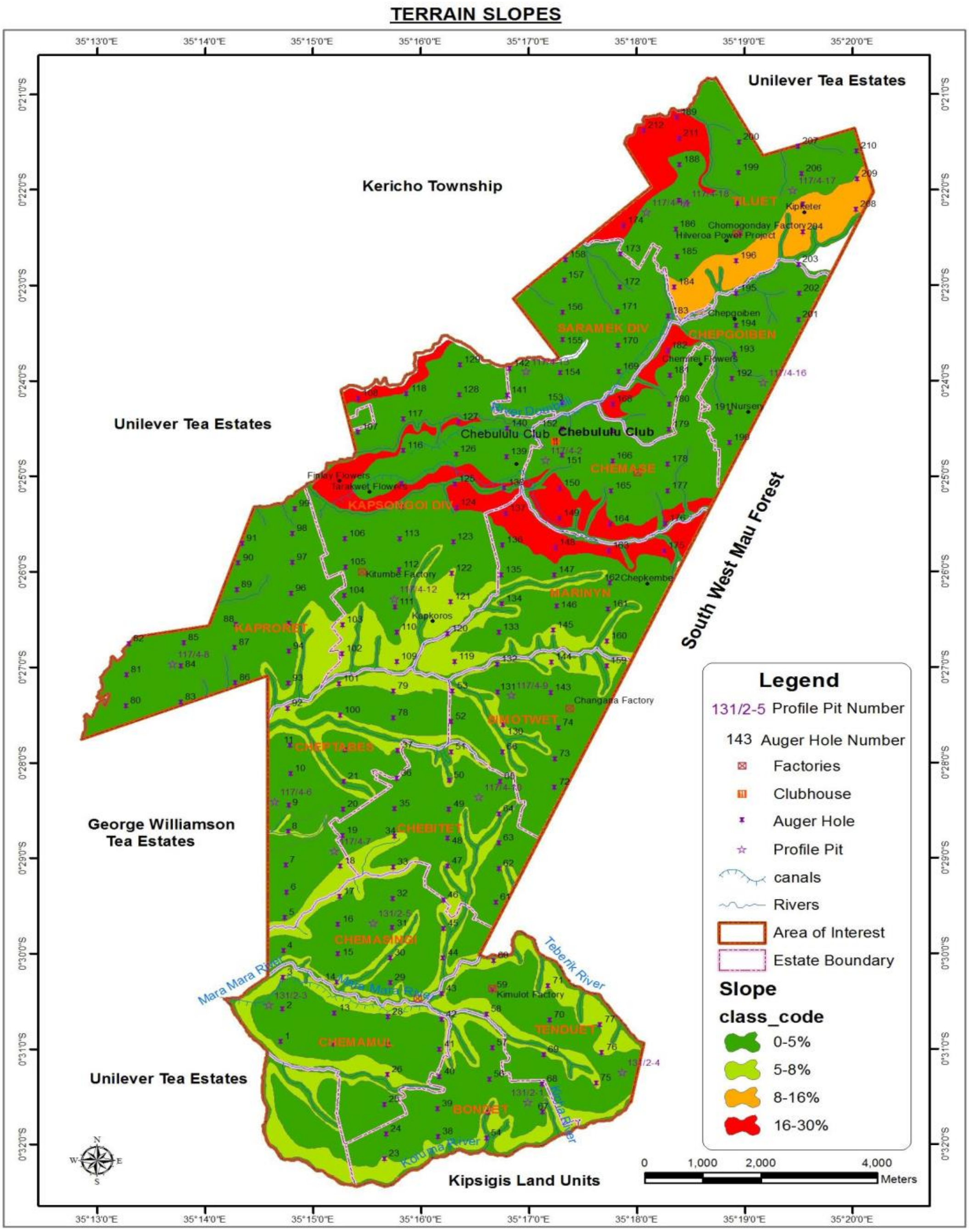

Fig 4. 9 Terrain slope. . (Author, 2015)

Having created the terrain slope map w of the study area, slope map was created. Site slope for a landfill should be less than 5 % (UNEP, 1994).

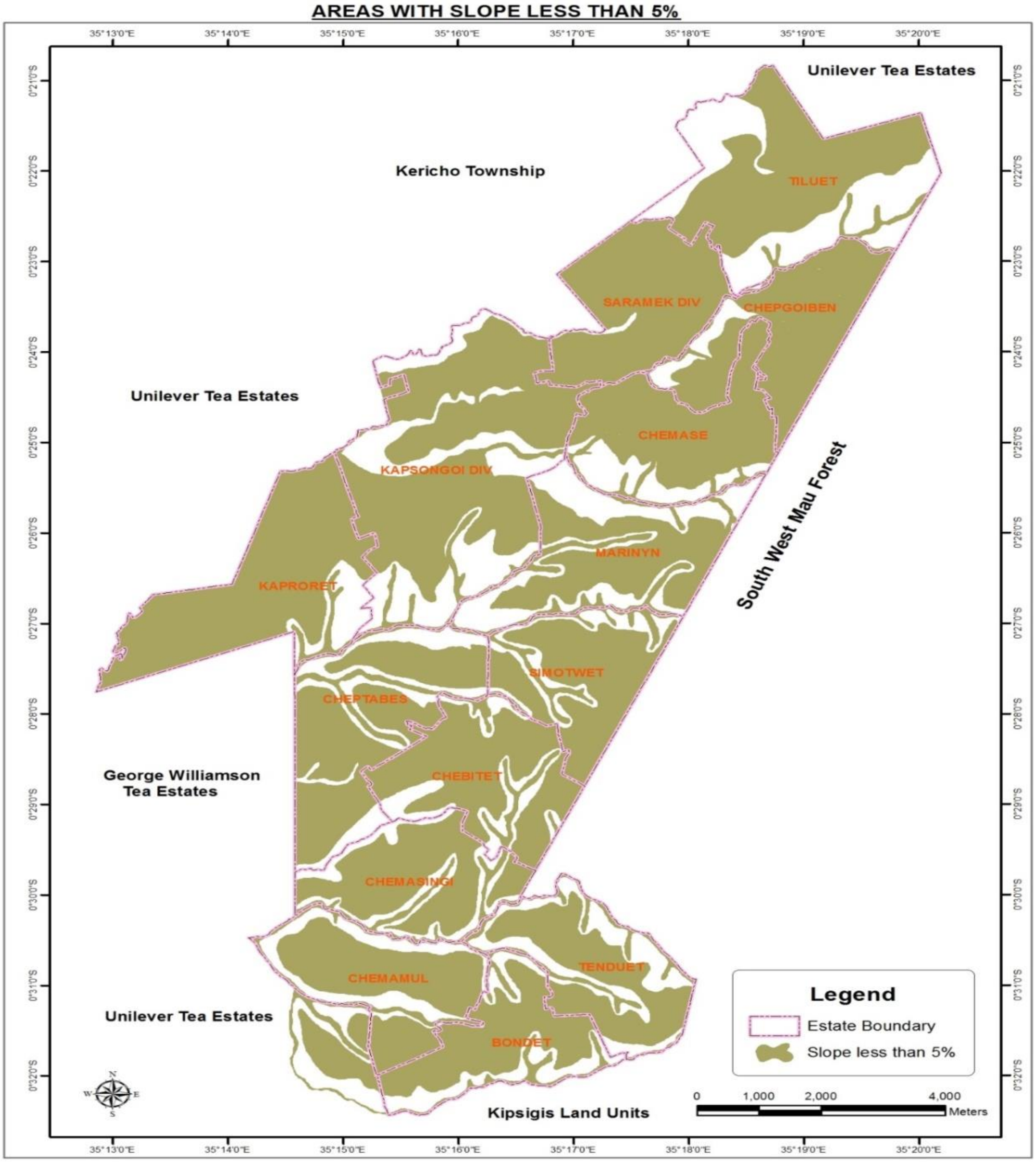

Fig 4.10.Slope Map (Author, 2015)

4.3.2.4. Soil map

The available soil cover maps (scale 1:200,000 from Kericho topo sheet were digitized and prepared for Kericho. The permeability of the underlying soils and bedrock will greatly influence how much leachate is escaping a landfill site; therefore, preference is given to a landform that is somewhat located in flat or undulating land. The soil below and adjacent to the landfill must be firm to allow for construction of roads and other structures. The ideal soils are silt and clay soils.

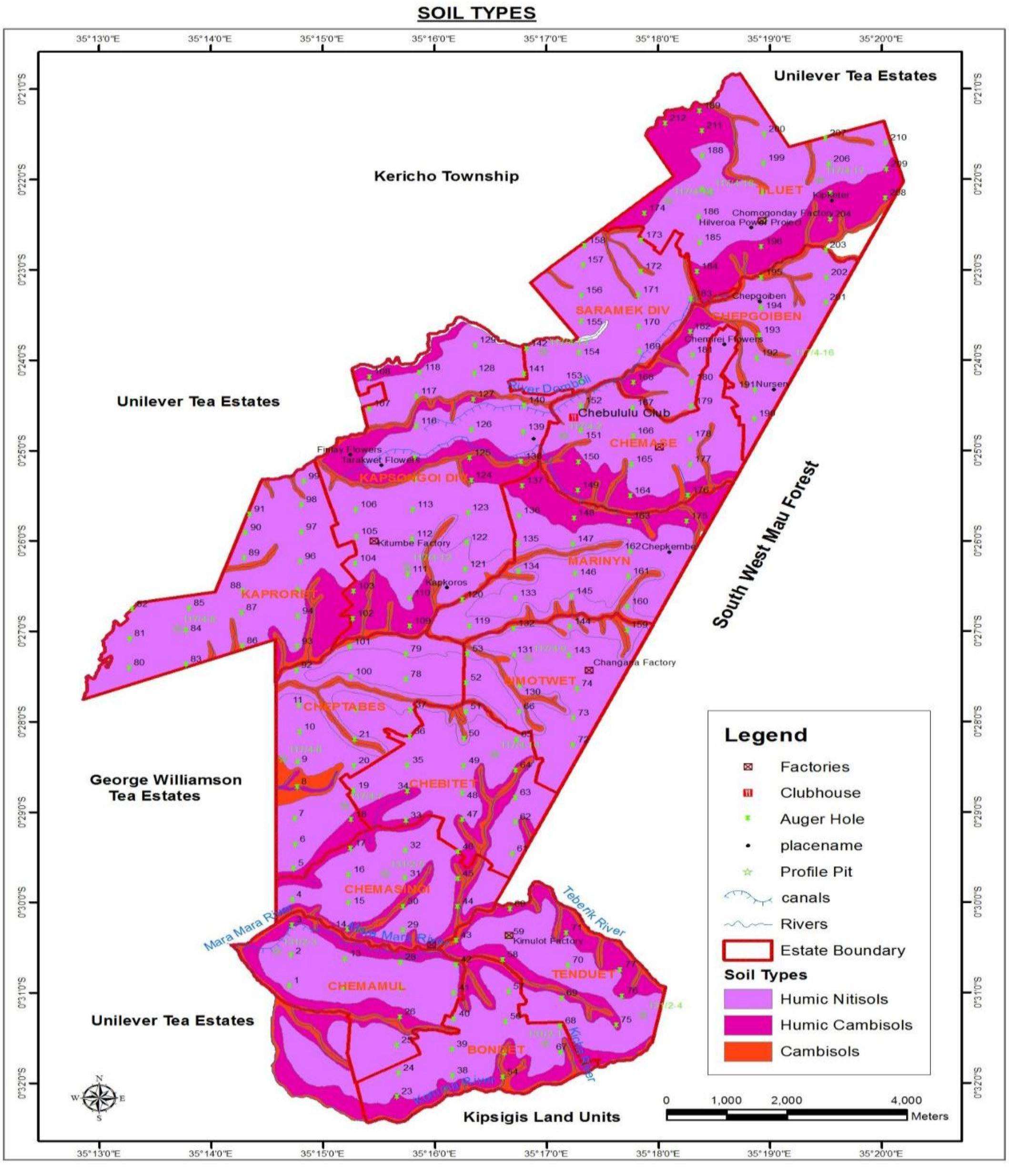

Fig 4.11 Soil map (Author ,2015)

CHAPTER FIVE

DISCUSSION

5.1 Current dumpsites

The company has tried its best to adopt the ISWM policy in the management of waste. Most of the organic wastes that is generated is composted to generate manure for use in the gardens there is a compost facility located at Chemasingi and two others at flower one and flower 2 at Marinyin and Chepgoiben respectively. Inspite of all these efforts there is still waste that has to be disposed and open dumpsites are used. The trash is left exposed to the wind, rain as well as rodents; some of the sites used are also abandoned quarries one this is the kapsongoi dumpsite. Solid waste disposal facilities should be environmentally sound with regard to the economy, aesthetics, and should be sustainable. Fig 5.1 shows the current dumpsites in the study area.

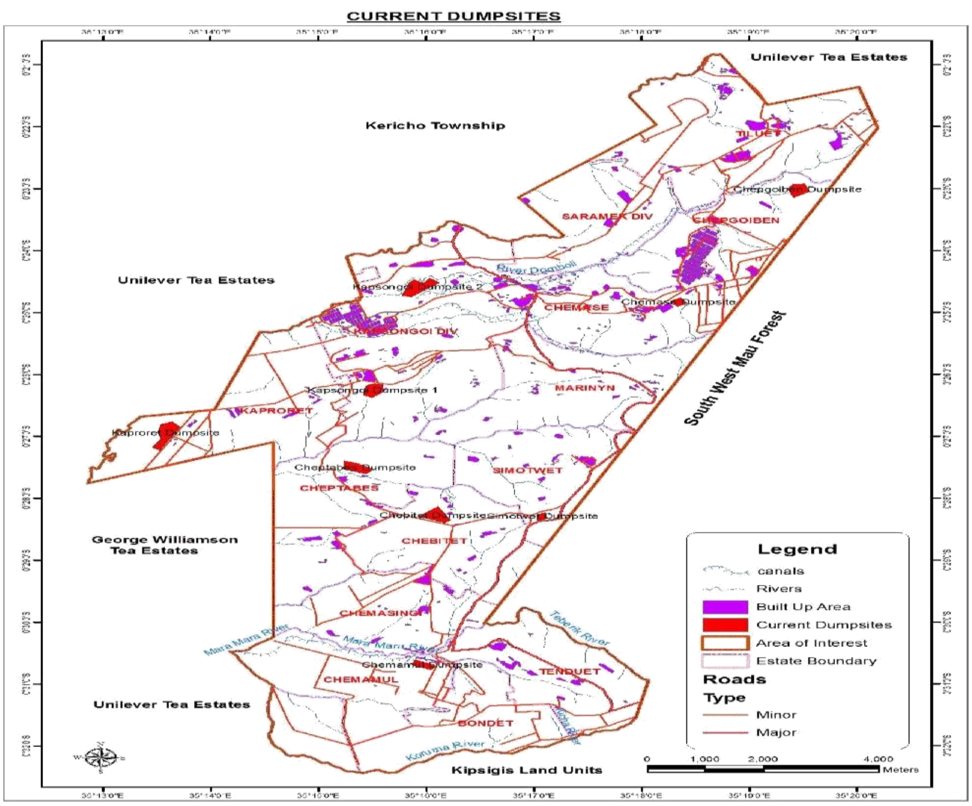

Fig.5.1. Current Dumpsites (Author ,2015)

5.2 Unsuitable areas for siting a sanitary landfill

CMT identifies areas that are suitable or unsuitable for siting a sanitary landfill. These areas are unsuitable because the slope is more than 5%, they are close to water bodies, they are densely populated, the soil is not stable because of the slope. These areas include Tiluet, Chemasingi, Marinyin, Simotwet, Chemase.In cases where GIS cannot identify appropriate sites then the constraints have to be further relaxed to come up with an appropriate site

Fig 5.2 Unsuitable Areas for a sanitary landfill (Author ,2015)

5.3 Suitable areas for siting a sanitary landfill.

According to CMT, sites were selected based on performance basis, on ability and on economic grounds. Any site located within 10 km fromthe waste generation source is more suitable, and sites will be less favorable if greater than 20 km from the waste generation Source. The study came up with seven appropriate sites namely Saosa, Kaproret, Chebitet, Chemamul, Bondet, Kapsongoi and Chepgoiben.The sites are shown in Fig 5.3,however a matrix comparison was still done to givw the most suitable sites.

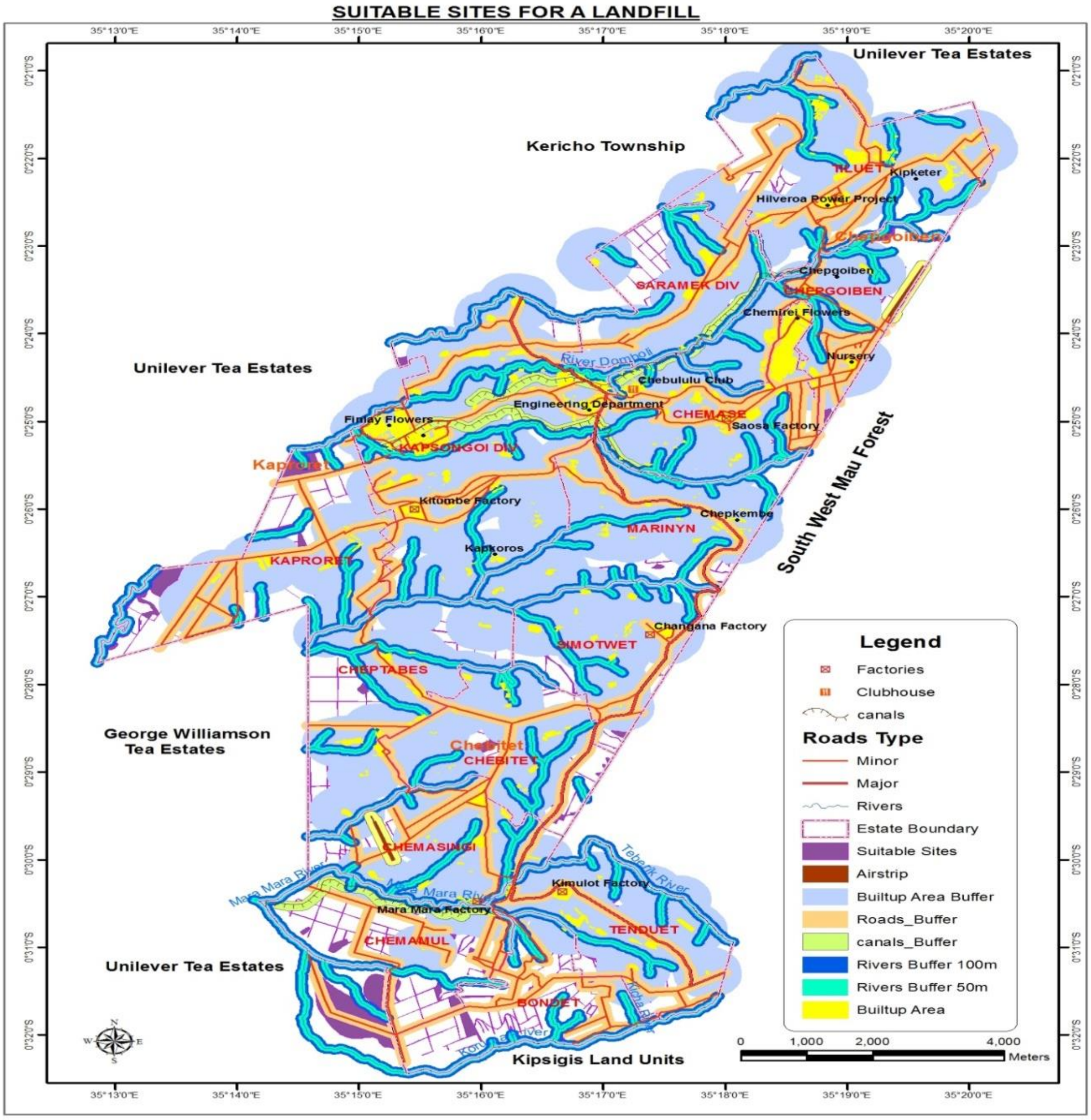

Fig 5.3 suitable areas for siting a landfill (Author ,2015)

5.4 Most suitable areas

Potential sites were further subjected to rapid preliminary screening to narrow down numbers to more desirable sites which were then be subjected to detail evaluation studies. The three selected sites Kaproret, Chebitet and Chepgoiben were found more suitableupon running a constraint mapping analysis. The three sites were found to be the most suitable. The slope is less than five percent (UNEP, 1994), the soils are more compatible. They are not close to a river, the haul distance from the waste generating sites is economical and there will be no high costs incurred in transportation. The sites are not also close to human settlements and the land use and land cover is suitable for a landfillsite.

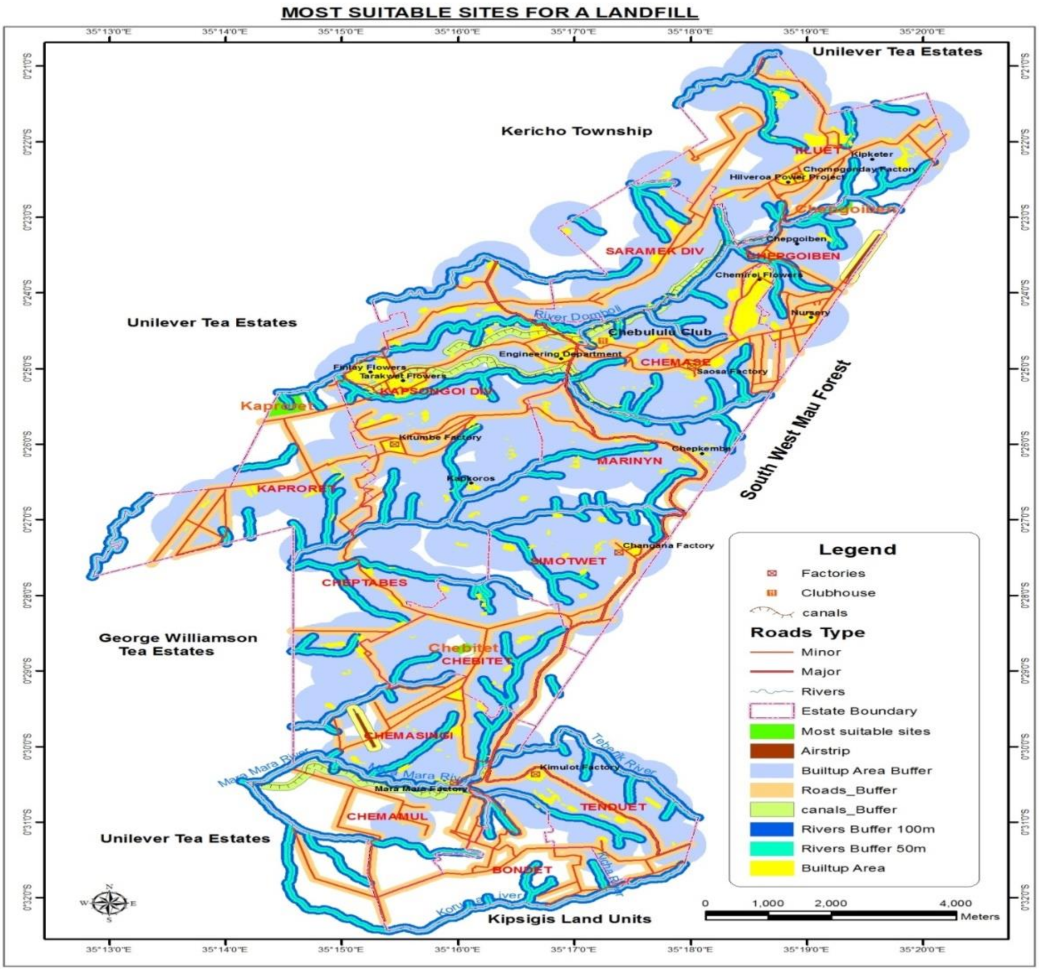

Fig5. 4. Most suitable areas. (Author, 2015)

5.5 Conclusions and Recommendations

5.5.1 Conclusion

This study was aimed at establishing an integrated and sustainable solid waste management practice in the study area. All the waste that cannot be composted, recycled or reused have to be finally disposed; therefore an appropriate site for the dumping has to be established. Facility siting can affect the success or failure of a disposal facility in terms of the associated environmental, economic and social impacts. This study has outlined a siting methodology that is appropriate for siting a sanitary landfill facility within the context of the study area, but is also flexible enough to be used in facility siting in other parts of the world. This project has shown that GIS, can be a powerful tool in planning, managing a research work involving spatial data analysis, particularly in site suitability studies by invoking CMT. The outcomes of the project are enumerated below:

1. In the present study, a technique has been developed, calibrated and finally implemented for landfill siting in Finlay's (K) Limited using GIS.With the help of visual displays of maps created using GIS, company officials can defend their decisions publicly. By incorporating user preferences and legal restrictions before identification of actual candidate sites, GIS increases the probability of successful siting.
2. The CMT provides an enhanced environment for analysis, evaluation and decision making in preliminary site selection studies. However, to make an effective use of this technique in site selection study, comprehensive digital databases are essential.GIS capability for registration, integration and analysis has been found indispensable.GIS investigations can provide valuable

information concerning the spatial effects of changes in these parameters. This information could be used in devising optimum weighting schemes, landfill sizes, and for forming adequate landfill location regulations.

5.5.2 Recommendations

Wastes in the study area are composed of both organic and inorganic materials. The company has tried its best to adopt an ISWM policy where by organic wastes are composted and the compost used in the gardens. The packaging materials from the factories are also re used and recycled wastes that cannot be recycled, composted or reused have to be finally dumped. The company has been using open dumps for disposing its waste the study therefore recommends use of sanitary landfills because its environmental friendly and sustainable. The waste management issues of adopting the principle of "refuse to resource" and also proceed in a structured way towards "landfill mining" concepts are considered to solve some of the present situation waste problems

1. Geographical Information System can be used as a decision support tool for planning waste management

2. Kaproret, Chepgoiben and Chebitet were found to be the most suitable sites for the landfill. The slope is less than five percent (UNEP, 1994), the soils are compatible, it's not close to a river, the haul distance from the waste generating sites is economical and there will be no high costs incurred in transportation. The site is not also close to human settlements and the land use and land cover is suitable for a landfill site.

3. If the company decides to construct a sanitary landfill then an environmental impact assessment has to be carried out as required by National Environment Management Authority. Landfill projects must comply with the standards for air, water (ground and surface), pollution, and other environmental norms (NEMA, 2003).

4. Buffer zones be employed around potential landfill sites and the same be incorporated by the urban planners in the master plans for future developments

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