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Multi-Criteria Selection of Waste Transfer Stations in the Kumasi Metropolis.

A Thesis submitted to the Department of Environmental Science, Kwame Nkrumah University of Science and Technology in partial fulfilment of the requirements for the degree of

(MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE)

By

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(BSc. (Hon.) Geomatic Engineering)

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DECLARATION

I, Bosompem Christian hereby declare that this thesis, "Multi-Criteria GIS Based Selection of Waste Transfer Stations in the Kumasi Metropolis.", consists entirely of my own work produced from research undertaken under supervision and that no part of it has been published or presented for another degree elsewhere, except for the permissible excepts/references from other sources, which have been duly acknowledged.

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ABSTRACT

Increase in the quantity of municipal solid waste generated as a result of population growth in most urban areas has resulted in the difficulty of locating suitable land areas to be used as landfills. To curb this, transfer stations, which are facilities located close to residential areas and are used to receive and hold waste temporarily until it is transported to distant landfills, all with the purpose of reducing waste transportation cost and environmental health implication, are used. KMA currently disposes off all its waste at the Oti landfill site which will be full to its capacity in no time and the problems associated with locating a new site for another facility within its catchment is anticipated due to the difficulty in land acquisition and recent public agitations. This research was carried out within the framework of Multi-Criteria Decision Analysis (MCDA) incorporated into Geographic Information System (GIS). Geographic data such as coordinates of sanitary sites, geology, fault, water bodies, road, slope and urban areas were analysed using the spatial analyst extension in ArcGIS 10.0 software. Using the pairwise comparison method relative importance of each criterion was computed. A weighted linear combination method was used for spatial multi-criteria layer combination. The results of the research revealed that several communal sites within the study area have been encroached and struggle for space with human settlement. Four potential sites were selected from which two are located in Oforikrom sub-metro, one in the Bantama sub-metro, and the other in Asokwa sub-metro. The optimal sites cover a total land area of 2.044 km^2 which is approximately 1% of the total land area under study. The results suggest the concept of transfer station be incorporated into the land use/ land use planning and waste management system of the Metropolis.

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LIST OF ABBREVIATIONS AND ACRONYMS

GIS	Geographic Information System
GPS	Global Positioning System
MCDA	Multi-Criteria Decision Analysis
WLC	Weighted Linear Combination
USEPA	United States Environmental Protection Agency
KMA	Kumasi Metropolitan Assembly
ZLS	Zonal Land Suitability
LSA	Land Suitability Analysis
C&D	Construction and Demolition
MSWMS	Municipal Solid Waste Management System
UNEP	United Nations Environment Programme

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Rapid urbanization over the years has led many developments around waste disposal sites. The environmental nuisance associated with these sites, one way or the other, affects the population and has led to are to growing public opposition. This, together with scarcity of land, has contributed to the difficulty in obtaining sites for new landfills. The farthest a landfill is sited from the urban areas, the lesser its public opposition. Such landfills are therefore, at a distance from their source of waste generation and will increase the cost of waste transfer (Zurbrugg, 2002).

Throughout the world, particularly in highly urbanized areas and in developing countries, management and disposal of municipal solid waste has been a major challenge (Washburn, 2011). Even though much effort has been devoted by some countries in recent years to improve solid waste management services, the challenge in the proper handling of the increasing volume of waste produced exist. Rise in population, economic, urban and industrial activities in most developing countries such as those in Africa, have increased the volume of waste they generate (Taylor, 1999).

Waste management is a discipline associated with the control of generation, storage, collection, transfer and transport, processing, reusing and recovery, and disposal of solid waste in a manner that is in accordance with the best principles of public health, economics engineering, conservation of nature, aesthetics, and environmental considerations in general and that is also responsive to public attitude (Fei-Baffoe, 2010).

Waste management systems differ between countries and regions. The local government authorities and private waste management companies often provide waste collection services in Ghana. The two collection methods practiced in Ghana are the communal and the franchised methods. The communal method of waste collection has several waste collection points known as 'transfer stations' and are found in the communities where all the waste are gathered from households and from other public institutions before they are transported to the final disposal sites. The franchise method of waste collection operates by having waste collected from homes, institutions and public places and transported directly to the disposal sites (Hamdu, 2009).

A waste transfer station is an important component of a waste management system and functions as a link between a community's solid waste collection plan and a final waste management system (USEPA, 2002). Significant differences may exist in the facility size, ownership and services offered but the basic purpose is to consolidate waste from multiple collection vehicles into larger long-haul vehicles for more economical haulage to a final waste management system. The basic type of transfer station has an assigned receiving section where waste is unloaded, often compacted and reloaded into high volume trucks, within shorter durations (Öberg, 2011; USEPA, 2002).

Due to the fact that waste kept temporally at the site which reduces long term storage with all waste being well-managed while on site, the environmental implications of a waste transfer station are anticipated to be minimal. Transfer stations facilities may also serve as centres for separation or sorting of waste into portions that may be reused or recycled. This will have an advantage of reducing the final volume of waste that is transported to the final disposal site.

1.2 PROBLEM STATEMENT

Due to increasing population and population density, urbanization rate in Ghana is likely to experience an increase. Kumasi being the second largest settlement in Ghana, after Accra, is likely to be one of the most preferred destinations. The increase in population will be accompanied by increase in slum areas in Kumasi due to the inability of the housing sector to meet the demand for housing and will further worsen the environmental condition of the built-up environment. The population size and standard of living reflects the volume of waste generated (Mensa-Bonsu and Owusu-Ansah, 2011).

Statistics on the volume of waste generation was estimated at a rate of 600 ton/day in the Metropolis in 1995. It increased to 1,000 ton/day in 2006 and 1,200 ton/day in 2008. Currently, it is estimated that about 1,500 tons of solid waste is generated in a day in the Metropolis (Mensa-Bonsu and Owusu-Ansah, 2011). Kumasi has nine sub-metros with a total of 150 communal dumpsites where waste collection containers of sizes 10, 12, 15 and 23 m^3 are placed and emptied from once a day to once a month at the only landfill facility at Oti, Kumasi. Today, all of the collected solid waste in the Kumasi metropolis is transported to the engineered landfill site at Oti which is situated in the outskirt of Kumasi. An engineered landfill is a waste disposal site where measurements have been taken to prevent environmental impact from the waste. This was started in 2003 and has an expected lifetime of 15 years (Wikner, 2009).

Currently, KMA together with the private waste collection companies are able to collect between 80-85% of the daily waste generated in the Metropolis. The major problem is the difficulty in obtaining sites for final disposal of waste, as urban development is consuming all the space for other development.

KMA is likely to face this same problem since there are no current plans of reserved land areas to cater for the future waste disposal. This will result in decision makers locating such facilities at farther distances from the city. Consequently, KMA will spend larger proportions of their revenue on transporting waste and the city will be engulfed with filth when KMA cannot meet the demand. To curb this, transfer stations which are an integral part of municipal solid waste system, have to be sited at reasonable locations in the metropolis to minimize transport costs, since it is cheaper to transport great amounts of waste over long distances in large loads than in small ones.

This study seeks to use multi-criteria analysis and Geographic Information System to select suitable sites within the Kumasi Metropolis that can be used as transfer stations.

1.3 RESEARCH OBJECTIVES AND QUESTIONS

1.3.1 Main Objective

The main objective of the study was to select suitable sites for waste transfer stations using a multi-criteria Geographic Information System (GIS) based approach in the Kumasi Metropolis.

1.3.2 Specific Objectives

The specific objectives are:

- Map out the spatial distribution of waste generation centres in the Metropolis.

- Identify suitable land areas within the Metropolis for waste transfer station facilities.

1.3.3 Research Questions

The following questions need to be asked and addressed:

- Does KMA have transfer stations?
- Is there the need for transfer stations?
- What is the appropriate location for siting transfer stations?

1.4 Justification of Study

Developing an effective solid waste management system requires the establishment of legislation, regulations and proper managerial practices that are specific enough to address the characteristic needs of solid waste systems in the Kumasi Metropolis. The growth in population has caused the expansion of the Metropolis to cover a total land area of 254 km^2 by absorbing most peri-urban development at its fringes. Much waste is therefore generated and haulage distances coupled with cost of collection, fuel consumption have increased putting so much pressure on the revenue of KMA (Adarkwa and Poku-Boansi, 2011). Trucks often breakdown due to the nature of the road, distances, load and the pressure on their usage. Environmental and health implications are posed to human life in the city due to delays in the evacuation of waste. To curb this, there is the need to incorporate into the waste management system the establishment of transfer stations to help reduce the above discussed problems.

This thesis will also provide adequate field data for other researchers, development officers, policy makers, organizations and institutions that intend to make interventions to develop the administrative and the infrastructure sections of sustainable waste management system in the Kumasi Metropolis to improve the environment and public health.

1.5 Scope of Study

Kumasi Metropolis which formerly had 10 sub-metros but currently reduced to 9 is the area under study in this thesis. The research employs the application of geographic information system (GIS) and multi-criteria analysis using geographically acquired data such as water bodies, geology, settlement and several environmental factors in the process. It involves data on current as well as areas likely to have high waste generation that will pose the challenge to waste management as the population and businesses grow. Data on land use, population density and traffic trends will be analyzed together with public views, since they form a core part of the decision making and implementation.

CHAPTER TWO

LITERATURE REVIEW

2.1 WASTE TRANSFER STATIONS

Waste Transfer Stations, according to United States Environmental Protection Agency (USEPA, 2012), are facilities where municipal solid waste is unloaded and held for a while and reloaded onto larger long-distance travelling trucks to landfills or other treatment or disposal facilities. Communities can save money on cost of labour and transporting since waste taken to distant disposal sites are brought together from several individual waste collection trucks into a single shipment. The total number of vehicular trips to and from the disposal site is also reduced. Although waste transfer stations help reduce the impacts of trucks travelling to and from the disposal site, they can cause an increase in traffic in the immediate area where they are located. The siting, designing and operation of a transfer station, if not properly done, can cause problems for residents living closer.

Bovea *et al* (2007) also described Waste Transfer Stations as an integral part of present-day in municipal solid waste management systems. The main measure used to decide on transfer station's location has generally been to reduce transport costs, since it is cheaper to haul great volumes of waste over long distances in large trucks than in smaller ones. Where the distance from the waste collection area to the waste treatment facility is large, a transfer station may be used to bulk up the waste for more efficient transport by a larger truck.

Gil and Kellerman (1989), discussed three reasons why transfer stations are useful. First, because small or medium sized communities may not generate sufficient waste to support a disposal facility. Second, if the distance to the disposal plant is long the use of small collection trucks may be unnecessarily high. Thirdly, the location of a single disposal plant in a remote location to serve several communities will remove negative environmental impacts from residential areas.

2.2 TYPES OF TRANSFER STATIONS

The USEPA's Decision Maker's Guide to Solid Waste Management (1995) handbook, describes the feasibility of community's transfer station as being dependant on the design variables such as capacity required and volume of waste storage needed, the types of wastes received, processes required for recovery of material from wastes before haulage, types of collection vehicles that use the facility, types of transfer vehicles that can be accommodated at the disposal facilities, and topography and access of the site. Waste transfer station types usually used are described under three categories:

- Small capacity (less than 100 tons/day)
- Medium capacity (100 to 500 tons/day)
- Large capacity (more than 500 tons/day).

Herbert (2001) recycling handbook describes five types of waste transfer stations: The Direct dump-no floor storage, Direct dump-floor storage, Compactor, Pit and Combination. These are well developed and are in operation. Representatives of the equipment manufacturers do have sales on promotion basis and has resulted in several larger numbers of the compactor stations

2.2.1 Small to Medium Transfer Stations

Small to medium transfer stations function as direct-dump stations which gives no intermediate area for waste storage. They usually have drop-off areas for use by the general public to accompany the principal operating areas dedicated to municipal and private refuse collection trucks. Transfer operations of this size may be located either indoors or outdoors, depending on weather, site aesthetics, and environmental issues. More complex small transfer stations are usually visited within hours of operation and may include some simple waste and materials processing facilities (USEPA, 1995).

Direct-discharge stations usually have two operating floors and a compactor or open-top container is located on the lower level. Hoppers connected to these containers receive waste from the top level by station users. These floors are set with elevations lower than the tipping floor, low enough to allow easy loading. Smaller transfer stations in rural areas mostly have a simple design and are often left unattended. Here, the drop-off collection method, which consist of a series of open-top containers that are filled by station users. These containers are emptied into larger trucks at the station or hauled to the disposal site. The general station capacity needed (i.e., number and size of containers) is dependent on the size and population density of the area served and how frequent waste collection is done. A good design to ease loading can be a simple retaining wall will allow containers to be at a lower level so that the tops of the containers are at or lifted slightly above ground level in the loading area (USEPA, 1995).

2.2.2 Larger Transfer Stations

Larger transfer stations are mostly designed for heavy commercial use by private and municipal collection trucks. The public, in some instances, has access to sections of the station (USEPA, 1995). According to the United Nations Environment Programme (UNEP, 2013), large-scale transfer station design in industrialized countries generally includes a floor for tipping the waste, after which bulldozers are used to push the waste into transfer trucks or a compacting chamber for packing the waste into trucks or compacting the waste into a high-density bale that is mostly wrapped in wire mesh. Recyclables and special wastes are increasingly being sorted and processed at transfer stations. It further describes three common types of transfer station that represent sound practice and they are Open tipping floor, Open pit design and Direct dumping transfer stations.

It is recommended that, Larger-scale transfer stations, be located at farther distance from places designated for residential use due to noise, odours, leachate from waste, and vehicular traffic; but closer to the generation points that collection trucks can quickly do a return journey to and from the area; at locations that are planned and zoned for industrial or commercial use; where there is ease in accessing a major road; on the location of landfill which has served its lifetime , since the road network landuse existing around the landfill are deemed suitable for siting transfer stations; and where road restrictions (weight, noise, speed, surface, axle weight, truck length) do not vary with the usage terms related to transfer (UNEP, 2013).

More than one transfer station may be needed to service large or heavily populated areas, especially in regions where the population centres are separated by relatively sparsely populated areas. To know the appropriate number of transfer stations for an area, will depend primarily on the number and size of service areas covered by the Municipal Solid Waste Management system (MSWMS), the distance between the areas, the volume of MSW generated, the distance to disposal site, the types of vehicles used in primary collection, and the size and type of transfer stations selected (UNEP, 2013).

Open Tipping Floor: In the open tipping floor design, uncompacted waste is unloaded onto the tipping floor by collection trucks. Once the waste is deposited on the tipping floor, a front-end loader or bulldozer (with huge bucket to accommodate enough waste objects) is used to push, lift, and organise the waste across the floor to the next stage in the process. Damage to the tipping floor is avoided by using wheeled loaders instead of tracked vehicles.

Treating small volumes of waste is an appropriate choice for developing countries, and this type of facility becomes more efficient for small volumes of waste than for large; can serve to transfer different types of waste at different durations or into different trucks; can accommodate recovery of bulky wastes; allows for waste picking at the transfer station; and maximizes the option of spreading the waste, on concrete platforms, to pre-dry or pre-compost for a day or two before transferring it to a landfill or processing facility (UNEP, 2013).

Open Pit Design: Here, collection trucks dump waste directly into an open pit. Bulldozers are then used to organize the waste. The waste is compacted and loaded into enclosed trailers. Multiple collection vehicles are able to unload at the same time that loading and transfer operations are in progress due to its design. The open pit design is able to also accommodate larger trucks than an open tipping floor design and so has higher capital and operating costs as compared to the open tipping floor.

Direct Dumping Transfer Stations: In direct method, open-top trailers or compactors receive waste directly from collection trucks. This system has no in-between handling, which results in an increases in efficiency and a decrease hired labour. Waste picking or any other type of in-between handling is not allowed, therefore effectively preventing recovery. Greater numbers of trucks are needed since no compaction or recovery is done to reduce the volume of waste and so highly vulnerable to truck shortage. It is considered as a poor choice since there is no buffer when there are insufficient trucks present to load the waste. (UNEP, 2013).

2.3 PLANNING AND SITING A TRANSFER STATION

Numerous issues must be considered during the planning and siting stages of transfer station establishment because the various developmental stages require significant investment of resources and the success of the project should be ensured as the host community becomes sensitive to its outcome (USEPA, 2002). Not every community is appropriate for siting a transfer station and to determine that, economic feasibility, station type, additional design elements, re-cycling and capital costs must be taken into consideration (UNEP, 2013).

2.3.1 Types of Waste

Waste types may vary from one locality to the other and hence are handled differently. The following are types of waste that are normally handled at transfer stations:

Municipal Solid Waste (MSW): These waste types are produced by various households, institutions, businesses, and the industries. A wide variety of materials as well as unwanted containers, cans, food wastes, and several paper products. It is a combination of easily degradable and inert materials. The types of MSW are usually given attention separately (USEPA, 2002). These include:

Yard waste (green waste) usually includes leaves, grass clippings, trimmings from trees. Because it may be may be composted or mulched, they are often diverted instead of going for disposal.

Household hazardous waste (HHW) includes hazardous materials produced by various households, such as detergents; drain cleaners, Oil-Based Paints, Sharps, pesticides,motor oil, antifreeze, fuel and poisons herbicides

Recyclables include various kinds of glass, metal, plastic, textiles, paper, and electronics. Some common recyclable waste also includes newsprint, aluminium, cans, oil residues from motors, and tyres (USEPA, 2002).

Construction and Demolition (C&D) consists of debris that results from the construction, renovation, and demolition of buildings, roads, and bridges. It typically consists bricks, rocks, stones, reclaimed broken concrete without protruding metal bars, asphalt and pavement of concrete, masonry, roofing materials, wood, and sheetrock, plaster, metals, and tree stumps (USEPA, 2002).

Not all waste is acceptable at a transfer station for a numerous reasons. Some wastes are forbidden by certain states and are openly inscribed in regulations. Some are as well difficult and expensive to process while other has a high potential of health or fire hazard. Very large waste type which could damage trucks or operation equipments at a transfer station might be prevented (USEPA, 2002).

2.3.2 Transfer Station Size and Capacity

Determining the size of a transfer station is normally based on factors such as the volume of generated waste within an area to be serviced, which might include anticipated population growth and recycling programs. The type of waste delivery truck may be compared and will as well determine the land area needed for the facility. Waste materials when compacted, reduces in volume but while loose is bulky to transfer (USEPA, 2002).

In planning a facility size, the present and projected waste volumes for daily, weekly and monthly and annually are of importance not excluding seasonal changes. This will help accommodate waste deliveries It is therefore recommended to build a facility to accommodate present and projected maximum volumes of waste considering variations with enough space for future expansion (USEPA, 2002).

A study by the Metro Solid Waste and Recycling Department of Portland in 2004, reports transfer stations capacity as primarily being dependant on these three factors:

Receiving: This is the rate at which waste can be unloaded from collection trucks and depends both on the number of stalls for unloading waste and the distance to be covered during the process to position a collection vehicle for dumping.

Load-out: Rate that waste can be loaded into transfer vehicles. Various methods are used for loading transfer trailers. These vary from dumping directly into the trailer to the use of large pre-load compactors. The load-out rate depends on both the method and load size.

Storage: Amount of space available to stage waste for later loading into transfer vehicles. Waste is generally not delivered to a transfer station at a uniform rate throughout the day. Storage space permits a station to handle peak delivery rates that exceed the rate that transfer vehicles can be loaded. Storage also increases the reliability of the facility by mitigating the impacts of equipment failures or other problems.

2.3.3 Site Selection

The selection of a site for any waste-related facility can be a sensitive issue, particularly for those living nearby. In principle, most people realize that such facilities are needed and will be needed in the future. In some cases, however, concern arises about a specific location for a waste transfer station and whether the facility will be properly managed (USEPA, 2001). General site selection for most facility establishment will consider factors such as accessibility, Image/Visual Quality, Visibility, Demographic Patterns, Site Capacity, Neighbourhood Compatibility, Legal Matters, Utilities Availability, Physiography (Anon.,2004).

2.3.3.1 Siting Criteria

Local residents are most likely to accept a transfer station facility if the site is carefully selected with the buildings designed fittingly for the site, with landscaping designs that are appropriate for the site. These design features are to be accompanied by a detailed plan of operations (USEPA, 1995). When selecting a site, these factors should be well thought-out:

Proximity to Waste Collection Area: helps to increase savings from reduced transportation time and distance.

Ease in Accessibility of Haul Routes to Disposal Facilities: facilitates transfer trucks to enter highways or other major routes, hence reducing haul times and possible impacts on close by residences and businesses. The economic and technical feasibility must be determined when considering sitting for necessary improvements on local road.

Visual Impacts of transfer station are to be oriented so that the operations during waste transfer are not visible to area residents. Visibility, to some extent, can be controlled if the site is large enough and the required area will depend on traffic created by haulage trucks, storage capacity, allowed buffer areas, and station design.

Site Zoning and Design Requirements are to be confirmed by residents of the responsible community whether the use meets the zoning requirements of the site.

2.3.4 GIS-Based Multi-Criteria Decision Analysis

There is a growing body of literature which brought about advancement in the use of GIS as part of a multi-partaker and multi-criteria framework that considers multiple views and consensus (Jankowski *et al*. 1997; Malczewski, 1999; Higgs, 2006). In a study by Boroushaki and Malczewski (2010), GIS-based multi-criteria decision analysis (GIS-MCDA) is a process that is able to transform and combine geographical data and value judgments to acquire relevant information for decision making.

The main rationale behind integrating Geographic Information System (GIS) and MCDA is that these two distinct areas of research are able to harmonize each other. While GIS is commonly recognized as a powerful and integrated tool with unique capabilities that is able to store, manipulate, analyze, and visualize spatial information for decision making, MCDA on the other hand, provides a rich set of procedures and algorithms to structure decision problems, design, evaluate, and prioritize alternative decisions. The integration abilities of GIS and MCDA has resulted in the benefits for advancing theoretical and applied research on GIS (Malczewski, 1999; Boroushaki and Malczewski, 2010).

According to Malczewski (2004), one of the most useful applications of GIS for planning and management is the land-use suitability mapping and analysis. Land-use suitability analysis broadly defined as aiming at the identification of the most appropriate spatial blueprint for future land uses according to detailed requirements, preferences, or predictors of some activity. Most GIS have been developed with theories of spatial representation and of computing in mind, and with strong assumptions about the instrumental rationality underlying planning procedures.

The rationale is based on a positivist idea, which puts spatial interpretation and scientific analysis at the central part of planning. It assumes a direct relationship between the available information and quality of planning and decision making based on this information. Communicative rationality, on the other hand, postulates an open and all-encompassing planning process, public participation, dialogue, consensus building, and conflict resolution (Innes, 1995; Malczewski, 2004).

GIS-based land suitability analysis (LSA) assumes that a specified study area is categorised into a set of basic unit of observations such as polygons or rasters. Then, the land-use suitability problem involves evaluation and classification of the areal units according to the respective suitability for a particular activity. Land-use suitability problems have increasingly been conceptualized in terms of the GIS-based multi-criteria evaluation procedures over the last 10 years and there are two fundamental classes of multi-criteria evaluation methods in GIS: the Boolean overlay operations which is a non compensatory combination rules, and the weighted linear combination (WLC) methods which deals with compensatory combination rules. These two are the most often used approaches for landuse suitability analysis (Jankowski, 1995; Malczewski, 2004).

2.3.4.1 Boolean Overlay Operations

Boolean is derived from the name of the English mathematician, George Boole, who first abstracted the basic laws of set theory in the mid 1800s. It is used here to indicate any crisp spatial mapping in which areas are selected by a simple binary number system as either belonging or not belonging to the selected set. Boolean variables can be usefully thought of as constraints for the reason that, they serve to delineate areas that are not suitable for consideration. These constraints are then bought together by some combination of intersection (logical AND) or union (logical

OR) Boolean constraints. These criteria are normally called *factors*, and express varying degrees of suitability for the decision under consideration. Thus, for example, proximity to roads would be treated not as an all-or-none buffer zone of suitable locations, but rather, as a continuous expression of suitability according to a special numeric scale (e.g. 0–1, 0–100, 0–255, etc.). The process of converting data to such numeric scales is most commonly called standardization (Eastman, 1999). Traditionally, standardised factors are combined by means of weighted linear combination that is, each factor is multiplied by a weight, with results being summed to arrive at a multi-criteria solution. In addition, the result may be multiplied (i.e. intersected) by the product of any Boolean constraints that may apply (Eastman, 1999; Eastman *et al*., 1995).

Rafiee *et al*. (2011), explain that in Boolean overlay a crisp decision is made regarding the suitability of each criterion; after which criteria maps are combined by logical operations OR and AND, such that the resultant image simply has two classes indicating the suitable and unsuitable areas. In contrast, with the WLC method, each criterion is standardized in terms of suitability in a numerical range, and criteria are then combined using weighted averaging. The final image is a continuous map that can be used as a useful tool for decision making.

2.3.4.2 Weighted Linear Combination

Ayalew *et al*. (2004), describe weighted linear combination (WLC) as a concept where event-controlling parameters can be combined by applying primary and secondary level weights. The primary level weights are rule-based in that ratings are given to each class of a parameter on the basis of a certain criterion. Rafiee *et al.* *(*2011), in their research conducted a WLC analysis that resulted in the production of a map containing zones and allowed the selection of 12 potential sites. The research explains the availability of several methods that can be used to analyze the LSI layer to select the potential sites; spatial cluster analysis and the zonal land suitability (ZLS) method are two of them.

There is a growing body of literature that is advancing the use of GIS as a part of a multi-participant, multi-criteria framework that takes into account multiple views and consensus
(Malczewski, 1999; Higgs, 2006). Higgs (2006), explain that MCDA has been used in a number of such siting studies to open up the decision-making process to more scrutiny, typically by incorporating multiple perspectives through negotiated factors and constraints. He reports that although there have been a number of studies concerned with incorporating multi-criteria evaluation techniques in a GIS framework to find suitable disposal sites for waste, few have involved public input. The development of Internet-based GIS techniques could address this and has led commentators such as Malczewski (2004), to suggest that as the software visualization tools become more widely available on the web, the potential exists to undertake networked GIS-based land-use suitability analysis, which may be particularly applicable to widening public participation approaches to land use planning. In particular, the need to combine qualitative and quantitative data within such exercises has posed problems for researchers in this field.

Cheng *et al*. (2002) and Higgs (2006) suggest that the 'design of solid-waste management systems requires consideration of multiple alternative solutions and evaluation criteria because the systems can have complex and conflicting impacts on different stakeholders. The research demonstrated the potential of five different multi-criteria methods as part of a decision-support system in comparing sites for landfill facilities in Saskatchewan, Canada. The advantages of their approach is that it does not only involve input from experts in areas such as those concerned with the potential impacts on wildlife, but also incorporated the opinions of local residents on their preferred location in the form of criteria weights expressed in qualitative terms.

2.3.5 Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) as described by Marinoni, (2004) has successfully been incorporated into the GIS environment. According to Lawal et al. (2011), the weightages of the required factors associated with criterion map layers are calculated by adopting a preference matrix from which all identified relevant criteria are compared against each other with reproducible preference factors. The method is explained as being carried out in three steps. The first is step is a pair-wise comparison of the criteria and the results put into a comparison matrix. The matrix is completed with values from 1 to 9 and fractions from 1/9 to 1/2 which represents the significance of a criterion to another in the pair. The values in the matrix need to be consistent, which implies that if x is compared to y, it receives a score of 5 (strong importance), y to x should score 1/5 (little unimportance). Something compared to itself gets the score of 1 (equal importance). The linguistic explanation of scores is attached to the table. The next step is to calculate criterion weights. Firstly, values from each column are summed and every element in the matrix is divided by the sum of the respective column. The new matrix is called normalized pair-wise comparison matrix. Finally, an average from the elements from each row of the normalized matrix is calculated. The consistency ratio (CR) is calculated in order to ensure that the comparison of criteria made by decision makers is consistent. The rule is that a CR less than or equal to 0.10 signifies an acceptable reciprocal matrix, whereas greater than 0.10 is not acceptable. Weights obtained by this method are interpreted as average of all possible weights. Moreover, the advantage of this method is that only two criteria need to be compared at a time (Malczewski, 1999).

2.3.5.1 Pairwise Comparism matrix

This is an effective process for the determination of relative importance. This method was proposed in the context of the analytic hierarchy process Saaty (1990). The pairwise comparison uses a ratio matrix to compare one criterion with another. With the Saaty technique, the weights are derived by normalizing the eigenvector of the pairwise comparison matrix between criteria. The consistency of the weighting should however be evaluated. According to Saaty (1990), a consistency ratio (CR) index CR is a measure that provides a departure from consistency. He further described Consistency Ratio (RI) as a comparison between Consistency Index (CI) and Random Consistency Index (RI), or in formula:

$$\mathbf{CR} = \frac{\mathbf{CI}}{\mathbf{RI}} \qquad \text{Equation 1}$$

If the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, we need to revise the subjective judgment.

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY AREA

3.1.1 Location

Kumasi is located in the transitional forest zone, about 270 km north of the national capital, Accra. It covers a total land area of 254 km^2, stretching between latitude 6.35^o – 6.40^o N and longitude 1.30^o – 1.35^o W, and an elevation which ranges between 250 – 300 metres above sea level. Kumasi is bounded to the north by Kwabre District, to the east by Ejisu Juabeng District, to the west by Atwima Nwabiagya District and to the south by Bosomtwe-Atwima Kwanwoma District (KMA, 2006).

The beautiful layout and greenery environment of has accorded it the accolade the-Garden City of West Africa. Kumasi has grown in a concentric form to cover an area of approximately 10 kilometres in radius. The direction of growth was originally along the arterial roads due to the accessibility they offered resulting in a radial pattern of development. The city is a rapidly growing one with an annual growth rate of 5.47%. It encompasses about 90 suburbs, many of which were absorbed into it as a result of the process of growth and physical expansion (KMA, 2006). Figure 3.1 is a map of Kumasi Metropolitan Area.

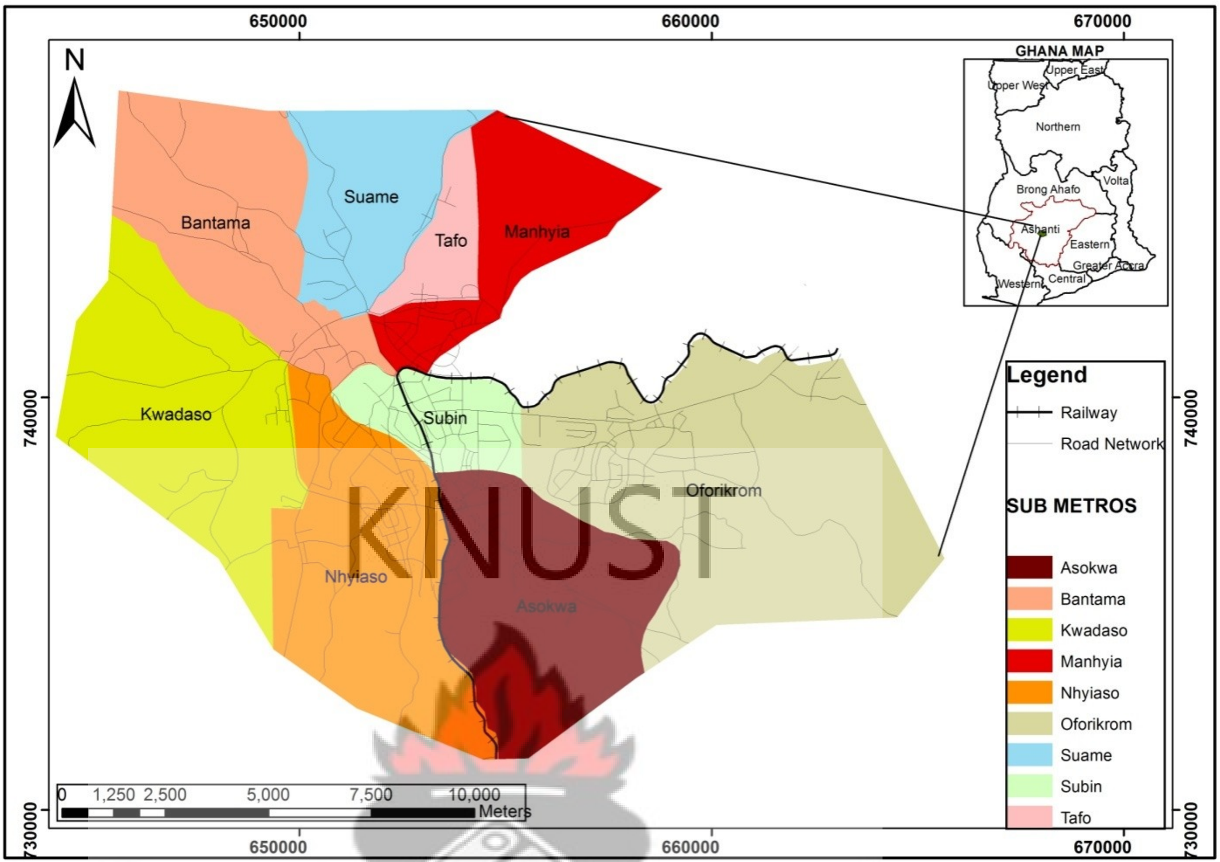

Figure 3.1: Map of Kumasi Metropolitan Area

3.1.2 Population Characteristics

The Kumasi Metropolis is the most populous district in the Ashanti Region of Ghana and the second most populated area in Ghana after Accra. The population of the area increased from 1,170,270 in 2000 to 2,035,064 in 2010 showing an increase of 864794 over the ten year period (KMA, 2014). The fast population growth in the area would be attributed to Kumasi being the regional capital of the Ashanti region as well as most commercialised centre in the region. Other reasons include the centrality of Kumasi as a nodal city with major arterial routes linking it to other parts of the country and also the fact that it is an educational centre with two State Universities, a Private University, a Polytechnic, two Teacher Training Colleges, Secondary Schools and a host of basic schools (Eminsang, 2011).

The growth of industries and the large volume of commercial activity in and around Kumasi as well as the high migrant number may account partly for the relatively high urban population (KMA, 2014).

3.1.3 Spatial Distribution

The population of the Central Business District (CBD) comprising Adum, Asafo and Ashtown continue to reduce over the years. Census reports that, Adum recorded 12,991 in 1970, 9,693 in 1984 and 8,016 in 2000. This is expected to further fall. On the other hand areas such as Ayigya, Dichemso and Tarkwa Maakro, which were small communities in 1960 and 1970, have grown into densely populated residential areas with 20,000 – 40,000 people. Areas comprising the CBD therefore continue to reduce in terms of human numbers whereas the population in the new developing areas increases. This is accounted for by the mere reason that residential accommodations in the former are being converted into commercial use (Eminsang, 2011).

3.1.4 Spatial Analysis

The present physical structure of Kumasi Metropolis could be described as circular or concentric in nature, encouraging development in all directions. All major roads converge at Kejetia, which is the city centre. Settlement growth is towards all directions from the city centre. Urban planning is to manage the spatial organization of cities for effective land use. Urban infrastructure can therefore be categorized into five major sectors; namely Transportation, Housing, Water and Sanitation, Electricity supply and Telecommunication. The urban form of a city and distribution pattern of land use affects air quality and its health impact. The major economic activity points in the city can be grouped into four. These are Kejetia Lorry Park, Central Market, the defunct Kumasi Race Course that is temporarily being used for commercial activities; Adum Shopping Centre; Suame and Asafo Magazines; Kaase/Asokwa Industrial Area and the Sokoban Timber Products Markets (Eminsang, 2011).

3.1.5 Land Use of KMA

The total land coverage of Kumasi Metropolitan Area is approximately 254 km^2 (25,415 hectares). Out of this 79.0% has been planned, approved and developed. The major landuse that make up the metropolis are residential, commercial, industrial, educational, civic and culture, open spaces and circulation. Residential Land use refers to the predominantly living areas in the metropolis and takes up 43.9 percent of the total land use of the metropolis. Commercial activities in the metropolis take approximately 2.4 percent of the total land area. Commercial activities are mainly concentrated in the central area of the metropolis. However, these activities are now taking up new locations along the radial roads. Sites for Educational facilities take up about 17.3 percent of the metropolitan area. Civic and Cultural facilities occupy 7.3 percent of the total land area of the metropolis. It comprises locations for public and private offices, health delivery facilities, security establishments and centres for religious and social functions (Eminsang, 2011).

3.2 MATERIALS

Several available data, both soft and hard copies at different scales, were used during this study. They were gathered from different sectors of the country. Data used was based on its availability and suitability for the purpose of the study. Table 3.1 show the data types used for the study.

Table 3.1: Data Types used for the study

Data	Date Obtained	Scale	Source
Aerial Photograph	2007	1:50000	Survey Department Ghana
Land Cover Map	2007	1:50,000	Survey Department Ghana
Topographic Map		1:50,000	Survey Department Ghana
Metropolitan Area Map	2009	1:100,000	Town & Country Planning Dept., Kumasi
GPS Coordinates	2013	126 Points	Field Mapping

3.2.1 Data Used

Sub-Metropolitan map of KMA was obtained from the Town and Country Planning Department from which the current extent of Kumasi Metropolitan Boundary was extracted together with locations of constraint areas within the study area. Several ground positions, especially road intersections were obtained using a Global Positioning System (GPS) device (Garmin GPSmap 60CSx) with an accuracy of ±3 m. Current locations of waste generation centres, describes by KMA as sanitary sites, were visited and their GPS coordinates together with pictures taken. Figure 3.2 shows a map of GPS locations of communal sites within KMA. Aerial photograph as well as topographic map of the study area also obtained from the Survey and Mapping Department (SMD) was used together with the field obtained data for the analysis.

3.2.2 Data Validation

Several known locations such as road intersections, bridges, building corners and 126 locations for waste collection container within Kumasi Metropolis were obtained during the field navigation, using a GPS device. These coordinates were plotted onto the secondary data (aerial photograph, topographical map) using ArcGIS software to validate its accuracy. The variations were minimal. Figure 3.2 show a map of map of GPS locations of communal sites within the Kumasi Metropolis.

3.2.3 Software Used

This study used ArcGIS 10.0 for all data processing, editing, management and analysis. It was also to generate all the map outputs. All raster and vector data types were converted into a format acceptable by the software. All field data collected were transformed into Universal Transverse Mercator (UTM) zone 30 North coordinate system. Relevant locations needed in the research were also digitized from the area photographs into shapefiles format using the ArcGIS software.

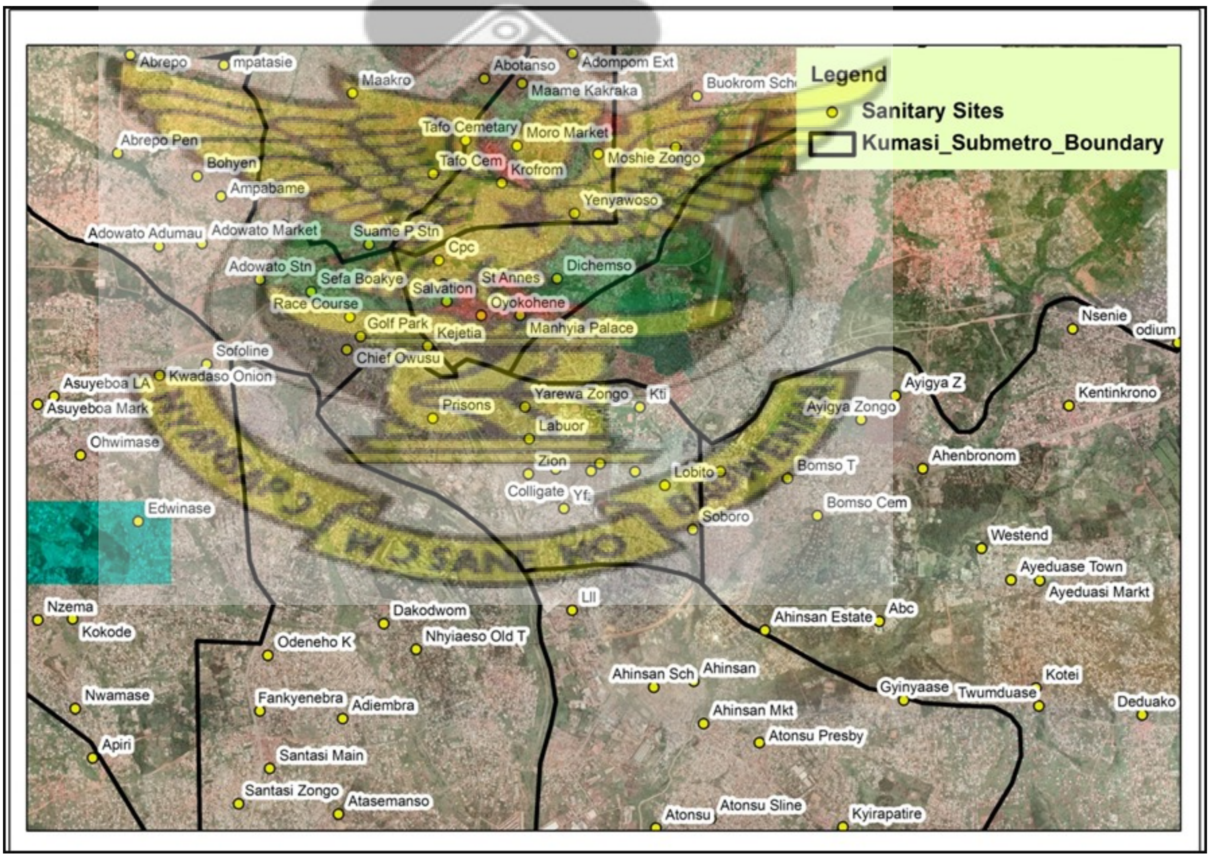

Figure 3.2: Aerial Photograph used with GPS Locations of Communal Sites

3.3 METHODS

This study made use of the Weighted Linear Combination (WLC) method in a GIS environment. By the GIS approach, this procedure was implemented by firstly determining criteria and constraints, then attributes of criteria and their standardization were developed. Relative importance weights were determined, and finally, combination of the criteria to calculate the suitability index. The criteria used for evaluation of the land suitability for establishment of transfer stations included the following: geology, slope, proximity to residential areas, location of waste generation centres, and distance to rivers, streams, faults, and highways. The constraints included buffer zones of 1,000 m from the local airport and of 500 m from some environmentally and socially sensitive areas. Figure 3.3 show a flow chart of the methodologies that were used to execute this work.

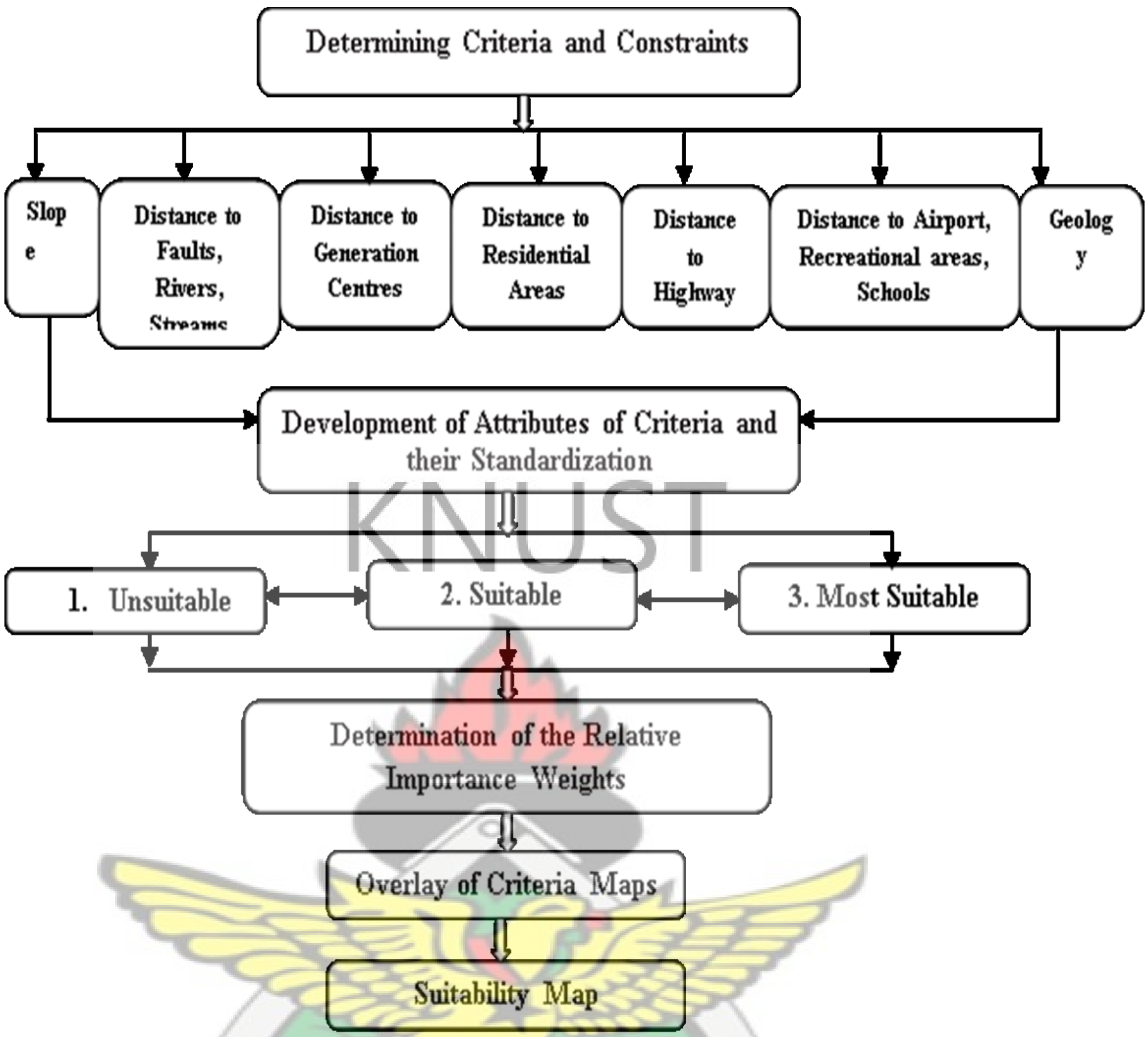

Figure 3.3: Flow Chart Summarizing the Methodology Employed

3.3.1 Development of Criteria and Standardization

This process involved the development of a database for evaluating the criteria, followed by standardization of the criteria in terms of suitability for locating waste transfer stations. The required information were imported from existing geological, residential, highway, digitized features from aerial photographs and with additional information obtained from the field with global positioning system device. The criteria that were selected could be grouped into three main categories: (1) Unsuitable, (2) suitable, and (3) most suitable.

The suitability score of each criterion was standardized with a weighted overlay. The map layers were standardized to a common scale using weighted overlay functions in the GIS context. The method is often applied in land use/suitability analysis, site selection, and resource evaluation problems (Eastman *et al*., 1995).

The primary reason for the popularity of WLC method is the fact that it is very easy to implement within the Geographic Information System environment using map algebra operations and cartographic modelling approach. The method is also easy-to-understand and intuitively appealing to decision makers. However, GIS implementations of WLC are often used without full understanding of the assumptions underlying this approach (Malczewski, 2000). The WLC model was adopted for this study because of its easy implementation within the GIS environment.

In this study, slope class was determined from the digital elevation model. Makhdoum, (1993) and Rafiee *et al*. (2011), described areas with a slope of 9^{o} as unsuitable for siting a transfer station and considered slopes measuring from 0 to 6^{o} most suitable. This classification was adopted in this research. Stream and river channel and the area within 500 m were considered unsuitable; those from 500 m to 2,500 m were considered moderately suitable, and those beyond 2,500 m were considered most suitable. Two fault lines located at the north eastern part of the study area within 1,000 m of faults were considered unsuitable while locations located beyond 4,000 m from faults were considered most suitable with those between 1,000 to 4,000 m from faults were deemed moderately suitable.

The land cover/landuse map was analysed and locations within 500 m of residences were considered unsuitable, with the suitability values increasing linearly from scores 2 to 3 for locations between 500 and 2000 m from residences; the highest value was assigned for locations beyond 2000 m from residences. The highway map was also used to determine the suitability of transfer stations. Locations within 500 m of a highway and beyond 5,000 m from a highway were considered unsuitable. Locations situated between 1,000 to 4,000 m from the highway were deemed more suitable. For waste generation centres, sites located more than 5000 m away from the centre point of waste generation were considered unsuitable, while those within 1000 to 4000 m of the centre point were considered most suitable. Suitability values between 1000 and 4000 m decreased linearly. The location of a transfer station in relation to a highway is relevant for controlling traffic from collection trucks as well as facilitating quick movement of waste to and from transfer stations to further distances for final disposal whiles frequent vehicular breakdown due to poor roads is considered

The impact of each parameter was determined by their influence. Among many aspects to be considered in site selection, it is important considering most criteria with their objective weightings. The degree of suitability of a specific factor may, however, be different from others and to express this variability, a scoring system is commonly used. This study gave scores to the criteria factors in percentages. The weights were given judgmentally based on consensus from professionals with expertise in site selection, transportation, waste management and from information obtained from technical literature.

3.3.2 Weighting the Criteria

To assign weights, seven criteria which are not of equal importance were used in determining the location of transfer stations. In order to ensure that each criterion was evaluated on the basis of its relative importance, two approaches could be considered: (1) selecting the same numerical range (0–255) for each of the various criteria (standardization), assigning each criterion a score based on its relative importance (weight), and multiplying each standardized criterion by the value assigned to its relative weight to calculate its suitability index or (2) using a variable numeric range for the various criteria depending upon the relative importance of each criterion (Rafiee *et al*., 2011). The second method was used in this study. Several methods are available with which to determine the relative weight of each criterion; these include the ranking method, the ratio method, the trade-off analysis method, and the pairwise comparison method (Malczewski, 1999). The pairwise comparison matrix was employed in this research as shown in Table 3.3. It uses a numerical scale with values ranging from 1 to 9, as shown in Table 3.2.

In this study, the focus was on the pairwise comparison method which has the added advantages of providing an organized structure for group discussions, and helping the decision making group focus on areas of agreement and disagreement when setting criterion weights (Drobne and Lisec, 2009).

Table 3.2: Relative importance in pairwise comparison

Criteria	Degree of Importance
1	Equally important
2	Equal to moderately important
3	Moderately important
4	Moderately to strongly important
5	Strongly important
6	Strongly to very strongly important
7	Very strongly important
8	Very to extremely strongly important
9	Extremely important

(Source: Malczewski, 1999; Rafiee *et al*., 2011).

Table 3.3: Pairwise Comparism table for the seven criteria

Criteria	1	2	3	4	5	6	7
1) Distance to Highway	1	1/3	1/5	2	1/3	1/2	1/2
2) Distance to Residential area	3	1	3	8	2	4	2
3) Distance to rivers and streams	5	1/3	1	7	1/2	3	1/2
4) Geology	1/2	1/8	1/7	1	1/7	1/5	1/6
5) Slope	3	1/2	2	7	1	3	1/2
6) Distance to faults	2	1/4	1/3	5	1/3	1	1/3
7) Distance from generation centres	2	1/2	2	6	2	3	1

The consistency ratio is defined as:

$$CR = \frac{CI}{RI} \text{..................} 3.1,$$

where RI is the random index, and CI is the consistency index which provides a measure of departure from consistency.

The consistency index is calculated as:

$$CI = \frac{\lambda - n}{n - 1} \text{..................} 3.2,$$

where λ is the average value of the consistency vector, and n is the number of criteria which was 7. The random index is the consistency index of the randomly generated pairwise comparison matrix and depends on the number of elements being compared. Table 3.4 shows random inconsistency indices (RI) for different numbers of criteria. A random consistency index of 1.32 was used in the computation.

Table 3.4 : Random Consistency Index (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

In this study, the weights were computed and the CR obtained was 5.70% which is less than 10% and acceptable.

CHAPTER FOUR

RESULTS

4.1 INTRODUCTION

The methodology employed in this project resulted in the creation of suitability maps for the various criteria used. Maps show unsuitable, suitable and most suitable land areas for each of the evaluation criteria. The total land area considered was about 203.760 km^2 forming the KMA boundary used, excluding Asawasi sub-metro which is now a metropolis. The sections below present the results that were obtained from the research.

4.2 SUITABILITY FOR STREAMS AND RIVERS

Table 4.1 and Figure 4.1 show suitability table and map for streams and rivers. A total land area of about 190.402 km^2 representing 93.4% of the total land area was classified as unsuitable, while 13.358 km^2 representing 6.6% of the land area was deemed suitable. No classification was obtained for land areas as most suitable per the criteria and importance attached to water bodies in this research. Most stream channels within the Metropolis upon site visit had been either converted to drainage channels or encroached by human activities such as settlement and illegal waste dump sites.

Table 4.1: Streams and Rivers Suitability.

Value	Suitability	Area (km^2)	Land Area (%)
1	Unsuitable	190.402	93.4
2	Suitable	13.358	6.6
Total Area		**203.760**	**100**

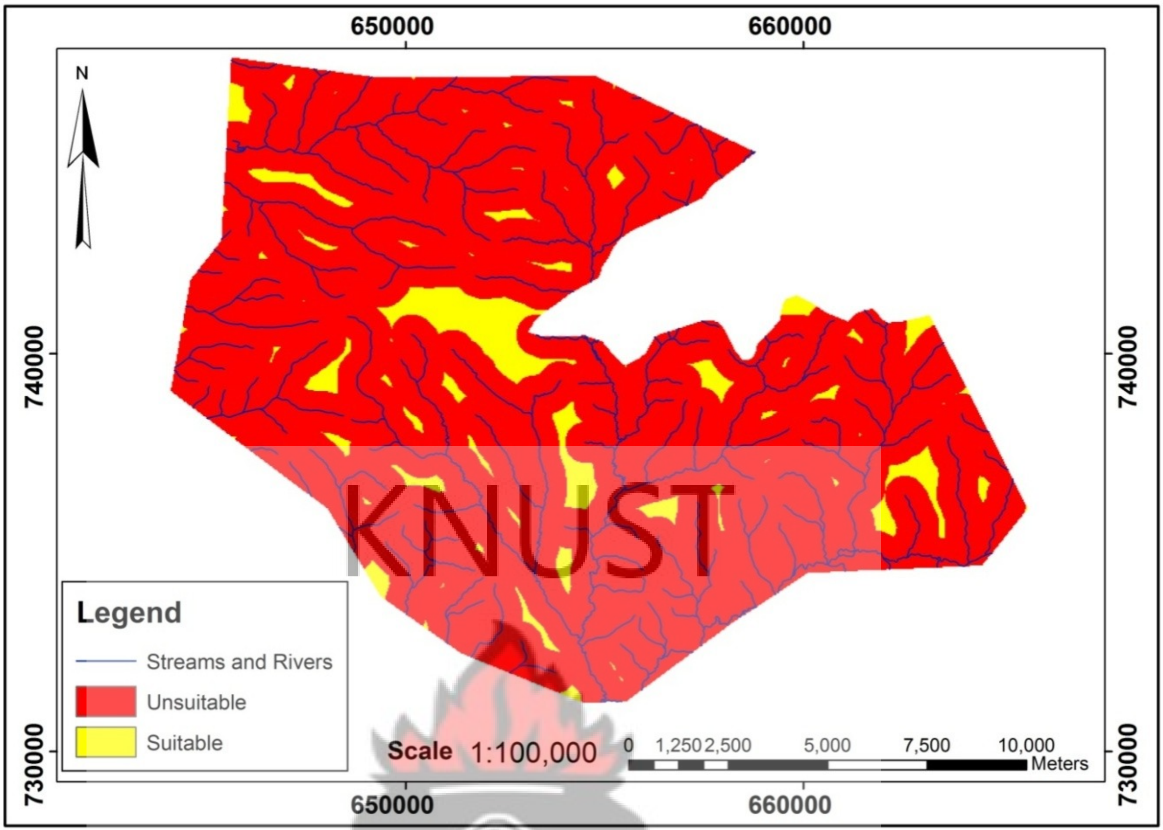

Figure 4.1: Suitability Map for Streams and Rivers

4.3 SUITABILITY FOR URBAN AREAS

Figure 4.2 and Table 4.2 show the suitability map and table for urban areas for siting transfer stations respectively. A total land area of about 118.280 km^2 representing 58.0% of the study area was classified as unsuitable for siting transfer stations while about 82.711 km^2 representing about 40.6% land area was deemed suitable. For the most suitable, a total land area of about 2.769 km^2 which represents about 1.4% of the study area was obtained.

Table 4.2: Urban Areas Suitability.

Value	Land cover type	Suitability	Area (km^2)	Land Area (%)
1	Urban	Unsuitable	118.280	58.0
2	Urban	Suitable	82.711	40.6
3	Urban	Most Suitable	2.769	1.4
Total Area			**203.760**	**100**

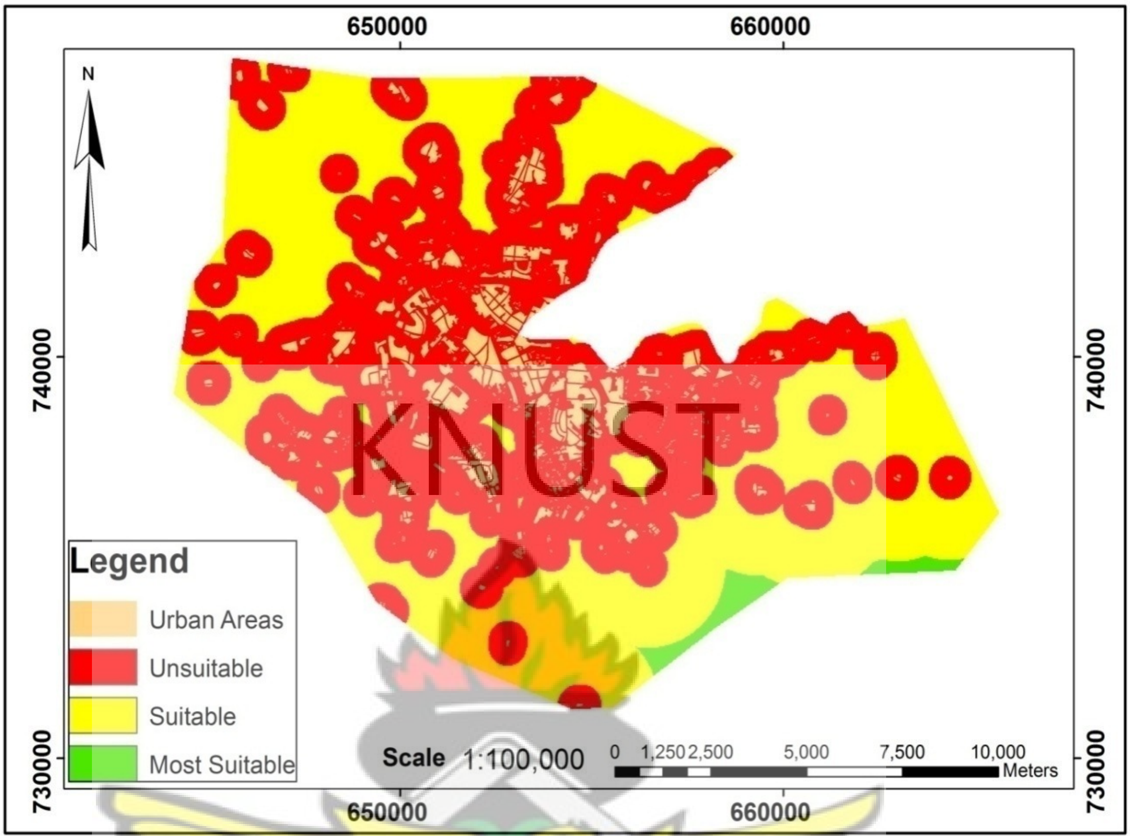

Figure 4.2: Suitability Map for Urban Areas.

4.4 SUITABILITY FOR SLOPE

The results for suitability for slope are shown in Figure 4.3 and Table 4.3. A terrain which is moderately sloping and can use topography as an advantage for site design is desirable for establishing a transfer station. The results for suitability of the study area for slope gave a total land area of 1.046 km^2 representing 0.5% of the study area as unsuitable for siting transfer stations whiles 10.178 km^2 representing 5% of the study area was deemed suitable. A total land area of 192.536 km^2 which represents 94.5% of the study area was classified the most suitable.

Table 4.3: Slope Suitability.

Value	Suitability	Area (km^2)	Land Area (%)
1	Unsuitable	1.046	0.5
2	Suitable	10.178	5.0
3	Most Suitable	192.536	94.5
Total		**203.760**	**100**

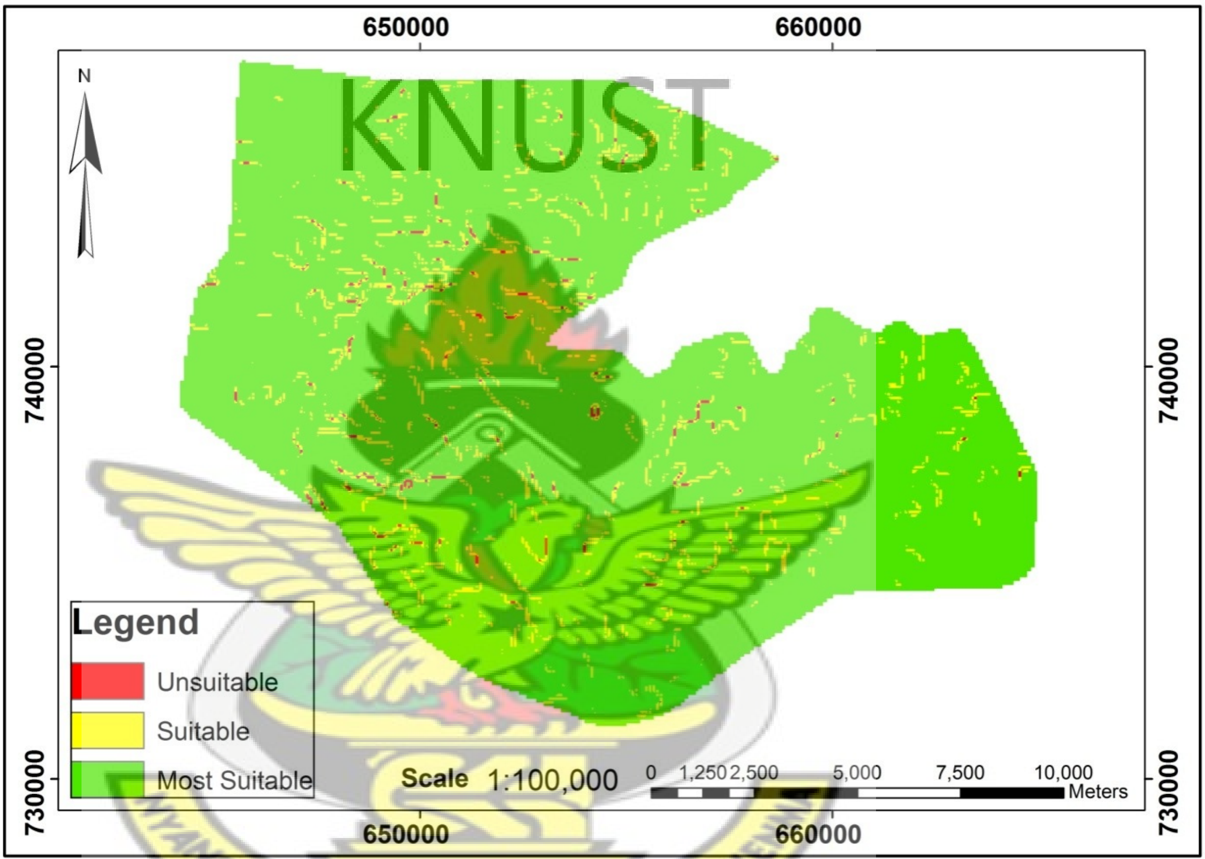

Figure 4.3: Suitability Map for Slope.

4.5 SUITABILITY FOR HIGHWAY

Figure 4.4 and Table 4.4 show the suitability for highways. A total land area of about 85.695 km^2 representing 42.1% of the study area was classified as unsuitable for siting transfer stations whiles about 37.912 km^2 representing about 18.6% land area was deemed suitable. For the most suitable, a total land area of 80.153 km^2 which represents about 39.3% of the study area was obtained.

Table 4.4: Highway Suitability.

Value	Suitability	Area (km^2)	Land Area (%)
1	Unsuitable	85.695	42.1
2	Suitable	37.912	18.6
3	Most Suitable	80.153	39.3
Total Area		**203.760**	**100**

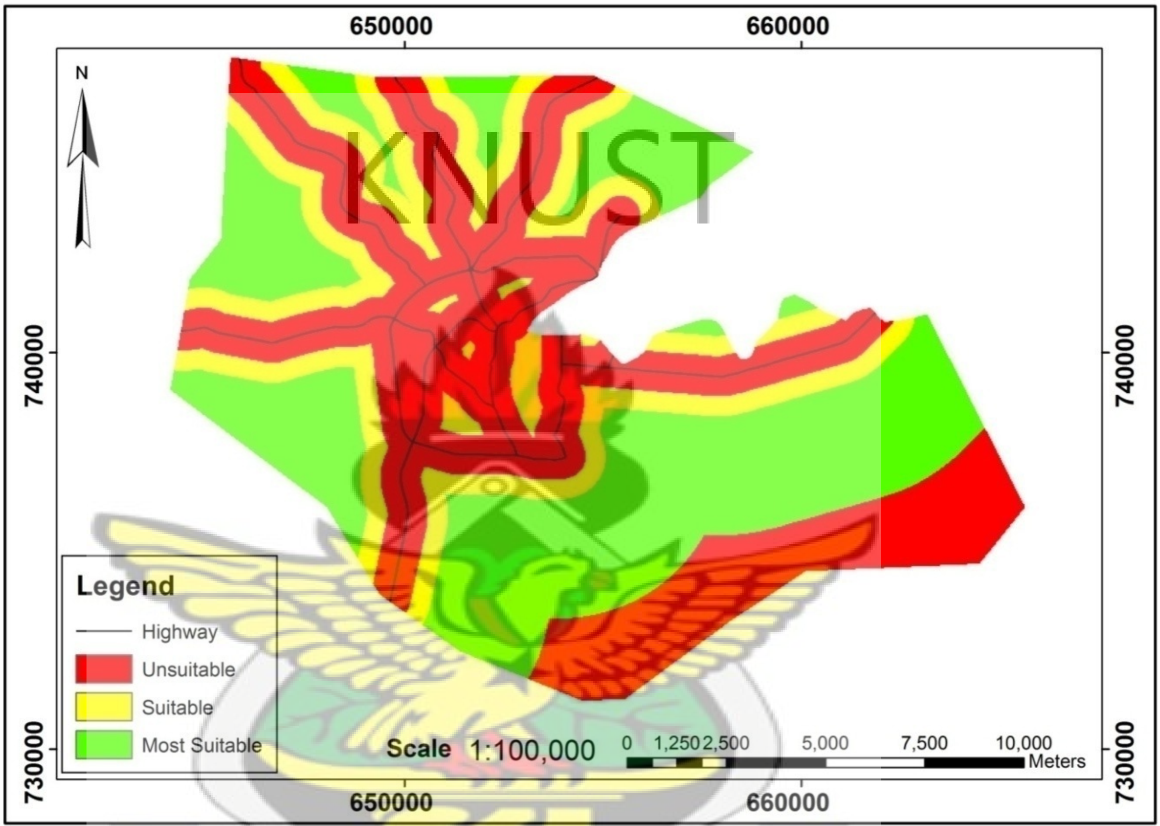

Figure 4.4: Suitability Map for Highway.

4.6 SUITABILITY FOR WASTE GENERATION CENTRES

Figure 4.5 and Table 4.5 shows the suitability results for waste generation centres. For suitability for waste generation centres, a total land area of 153.650 km^2 representing 75.4% of the study area was classified as unsuitable, whiles 50.11 km^2 representing 24.6% land area was deemed suitable. A total of 126 locations of communal sites within the Metropolis were mapped in this study. No classification was obtained for land areas as most suitable.

Table 4.5: Generation Centres Suitability.

Value	Suitability	Area (km^2)	Land Area (%)
1	Unsuitable	153.650	75.4
2	Suitable	50.110	24.6
Total Area		**203.760**	**100**

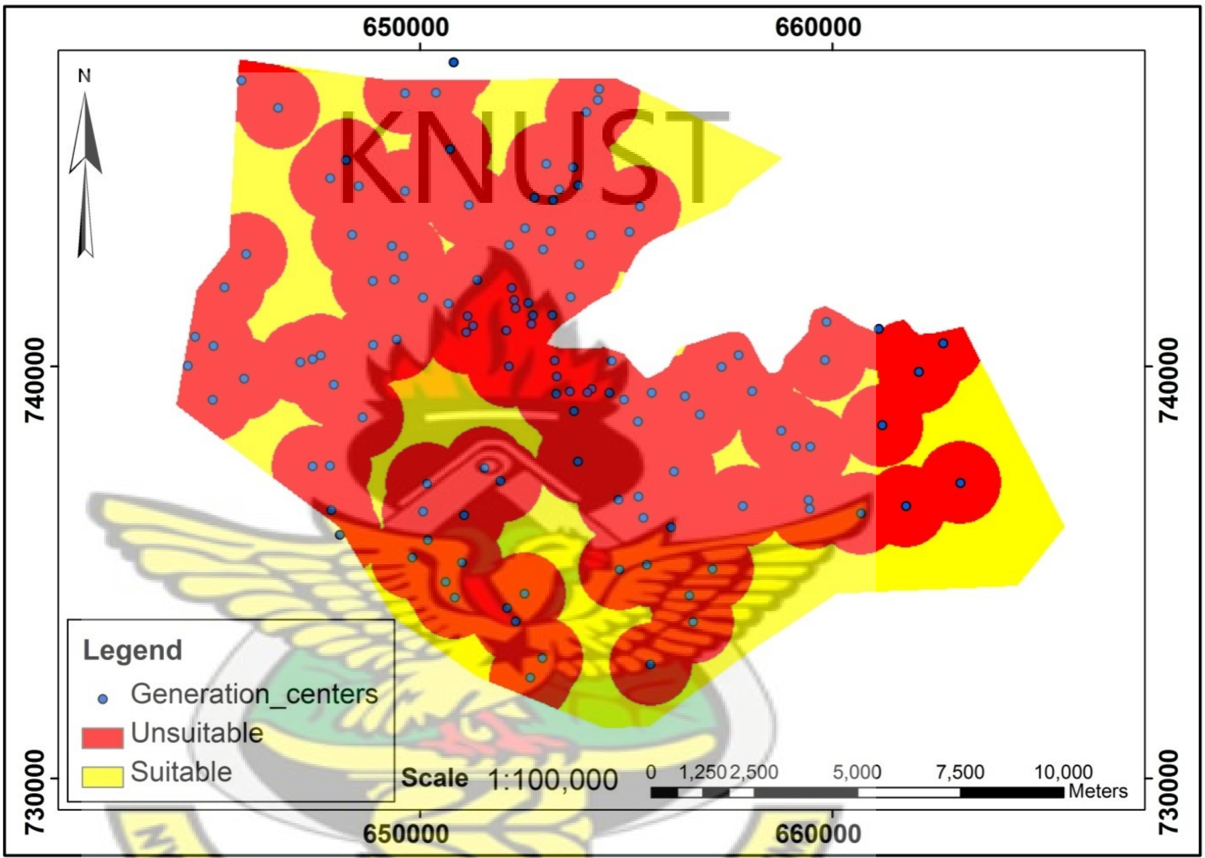

Figure 4.5: Suitability Map for Generation Centres.

4.7 SUITABILITY FOR GEOLOGY

Figure 4.6 and Table 4.6 show the results of suitability for geology of the study area. Two major geologic types (Granitoid undifferentiated and Phyllite, Schist, Tuff & Greywacke) that exist in the study area were classified as unsuitable and most suitable based on their characteristics and suitability to leachate. A total land area of 127.076 km^2 representing 62.4% of the study area was classified as unsuitable, whiles 76.684 km^2 representing 37.6% land area was deemed most suitable. No classification was obtained for land areas as suitable.

Table 4.6: Geology Suitability.

Value	Geology Type	Suitability	Area (km^2)	Land Area (%)
1	Granitoid Undifferentiated	Unsuitable	127.076	62.4
3	Phyllite, Schist, Tuff & Greywacke	Most Suitable	76.684	37.6
Total Area			**203.760**	**100**

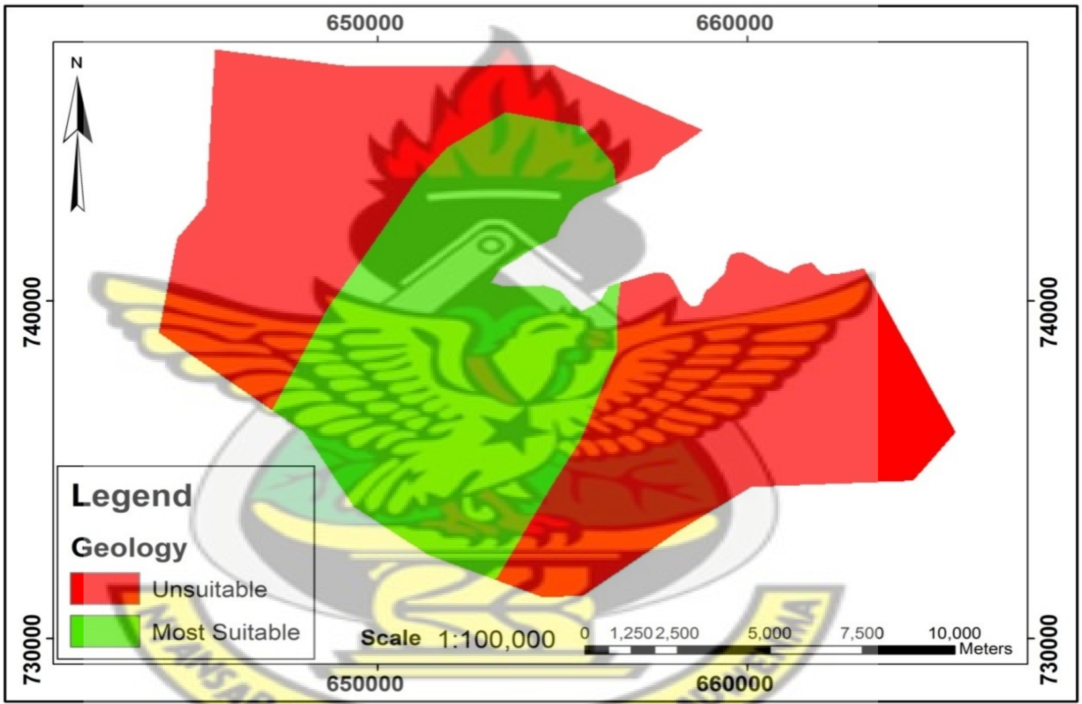

Figure 4.6: Suitability Map for Geology.

4.8 SUITABILITY FOR FAULT LINE

Figure 4.7 and Table 4.7 show suitability of the study area for fault line. Fault lines are one of the most critical features looked out for in siting waste facility to secure possible pollution of groundwater from leachate. A total land area of 13.643 km^2 representing 6.7% of the study area was classified as unsuitable, 52.265 km^2 representing 25.6% as suitable and 137.852 km^{2}representing 67.7% as most suitable.

Table 4.7: Fault Line Suitability.

Value	Suitability	Area (km^2)	Land Area (%)
1	Unsuitable	13.643	6.7
2	Suitable	52.265	25.6
3	Most Suitable	137.852	67.7
Total Area		**203.760**	**100**

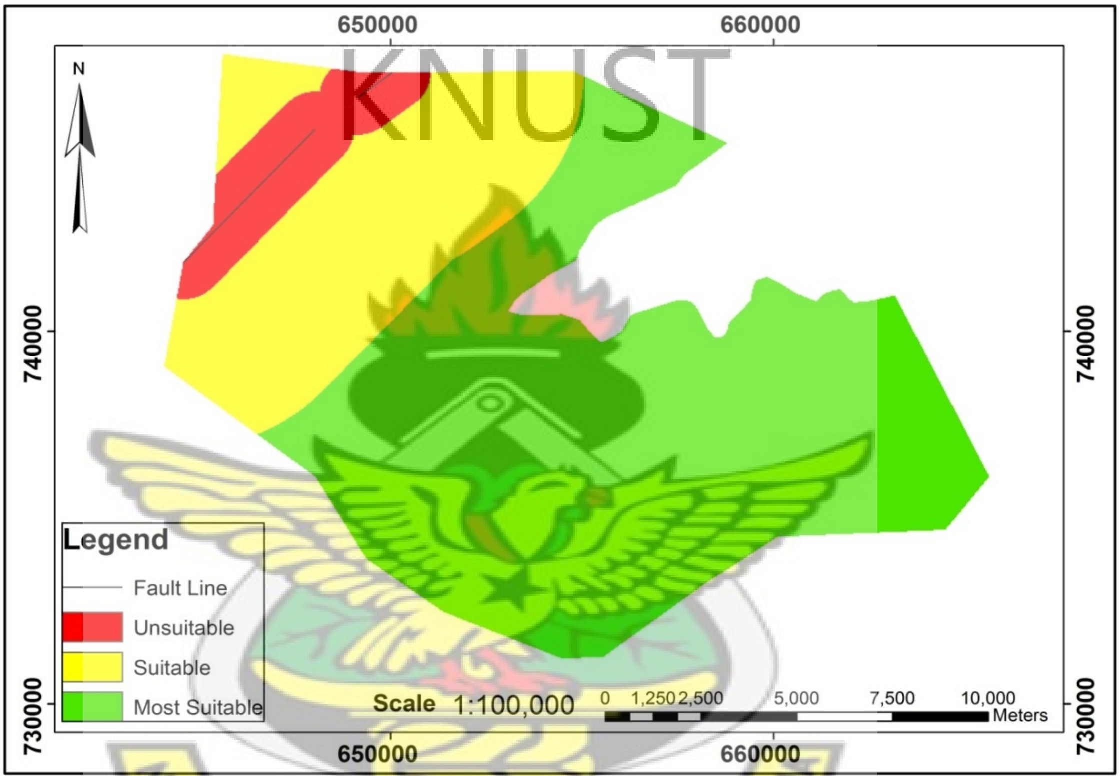

Figure 4.7: Suitability Map for Fault Line.

4.9 SUITABILITY INDEX

Figure 4.8 and Table 4.8 show the suitability index of the study area. The combination of all the weighted criteria in an overlay analysis resulted in a suitability index map of the study area. A total land area of 64.955 km^2 representing 31.9% was classified as unsuitable, 117.11 km^2 representing 57.5% was classified as suitable and 21.695 km^2 representing 10.6% classified as most suitable.

Table 4.8: Suitability Index.

Value	Suitability	Area (km^2)	Land Area (%)
1	Unsuitable	64.955	31.9
2	Suitable	117.11	57.5
3	Most Suitable	21.695	10.6
Total Area		**203.76**	**100**

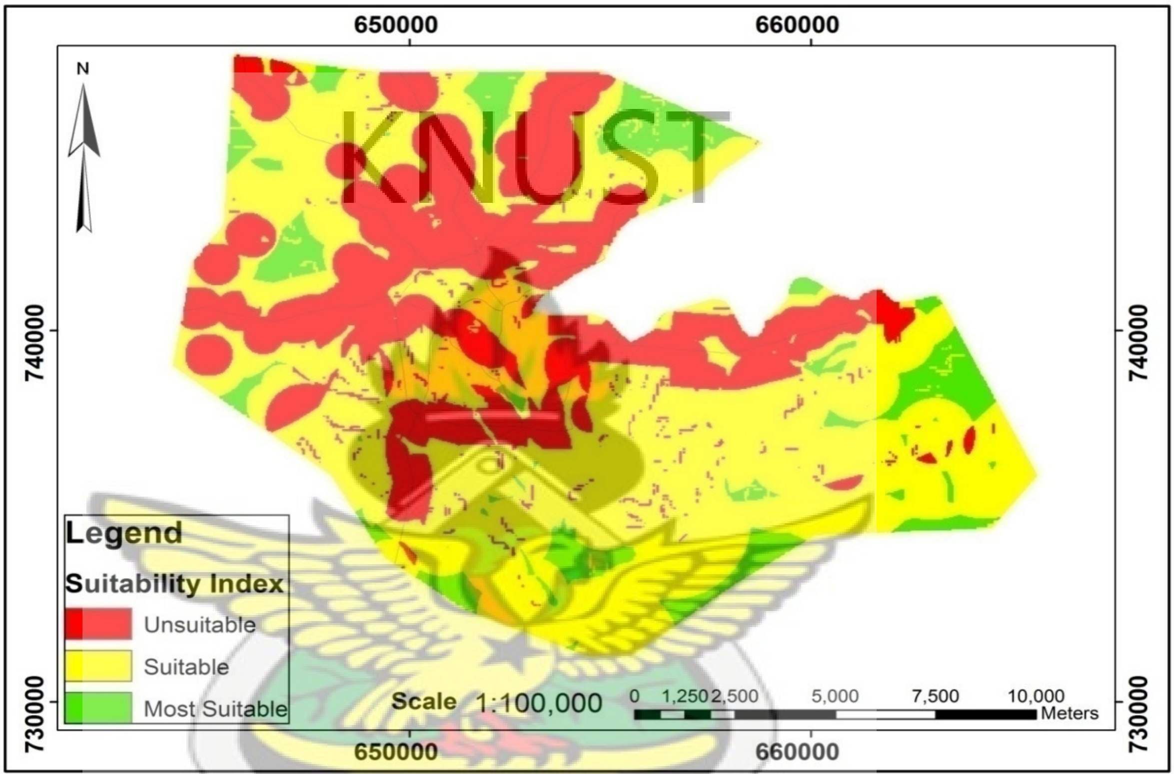

Figure 4.8: Suitability Index Map.

4.10 POTENTIAL SITES

Table 4.9 and Figure 4.9 show respectively the land sizes and the locations of the potential sites within the study area. Using the constraint map and a minimum of 20 Acres of land area for transfer station, 4 potential sites were proposed for which the average suitability index classified as most suitable.

Table 4.9: Potential Sites

Site_ID	Grid Code	Area (km^2)	Area_(Acres)	Land Area (%)
1	3	0.455	112.476	22.3
2	3	0.117	28.947	5.7
3	3	0.729	180.038	35.7
4	3	0.743	183.479	36.4
Total Area		**2.044**	**504.940**	**100**

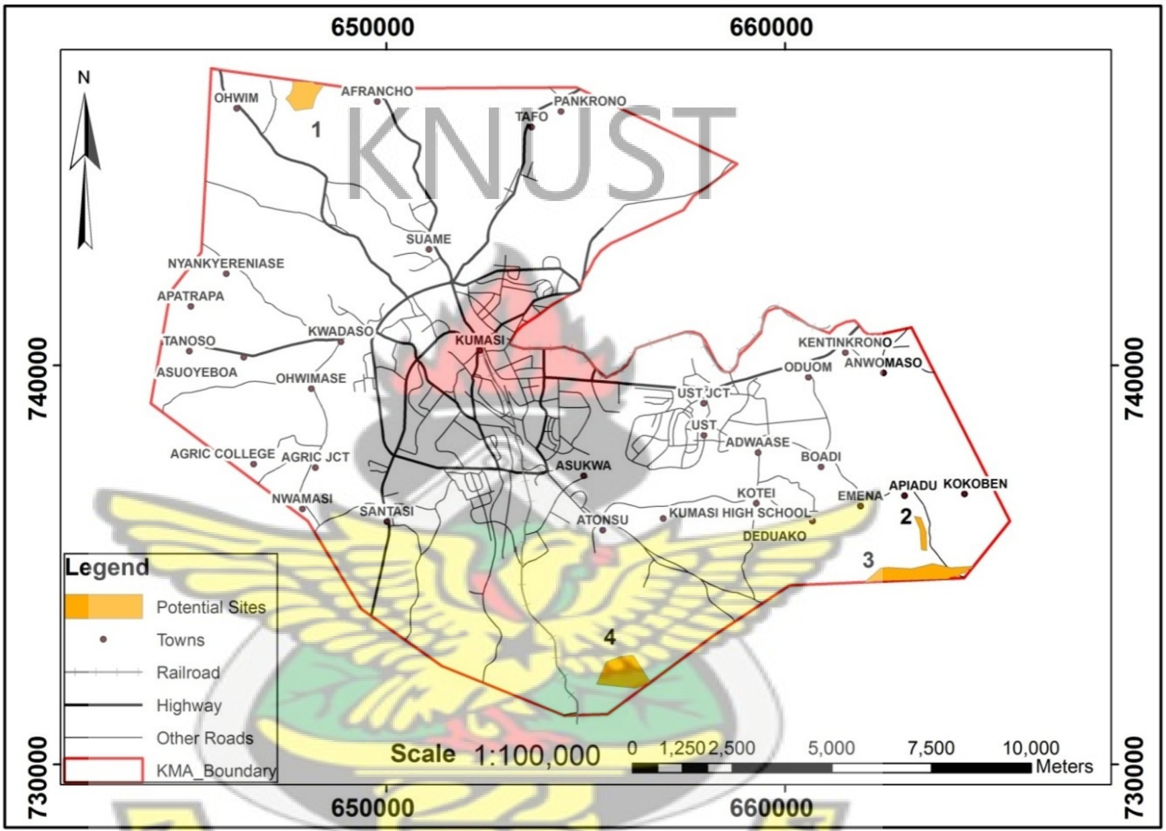

Figure 4.9: Locations of 4 Potential Sites.

4.11 CALCULATION FOR WEIGHTS

Table 4.10 show the weights that resulted from computation of the pairwise comparison matrix.

Table 4.10: Result of calculation for weights.

Criteria	1	2	3	4	5	6	7	Weights
1) Distance to Highway	1.00	0.33	0.25	2.00	0.33	0.50	0.50	**0.0622**
2) Distance to Residential area	3.00	1.00	3.00	8.00	2.00	4.00	2.00	**0.2954**
3) Distance to rivers and streams	4.00	0.33	1.00	7.00	0.50	3.00	0.50	**0.1579**
4) Geology	0.50	0.13	0.14	1.00	0.14	0.20	0.17	**0.0265**
5) Slope	3.00	0.50	2.00	7.00	1.00	3.00	0.50	**0.1762**
6) Distance to faults	2.00	0.25	0.33	5.00	0.33	1.00	0.33	**0.0812**
7) Distance from generation centres	2.00	0.50	2.00	6.00	2.00	3.00	1.00	**0.2005**

Consistency ratio = 0.06

CHAPTER FIVE

RESULTS

5.1 ACCURACY OF DATA ASSESSMENT

Primary as well as secondary spatial data are likely to be erroneous due to poor handling and acquisition methods. Data transformation, digitizing and analyzing are also associated with errors due to little knowledge of data acquisition equipments and software users. In view of these, the study critically assessed the accuracy of the data using aerial photographs, 'ground truth' coordinates of known locations within the study area and the vector data of roads, rivers, railway, and the boundary of the study area. Soil analysis of the study area was eliminated in the analysis owing to the difficulty in obtaining a detailed soil data. However, a more detailed soil map of the study area or suitable sites will be needed before any implementation.

5.2 SUITABILITY ANALYSIS ON CRITERIA

5.2.1 Analysis on Suitability for Streams and Rivers

To obtain a suitable site for establishing transfer station within the study area, geographic data on rivers and streams channel was used. This is of importance since factors such as population growth, industrialization and other human activities such as construction of residential facilities have over the years led to the destruction of water sources and channels. Field work revealed that, most of the stream channels have been converted into drains where households' liquid wastes are directed to. Several areas along water ways now serve as dumping areas within the study area. A study by Mensa-Bonsu& Owusu-Ansah (2011), describes the state of water bodies in Kumasi as becoming critical and considered the Aboabo and Subin streams as dead with no aquatic life. In view of these, streams and rivers were considered one of the critical environmental concerns in this study. With the incorporation of multi-criteria evaluation and Geographic Information System, locations are determined for transfer station by creating acceptable distances from the stream and river channels. The results as depicted in Figure 4.1 reveals the numerous water channels in the study area but currently most are converted to drains and others lost out due to settlement and other developments. With a greater section of people depending on groundwater in the study area, it is however of major importance if the surface water is protected to avoid any future groundwater contamination.

5.2.2 Analysis on Suitability for Urban Areas

The spatial location of the Metropolis has facilitated development in all direction of the city. This coupled with the high cost of land in the inner city and preference for single family houses has necessitated the rapid development of peripheral adjoining areas to the city. The extent of urban sprawl, encroachment and rezoning is massive and the city authorities seem to have no control over it. Public awareness and agitation on waste management centres closer to their surrounding has become a major issue to battle with and has led to the closing down of most dumping sites within the country.

The planning of the Metropolis and waste management system had not considered reserved areas for such a facility and so is battling with financing the evacuation of waste on time. About 2.769 km^2 which represents about 1.4% of the study area was classified most suitable for suitability of urban areas. It was realized that, most communal sites within the communities are struggling for space with settlement. Either the lands have been encroached, rezoned to suit settlement or there is no space at all for the collector bins.

Influx and rapid urbanisation, plus social and political pressures, have put land at a premium in the study area especially along the main highways leading out of the city and its surrounding towns. The Oti landfill, once thought of as being at an acceptable distance from suburban housing, now sits cheek by jowl with human settlement. With these, the search for acceptable transfer sites within an economically viable radius of collection operations becomes more and more problematic. Public participation and consultation is therefore of the utmost importance.

5.2.3 Analysis on Suitability for Slope

The general terrain of the study area is undulating with slightly rising elevations with few areas being flat. The most suitable slope type ranging from 0 to 6^{o} was desired to establish a transfer station. This has an advantage of controlling erosion. A highly eroded area is however not required for this facility. An area with a slightly existing slope will be of an advantage by providing benches for a transfer station and/or a combined recovery facility (Ryan, 2010).The study area had about 94.5% of land area being most suitable in terms of slope. The natural topography of a site is utilised wherever possible to take advantage as existing wind barriers and visual screens. Existing slopes can, however, be used to provide benches and to divert water flows from operational areas (Ryan, 2010).

5.2.4 Analysis on Suitability for Highways

The results of highways buffer as shown in Table 4.4 and Figure 4.4 indicate about 57.9% suitability (both suitable and most-suitable), with a corresponding land area of about 118.065 km^2. This implies there exist a considerable length of highways to facilitate the easy transfer of waste around the metropolis, with 500 m buffer for suitable and up to 4000 m for most suitable.

Proximity of a transfer station to highways was also of importance in this study. Most of the waste transportation delays have got to do with the heavy traffic on the roads coupled with the bad nature of most unengineered local roads that serve both old and newly developing suburbs at the periphery of the Metropolis. Frequent break down of collection trucks has been attributed to the poor nature of roads (Hamdu, 2009). To aid access to the site by smaller trucks and to support uninterrupted transfer of waste from the transfer station in large haulage trucks to final disposal sites, the highways were considered as effective.

5.2.5 Analysis on Suitability for Waste Generation Centres

The results on suitability for waste generation centres as in Figure 4.5 show spatially the distribution of 126 communal container sites mapped in this study. Different waste collection systems cut across the study area. Some settlement areas had no communal sites at all because their waste is collected by the house-to-house approach. Communal sites around major waste generation settlements and business areas were clustered. It is important to understand that flexibility of refuse collection is an important factor in today's urban development. Although it is understandable and logical that an efficient mechanical system of collection can evolve in a conventional suburban environment, it may be totally inappropriate for highly dense, congested settlements that have mushroomed on the fringes of the Metropolis.

Areas within the central business district for instance have temporal waste collection container placed on the road at certain hours of the day especially in the evenings where market activities are minimal to receive waste from its surroundings. Communal sites within most settlements were also very close to most homes which is likely to pose several health implications to the occupants. KMA in view of solving the health implications have resorted to building structures to cover the exposed bin from the rains to reduce the leachate produced.

5.2.6 Analysis on Suitability for Geology

The entire study area was characterised by two geology types which are the Granitoid undifferenciated and the Phyllite, Schist, Tuff & Greywacke with the latter intruding into the former from the south western to the northern section. Suitability was based on the characteristics of the geology type. Granitoids are volcanic rocks and are associated with rock types such as quartz, plagioclase and feldspar which are high in porosity and will easily conduct surface substances to underground. The Phyllite, Schist, Tuff& Greywacke on the other hand are metamorphic rocks with platy minerals alignment serving to further destroy permeability. About 37.6 % land area of the study area is characterised by suitable geology while a greater percentage of 62.4 is deemed unsuitable based on their soil characteristics. However, surface designs for transfer stations are always covered and little or no leachate which can be handled is anticipated. Detailed study on geology however needs to be undertaken for any specific site to be developed for use as a transfer station or any waste management facility to secure both surface and underground water from leachate.

5.2.7 Analysis on Suitability for Fault Line

The study area is characterized with two fault lines at the north western part from Afrancho through Nyankereniase to Apatrapa. Faults have been one of the major and fastest mode of conducting water into groundwater and hence pollutants. In view of this, a most suitable distance of 5000 m and above was assigned to the area around fault line and about 6.7% of land area classified as unsuitable, 25.6% as suitable and 67.7% as most suitable for siting transfer stations. The study area, having greater suitability to fault line, can be described as more suitable since leachate or other pollutants will not be conducted easily into groundwater.

5.3 ANALYSIS ON OPTIMAL SITE

The overlay of the various weighted suitability criteria maps resulted in a suitability index map from which optimal sites were obtained. The analysis as in Figure 4.8 showing the suitability index map of the study area depicted the various assigned weights. Urbanised areas were rejected despite suitabilities for other criteria. Several newly developed areas which were not updated in the data were eliminated as being suitable areas. The challenge with up to date data on settlement and other developments is a limitation to many site selection projects. Site visit always have to be done to confirm the results of optimal sites.

Four optimal sites were finally selected from which one (site 1) is located in the Bantama sub metro, one other (site 4) in Asokwa sub metro which lies at the location of the current engineered landfill serving Kumasi. The two others (sites 2 and 3) are located in the Oforikrom sub-metro. It should, however, be noted that, the sites were not ranked in relation to landfill locations and so their average distances were not considered in this study. For locating transfer stations, economic factors which include the cost of land acquisition, development, and facility operations must be taken into account (Erkut and Moran, 1991) and should be evaluated in terms of land use, land ownership, and availability of utilities (Rafiee*et al.*, 2011). This present study did not consider these economic factors; it did narrow down the total land area that could be considered for detailed investigation to 20 acres and above. This, therefore, will significantly provide some space for future expansion and a buffer for tree planting to serve as barrier for noise, dust and odour screening. It should also be noted that the availability of land on which to locate the transfer stations was not considered a limiting factor because no acquisition problems are anticipated.

If the destination of the final disposal of waste is far away from the area in which they are collected, then it may be more economical to transfer the wastes to large vehicles for haulage than to haul them directly in the original collection vehicles. This situation is becoming increasingly common, as landfills become more difficult to site and, therefore, more remote from populated areas.

A transfer station is often established at a landfill after it has been closed because people are accustomed to taking their waste to that location. Such a transfer station may or may not be economical. Site 4 however, lies at a location of a current operating landfill. It also stands a greater chance of being the most appropriate land area selected since it is just about 1000 m from the railroad leading out of the city.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Site selection for waste transfer stations is a complex approach that needs careful consideration of a number of environmental features of any area under study. This study demonstrates the use of the Multi-Criteria Decision Analysis (MCDA) and Geographic Information System (GIS) for site selection of waste transfer stations in KMA. The integration of MCDA and Geographic Information System provided an effective and efficient approach to identify suitable land areas for use as waste transfer station in the Kumasi Metropolis.

The study has revealed that, the study area is losing large tracts of land to human settlement. This occurs mostly along the highways leading to larger towns and other regions. From the study, 126 locations of communal sites within the Metropolis were mapped. It was however realized, that majority of the communal sites have been encroached by human settlement. This is as a result of rezoning in most of the areas and has in some cases led to the elimination of these sites.

The results for suitability for transfer station, from this study, selected 4 optimal sites. Site 1 is located within Bantama sub-metro with sites 2 and 3 in Oforikrom sub-metro. Site 4 lies at the location of the current engineered landfill site.

Finally, this research has been able to narrow down the search space for siting transfer stations using the medium to small scale maps. It included finer-scale maps for the defined zones to more precisely locate the best spots for transfer stations in the Asokwa sub-metro

6.2 RECCOMMENDATIONS

The following are recommendations drawn from the research;

i. The decision makers of KMA should ensure the proper demarcation and documentation of land areas to be used as sanitary sites in the various suburbs to avoid encroachment by human settlement. Further, rezoning of sanitary sites for residential use should be discouraged to enhance environmental health within the suburbs.

ii. The concept of transfer station should be incorporated into the waste management system of KMA.

iii. The selected locations from this research should be quickly acquired and prepared for the purpose of transfer station.

iv. Private waste management bodies are encouraged to incorporate this concept of transfer station in their activities to maximize profit and still providing quality service since the main idea is to remove waste from the human environment within the shortest possible time.

v. Urgent need for decision making body of KMA to secure suitable land area for landfill establishment to cater for the waste to be generated in the near future. Accra, the national capital cannot boast of a final disposal site for its waste and the designated area considered to be used have faced encroachment due to its delay in development. KMA is likely to face same and hence the urgency.

vi. Notwithstanding, using the results of this study, the decision makers of KMA should now complete a more detailed field analysis focused on the proposed zones, with special attention to land use, utilities, land acquisition, and accessibility, which will require more field investigation.

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APPENDICES

APPENDIX A

Table 1: Coordinates of Sanitary Sites within the Study Area

Location Name	Coordinates	
	Northings	Eastings
Aboahia	746617.416	649636.008
Abotanso	744085.422	652773.801
Abrepo	744370.295	648509.350
Abrepo Pentecost	743185.487	648355.569
Adabraka	746720.784	654345.996
Adiembra	736382.611	651068.449
Adompom	744826.989	653715.250
Adompom Extension	744388.327	653835.528
AdowatoAdumau	742065.861	648855.954
Adowato Market	742102.222	649371.519
Adowato Station	741665.094	650071.762
Ahenbronom	739389.780	658055.528
Ahinsan	736832.528	655297.139
Ahinsan Estate	737446.447	656155.894
Ahinsan Market	736323.115	655413.771
Ahinsan School	736760.623	654815.061
Amakom Division	739449.724	654166.645
Amakom Market	739355.424	654590.522
Amanfrom	746932.915	645670.724
Ampabame	742668.937	649599.325
Anwomaso	739860.263	662096.499
Apatrapa	741914.342	645256.416
Apinaman	734128.682	652110.819
Apiri	735910.437	648053.855
Appeadu	737167.121	663107.582
Aprabo	733795.180	656619.351
Asuyeboa LA	740259.011	647592.296
Asuyeboa Market	740165.732	647393.074
Asuyeboa Met P	740098.178	647096.892
Atafoa	744998.140	648204.668
Atasemanso	735231.765	651016.389
Atonsu	735066.226	654840.141
AtonsuPresby	736094.515	656086.634
AtonsuSline	735180.242	655501.077
Ayeduase Town	738052.195	659117.806
AyeduasiMarkt	738044.329	659464.214
Ayigya	740268.102	657724.720
AyigyaZongo	739980.916	657313.695
Bebre	740550.072	662686.690

Boadi	738568.175	661209.335
Bohyen	742910.950	649316.277
BomsoCemetry	738825.675	656785.257
Bomso Town	739271.794	656428.312
Breman	745263.819	650727.420
Bronikrom	744556.030	647819.415
Buokrom Pentecost	743259.309	655079.603
Buokrom School	743873.362	655334.259
Chief Owusu	740821.229	651119.040
Colligate	739386.280	653635.743
CPC	741898.838	652226.190
DabanKuma	734478.519	652536.716
DabanPanin	733809.682	652321.634
Dakodwom	737524.887	651561.556
Deduako	736427.545	660699.655
Denkyemuoso	739698.939	645731.871
Dichemso	741678.003	653650.561
Dome	746161.762	654032.940
Domoase	734435.276	656534.140
Edwinase	738755.748	648604.656
Emina	736608.063	661785.126
Fankyenebra	736472.734	650069.267
Golf Park	740980.026	651281.973
Gyinyaase	736605.186	657826.735
Kejetia	740864.861	652092.923
Kentinkrono	740147.750	659818.007
Kokode	737580.178	647813.746
KonaduYiadom	741605.934	652281.924
Kotei	736750.712	659420.484
Krofrom	742830.386	652982.442
Kron Market	734762.536	650617.177
Kronkomoase	734387.448	650837.800
KTI	740129.745	654647.866
Kwadaso Onion	740514.839	648859.943
Kwapra	747367.768	650814.028
Kwapra 2	746634.930	650383.307
Kyirapatire	735078.107	657092.347
Labuor	739749.196	653313.620
Lll	737686.494	653831.828
Lobito	739189.654	654948.041
Maakro	743909.236	651185.254
MaameKakraka	744027.054	653227.557
Manhyia Palace	741238.594	653205.594
Market	746455.175	654313.800
Mary Akuamoah	739360.689	654058.422
Moro Market	743275.631	653166.883

MoshieZongo	743180.520	654146.978
Mpatasie	744249.966	649635.600
Nhyiaeso Old T	737216.175	651951.665
Nsenie	741074.109	659859.759
Nwamase	736504.010	647846.020
Nyankyerenase	742720.312	645781.396
Nzema	737570.002	647396.213
Odeneho K	737144.467	650165.519
Odium	740904.200	661130.831
OforikromSch	739356.511	655618.180
Ohwim	746267.094	646556.659
Ohwimase	739551.767	647910.565
Oti Landfill	732767.360	655588.409
Oyokohene	741235.316	652737.014
Police Station	744905.119	653061.675
Post Office	741023.421	652698.182
Prisons	739997.120	652153.065
Race Course	741215.617	651151.226
Salvation	741401.949	652319.988
Santasi Main	735780.889	650188.425
SantasiZongo	735357.168	649814.304
SefaBoakye	741520.241	650687.558
Soboro	738656.369	655283.342
Sofoline	740647.624	649428.752
Sokoban School	732920.111	652963.671
ST. Annes	741532.245	652626.058
Suame Police Stn.	742089.090	651385.225
Tafo	742937.419	652157.269
TafoCemetary	743342.808	652549.968
Tafo Methodist	744287.194	653371.079
TanosoAnglcan Sch.	740488.388	644986.604
Tanoso K.	740006.252	644366.376
Tanoso Mkt.	740713.910	644544.748
Techiman	739180.776	644968.002
Timpom	732442.227	652673.188
Twumduase	736534.980	659454.663
Westend	738431.816	658762.881
YarewaZongo	740131.840	653264.679
Yenyawoso	742463.578	653859.879
YF	738911.052	653733.394
Zion	739327.281	653305.692

APPENDIX B1

Step 1: Pairwise Comparison

The criteria in the row are being compared to the criteria in the column. The next step is to normalize the matrix. This is done by totalling the numbers in each column.

Criteria	1	2	3	4	5	6	7	Average
1) Distance to Highway	1	1/3	1/5	2	1/3	1/2	1/2	**0.70**
2) Distance to Residential area	3	1	3	8	2	4	2	**3.29**
3) Distance to rivers and streams	5	1/3	1	7	1/2	3	1/2	**2.48**
4) Geology	1/2	1/8	1/7	1	1/7	1/5	1/6	**0.33**
5) Slope	3	1/2	2	7	1	3	1/2	**2.43**
6) Distance to faults	2	1/4	1/3	5	1/3	1	1/3	**1.32**
7) Distance from generation centres	2	1/2	2	6	2	3	1	**2.36**
SUM	**16.50**	**3.04**	**8.68**	**36.00**	**6.31**	**14.70**	**5.00**	**1.84**

APPENDIX B2

Step 2: Matrix Normalization

This step is to normalize the matrix by totalling the numbers in each column. Each entry in the column is then divided by the column sum to yield its normalized score. The sum of each column is 1.

Criteria	1	2	3	4	5	6	7	Average
1) Distance to Highway	0.06	0.11	0.02	0.06	0.05	0.03	0.10	**0.06**
2) Distance to Residential area	0.18	0.33	0.35	0.22	0.32	0.27	0.40	**0.30**
3) Distance to rivers and streams	0.30	0.11	0.12	0.19	0.08	0.20	0.10	**0.16**
4) Geology	0.03	0.04	0.02	0.03	0.02	0.01	0.03	**0.03**
5) Slope	0.18	0.16	0.23	0.19	0.16	0.20	0.10	**0.18**
6) Distance to faults	0.12	0.08	0.04	0.14	0.05	0.07	0.07	**0.08**
7) Distance from generation centres	0.12	0.16	0.23	0.17	0.32	0.20	0.20	**0.20**

SUM	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

APPENDIX B3

Step 3: Consistency Ratio Computations

Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	1	1/3	1/5	2	1/3	1/2	1/2
2	3	1	3	8	2	4	2
3	5	1/3	1	7	1/2	3	1/2
4	1/2	1/8	1/7	1	1/7	1/5	1/6
5	3	1/2	2	7	1	3	1/2
6	2	1/4	1/3	5	1/3	1	1/3
7	2	1/2	2	6	2	3	1

X

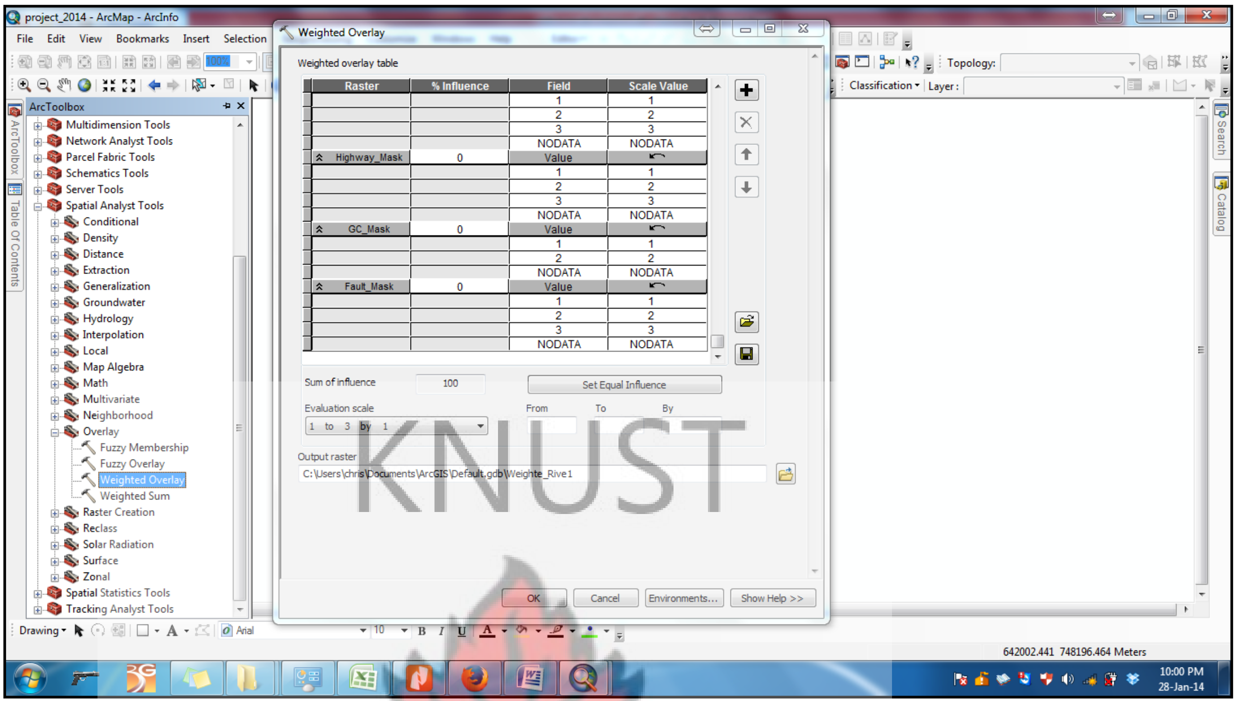
0.06	0.30	0.16	0.03	0.18	0.08	0.20

=

	1	**2**	**3**	**4**	**5**	**6**	**7**	**Average**
1	0.06	0.11	0.02	0.06	0.05	0.03	0.10	0.06
2	0.18	0.33	0.35	0.22	0.32	0.27	0.40	0.30
3	0.30	0.11	0.12	0.19	0.08	0.20	0.10	0.16
4	0.03	0.04	0.02	0.03	0.02	0.01	0.03	0.03
5	0.18	0.16	0.23	0.19	0.16	0.20	0.10	0.18
6	0.12	0.08	0.04	0.14	0.05	0.07	0.07	0.08
7	0.12	0.16	0.23	0.17	0.32	0.20	0.20	0.20

The consistency vector was determined by dividing the weighted sum vector by the criterion weights; and the average value of consistency vector was computed as shown in table 4 above.

APPENDIX C: OVERLAY ANALYSIS IN ARCGIS 10.0 SOFTWARE



APPENDIX D: SOME SANITARY SITES VISITED

Sanitary site at Prisons

Sanitary site at Santasi main

Sanitary site at Moshie Zongo

Sanitary site at Yenyawoso

Oti landfill site **Sanitary site at Labour**