GIS-Based Approach for Landfill Site Selection in Obuasi Municipality

By

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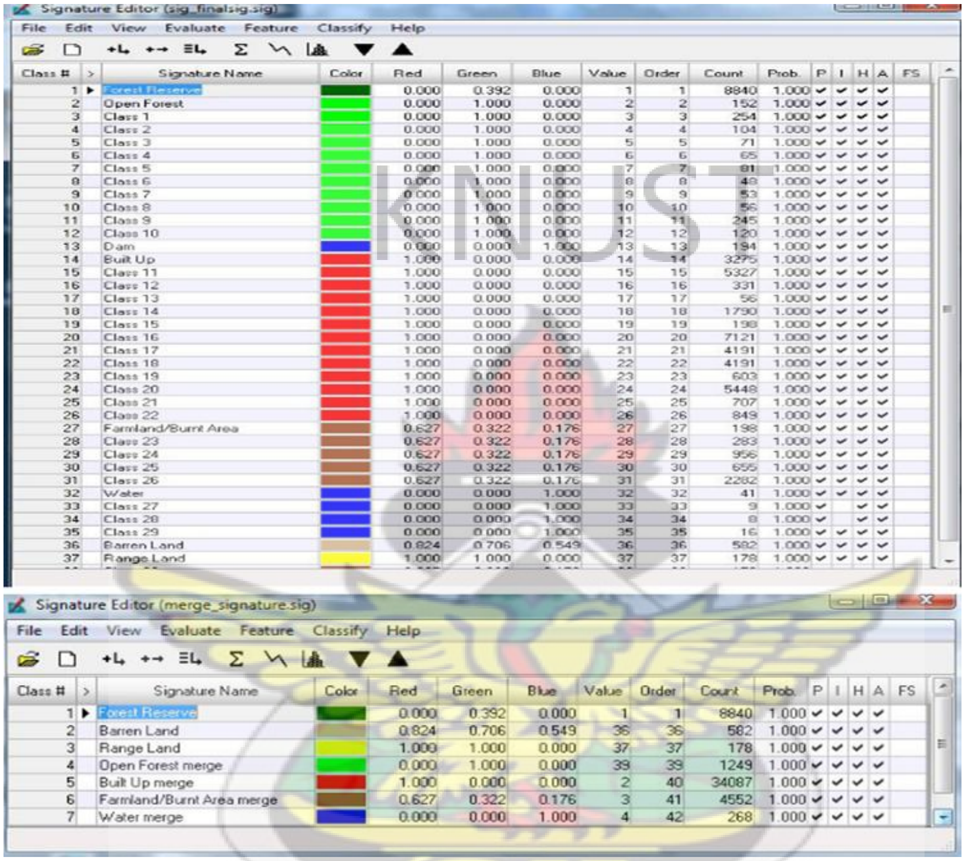
APPENDICES

APPENDIX A: SIGNATURE EDITOR SHOWING INDIVIDUAL TRAINING SETS AS WELL AS RECODED (MERGED) TRAINING DATASETS



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Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	▶	Forest Reserve		0.000	0.392	0.000	1	1	8840	1.000	✓	✓	✓	✓	
2		Open Forest		0.000	1.000	0.000	2	2	152	1.000	✓	✓	✓	✓	
3		Class 1		0.000	1.000	0.000	3	3	254	1.000	✓	✓	✓	✓	
4		Class 2		0.000	1.000	0.000	4	4	104	1.000	✓	✓	✓	✓	
5		Class 3		0.000	1.000	0.000	5	5	71	1.000	✓	✓	✓	✓	
6		Class 4		0.000	1.000	0.000	6	6	65	1.000	✓	✓	✓	✓	
7		Class 5		0.000	1.000	0.000	7	7	81	1.000	✓	✓	✓	✓	
8		Class 6		0.000	1.000	0.000	8	8	48	1.000	✓	✓	✓	✓	
9		Class 7		0.000	1.000	0.000	9	9	53	1.000	✓	✓	✓	✓	
10		Class 8		0.000	1.000	0.000	10	10	56	1.000	✓	✓	✓	✓	
11		Class 9		0.000	1.000	0.000	11	11	245	1.000	✓	✓	✓	✓	
12		Class 10		0.000	1.000	0.000	12	12	120	1.000	✓	✓	✓	✓	
13		Dam		0.000	0.000	1.000	13	13	194	1.000	✓	✓	✓	✓	
14		Built Up		1.000	0.000	0.000	14	14	3275	1.000	✓	✓	✓	✓	
15		Class 11		1.000	0.000	0.000	15	15	5327	1.000	✓	✓	✓	✓	
16		Class 12		1.000	0.000	0.000	16	16	331	1.000	✓	✓	✓	✓	
17		Class 13		1.000	0.000	0.000	17	17	56	1.000	✓	✓	✓	✓	
18		Class 14		1.000	0.000	0.000	18	18	1790	1.000	✓	✓	✓	✓	
19		Class 15		1.000	0.000	0.000	19	19	198	1.000	✓	✓	✓	✓	
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21		Class 17		1.000	0.000	0.000	21	21	4191	1.000	✓	✓	✓	✓	
22		Class 18		1.000	0.000	0.000	22	22	4191	1.000	✓	✓	✓	✓	
23		Class 19		1.000	0.000	0.000	23	23	603	1.000	✓	✓	✓	✓	
24		Class 20		1.000	0.000	0.000	24	24	5448	1.000	✓	✓	✓	✓	
25		Class 21		1.000	0.000	0.000	25	25	707	1.000	✓	✓	✓	✓	
26		Class 22		1.000	0.000	0.000	26	26	849	1.000	✓	✓	✓	✓	
27		Farmland/Burnt Area		0.627	0.322	0.176	27	27	198	1.000	✓	✓	✓	✓	
28		Class 23		0.627	0.322	0.176	28	28	283	1.000	✓	✓	✓	✓	
29		Class 24		0.627	0.322	0.176	29	29	956	1.000	✓	✓	✓	✓	
30		Class 25		0.627	0.322	0.176	30	30	655	1.000	✓	✓	✓	✓	
31		Class 26		0.627	0.322	0.176	31	31	2282	1.000	✓	✓	✓	✓	
32		Water		0.000	0.000	1.000	32	32	41	1.000	✓	✓	✓	✓	
33		Class 27		0.000	0.000	1.000	33	33	9	1.000	✓		✓	✓	
34		Class 28		0.000	0.000	1.000	34	34	8	1.000	✓		✓	✓	
35		Class 29		0.000	0.000	1.000	35	35	16	1.000	✓	✓	✓	✓	
36		Barren Land		0.824	0.706	0.549	36	36	582	1.000	✓	✓	✓	✓	
37		Range Land		1.000	1.000	0.000	37	37	178	1.000	✓	✓	✓	✓	

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Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	▶	Forest Reserve		0.000	0.392	0.000	1	1	8840	1.000	✓	✓	✓	✓	
2		Barren Land		0.824	0.706	0.549	36	36	582	1.000	✓	✓	✓	✓	
3		Range Land		1.000	1.000	0.000	37	37	178	1.000	✓	✓	✓	✓	
4		Open Forest merge		0.000	1.000	0.000	39	39	1249	1.000	✓	✓	✓	✓	
5		Built Up merge		1.000	0.000	0.000	2	40	34087	1.000	✓	✓	✓	✓	
6		Farmland/Burnt Area merge		0.627	0.322	0.176	3	41	4552	1.000	✓	✓	✓	✓	
7		Water merge		0.000	0.000	1.000	4	42	268	1.000	✓	✓	✓	✓	

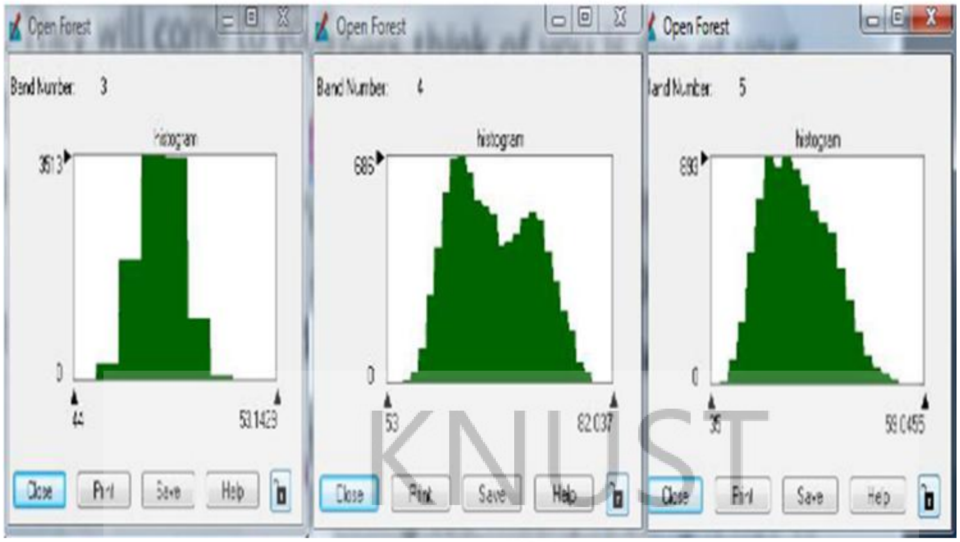

Figure 4.2 Histogram of an area Picked as a Training Set for Open forest.

The left Shows the Blue Band, Middle is the Red Band, and At Right is Green Band.

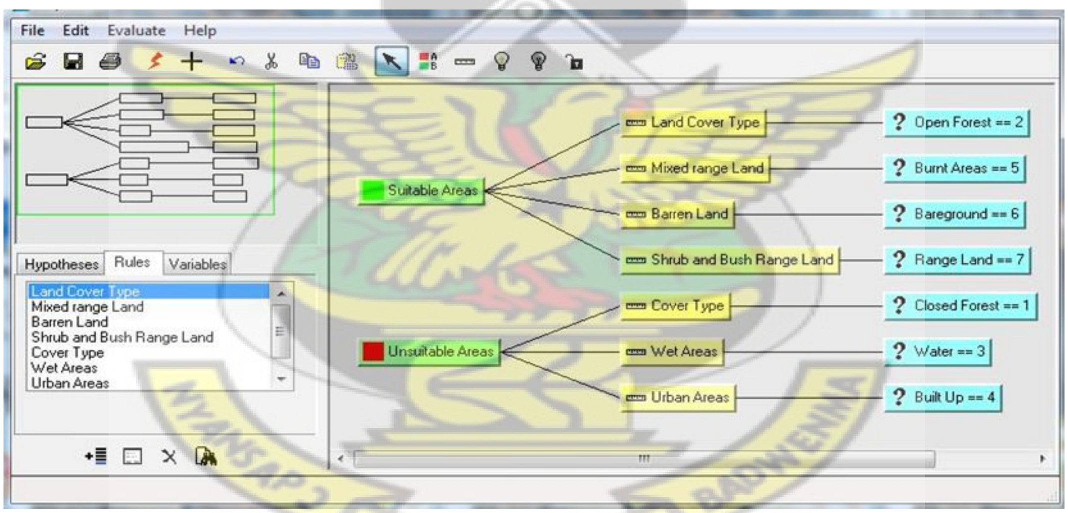

Figure 4.6 Hypothesis Used in Generating Suitability Map

Separability CellArray

Distance Measure: Transformed Divergence

Using Layers: 1 2 3 4 5 6 7

Taken 7 at a time

Best Average Separability: 1982.67

Combination: 1 2 3 4 5 6 7

Signature Name		1	2	3	4	5	6	7
Forest Reserve	1	0	2000	2000	1982.74	2000	2000	2000
Barren Land	2	2000	0	1999.58	1999.98	1999.99	1964.61	2000
Range Land	3	2000	1999.58	0	2000	2000	1692.96	1999.93
Open Forest merge	4	1982.74	1999.98	2000	0	2000	1997.99	2000
Built Up merge	5	2000	1999.99	2000	2000	0	1999.41	2000
Farmland/Burnt Area merge	6	2000	1964.61	1692.96	1997.99	1999.41	0	1998.99
Water merge	7	2000	2000	1999.93	2000	2000	1998.99	0

Close

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The ever increasing human population and its related anthropogenic activities have stimulated the phenomenon of urbanization in the past two decades. In Ghana, the rate of urban population growth has for the past twenty years been greater than population growth. The results of the 2010 population census indicate that presently urban growth rate is 3.7% whereas total population growth rate is 2.4%. The report also shows that 50% of the total population resides in the urban centers, which is likely to rise in the preceding years (Ghana Statistical Service, 2010).

The exponential growth rates of the urban centres, coupled with their huge population base, has left many cities within the nation lacking basic infrastructure and services such as adequate water supply, sanitation and sewage, and solid waste management. Among the many problems that confront cities in Ghana, solid waste disposal is a particularly worrying issue that seems to overwhelm the authorities. With the rising population coupled with increased demands in production and consumption of new products, there has been an enormous increase in the measure as well as the diversity of the solid waste being generated and the open spaces for dumping the wastes are becoming less and less available.

As a result, urban settlements in the country are saddled with a worsening solid waste situation which proves to be uncontrollable and threatens public health and environmental quality. As a matter of fact, the problem appears uncontrollable and can be likened to a ‘ghost’ staring the entire nation in the face.

Tamakloe (2006) as cited by Baabereyir (2009) has referred to the waste problem as "a nightmare" which is capable of delaying the nation in achieving the Millennium Development Goals (MDGs) by the target year of 2015 since solid waste disposal affects most of the issues to be addressed by the MDGs including child health and mortality (Goal 4), maternal health (Goal 5), the incidence of malaria and other diseases (Goal 7) and environmental sustainability (Goal 7).

The need of the hour is therefore to devise an efficient and effective solid waste management system wherein decision-makers and waste management planners can deal with the increase in complexity associated with this problem.

In spite of the increasing stress towards the waste reduction at the source, as well as recovery and recycling of the solid waste, disposal of solid waste by landfilling remains the most commonly employed method. This is because the residual matter even after the recovery process has to be disposed of by landfilling. Hence, landfilling is an aspect of the waste management system that cannot be overlooked (Sener *et al.*, 2006).

The development of a solid waste landfill requires siting in a pre-existing urban matrix comprised of diverse competing land uses. Siting a sanitary landfill requires an extensive evaluation process in order to identify the best available disposal location. This location must comply with the requirements of governmental regulations and at the same time must minimize economic, environmental, health and social costs. Therefore, landfill siting generally requires processing of a variety of spatial data. As noted by Ball (2005), proper landfill site selection is the fundamental step in sound waste disposal and the protection of the environment, public health and quality of life.

All over the world, landfill selection in an urban area is a critical issue in urban planning process because of its enormous impact on the economy, ecology and the environmental health of the region (Akbari *et al*., 2008). Difficulties arise for local authorities in finding suitable locations for these new landfill sites, particularly in context of the "not in my backyard" (NIMBY) syndrome predominant in today's culture. This stems from public perception of landfill as a potential polluter of soil, water and the atmosphere as well as a cause of decline in environmental aesthetics. Negative impacts of landfill arise in part from poor site selection procedures as the search for a new dump site is only carried out when an old site has reached the end of its life cycle. This results in pressurized site selection procedures with inadequate site investigations and little public consultation (Cummins *et al.*, 2002).

For the past years, simple overlaying of maps was done to identify possible areas available for landfilling. This method was not effective since it was time consuming, very expensive and did not take into consideration, factors such as groundwater and geology of the area. More recently, several researchers have discovered ways of partially solving this problem by applying computer based techniques in the process of selecting suitable landfill sites (Nakakawa and Ogao, 2006). Gao *et al*. (2004), noted that any decision making process that focuses on problems that are either dependent or influenced by geographical information is spatial decision making.

The integration of Geographic Information Systems (GIS) and Remote Sensing techniques provide a platform where spatial data can be analysed and assessed to select sites suitable for relevant projects of which landfill siting is part. Many works have been done using GIS to select landfill sites in many developed as well as developing countries. In India, Sumathi *et al*. (2007), used multi criteria decision (MCD) in GIS to select landfill sites in Pondicherry, a typical urbanizing city of

India. Keir *et al.* (1993) discussed the use of both vector-based and raster-based Geographic Information System (GIS) to determine potential waste sites based on suitability of topography and proximity with respect to key geographic features. Sener *et al*. (2006) used GIS for multi criteria decision analysis (MCDA) to help the landfill site selection problem and developed a ranking of the potential landfill areas based on a variety of criteria.

GIS is a computer-based technology and methodology for collecting, processing, managing, analyzing, modeling, and presenting geographic (spatial) data for a wide range of applications (Eldrandaly *et al.*, 2003). The integration of both GIS and expert based techniques improves decision-making because it enhances an environment for transformation and combination of geographical data and stakeholders' preferences (Malczewski, 2006). In site selection problems, GIS performs deterministic overlay and buffer operations while; expert based classification methods evaluate alternatives based on the decision maker's subjective values and priorities (Eldrandaly *et al.*, 2003).

The present study aims at using Geographic Information System (GIS) and Remote Sensing (RS) techniques in an expert based classification system to select sites suitable for landfilling within the Obuasi Municipality of the Ashanti Region of Ghana.

1.2 PROBLEM STATEMENT

Over the years, site selection for waste disposal within the Obuasi Municipality has mainly been done manually which makes the process time consuming and expensive.

Also, practices like daily covering is not done at the current site which makes the place unsightly and cause environmental problems like contamination of both surface and ground water.

A landfill site is therefore needed to be able to ensure safe disposal of the solid waste generated. This site will incorporate an engineered method of disposal of the solid waste on land in a manner that minimizes environmental hazards by spreading the solid waste in thin layers, compacting the waste to the smallest practical volume and applying soil cover at the end of the operating day.

The selection of such a site involves the manipulation of a number of spatial data and criteria to determine the optimal site. The ability of GIS and RS in determining this site is unquestionable hence, its application in this research.

1.3 JUSTIFICATION

Solid waste management is essential in the sense that it helps in reducing if not eliminating health and environmentally related issues. One aspect of solid waste management which is responsible disposal has been the main challenge of the Obuasi municipality. This is because, the dump site in Diawuoso lacks effective management system and this has resulted in issues of littering, odour, vermin and unsightliness.

A new site is needed where proper operational principles could be adhered to. To select such a site, a number of factors of spatial concern need to be considered to prevent the NIMBY syndrome.

This research seeks to use selected criteria in a GIS environment to select optimal sites within the metropolis. This will provide decision makers ready-made information and alternatives when selecting an area for such purpose.

1.4 OBJECTIVES

The main objective of the study was to use Geographic Information System (GIS) and Remote Sensing (RS) techniques to select sites suitable for landfilling within the Obuasi Municipality.

1.4.1 Specific Objectives

The research sought to specifically carry out;

- Land cover classification analysis of the study area
- Spatial analyses using selected criteria
- Weighted and Overlay Analyses
- Optimal sites selection of areas of at least 0.5 sq km.

1.5 ORGANISATION OF REPORT

The report is made of five chapters.

Chapter one: **Introduction**

This is the introduction to the entire thesis and presents the context of the research. It covers the statement of the research problem, the aims and objectives of the study, methodology and the justification for undertaking the research.

Chapter two: **Literature review**

The second chapter gives a literature review on the current waste management system in Ghana and the Obuasi Municipality to be precise. It also explains selected technologies and criteria employed in selecting suitable sites for landfilling. With examples of works that have been carried out.

Chapter three: **Materials and Methods**

This chapter describes the study area in terms of location, climate, geology, occupation and population. Materials and software used are listed and the methods employed are carefully described in details.

Chapter four: **Results**

The results of the land cover map, thematic maps representing the selected criteria are discussed here. Also, the suitability map and the map showing optimal sites are all discussed here.

Chapter five: **Discussions**

Here, the results are discussed in detailed taking into consideration similar works carried out elsewhere.

Chapter Six: **Conclusion and recommendations**

The last chapter details out the conclusions and recommendations to government, stakeholders, municipalities and policy makers and also for further studies.

CHAPTER TWO

LITERATURE REVIEW

2.1 MUNICIPAL SOLID WASTE

Many definitions have been given to the term "Waste". According to the German West of August 27, 1993 (cited by Fei-Baffoe, 2010), wastes are portable objects that have been abandoned by the owner. The WordWeb dictionary also defines wastes as any materials unused and rejected as worthless or unwanted. As noted by Gilpin (1996), the concept of waste embraces "all unwanted and economically unusable by-products or residuals at any given place and time, and any other matter that may be discarded accidentally or otherwise into the environment". He also argues that what constitutes waste must "occur in such a volume, concentration, constituency or manner as to cause a significant alteration in the environment". Hence, apart from waste being an unwanted substance that is discarded, the measure of it and the impact it makes on the environment also becomes important considerations in defining waste. It is against this background that Baabereyir (2009) has defined wastes to be any substance (liquid, solid, gaseous or even radioactive) discarded into the environment because it is unwanted, which causes significant nuisance or adverse impact in the environment.

On the other hand, Municipal Solid Waste (MSW) has been defined to include those durable and non-durable goods, containers and packaging materials, food wastes and yard trimmings, and miscellaneous organic wastes arising from residential, commercial, institutional, and industrial sources which are collected and managed by local authorities.

2.1.1 Factors Contributing to Rise in Quality and Quantity of Solid Waste

Population increase is proven to have significant influence on the amount of waste generated especially in the urban centres. The 2010 population census of Ghana indicated that presently 50% of the total population resides in the urban centers, which is likely to rise in the preceding years. This is as a result of rural-urban migration among other factors (Ghana Statistical Services, 2012). For example, the statistical service observed that approximately 50,000 economic migrants visit Accra daily and about 5,000 stay behind after close of business for weeks or months (Ghana Statistical Services, 2000). While the national population growth rate as at the year 2010 stood at 2.4%, that of urban growth stood at 3.7%.

This rise in population has not been accompanied by increase in housing and basic sanitation facilities. The consequences of these are increases in population density with low income settlements, large waste generation and increased pressure on waste management facilities (Ghana Statistical Service, 2010). The UN-habitat (2003), notes that today's true builders and planners of cities in developing countries are the urban poor who build houses and establish legal or illegal settlements where they can make life comfortable no matter what. "Slums have been the only large-scale solution to providing housing for low-income people. It is the only type of housing that is affordable and accessible to the poor in these cities" (UN-habitat, 2003). The nature of these settlements makes no room for access roads for effective waste collection. Therefore, wastes often generated here are dumped in open gutters, along road side and in open spaces.

Accompanying the increasing population are rising levels of affluence, shorter product cycles, large number of packaging materials that are often not biodegradable, rise in consumption levels and the demand for new and portable products. Ehrlich and Holdren (1971) established a relationship between the human environmental impact (I) (solid waste generation in this case under review), sub-national population size, growth, and concentration (P), people's affluence (A), and the methods (T) (Technological advancement in this case) it employs to obtain its livelihood and dispose of its consumed products. This relationship they expressed through a mathematical model, $I = PAT$.

Translating this into real life situation, this means a large, rapidly growing, and high density population (*holding Affluence, A and Technology, T constant*) would result in greater waste generation and its environmental impact and this is what has been the situation in urban centres including Obuasi.

2.2 MUNICIPAL SOLID WASTE MANAGEMENT

Gilpin (1996), defines waste management as "purposeful, systematic control of the generation, storage, collection, transportation, separation, processing, recycling, recovery and disposal of solid waste in a sanitary, aesthetically acceptable and economical manner." Schubeller *et al.* (1996), define municipal solid waste management as "the collection, transfer, treatment, recycling, resource recovery and disposal of solid waste in urban areas". Similarly, Gbekor (2003), has referred to waste management as involving "the collection, transport, treatment and disposal of waste including after care of disposal sites". It can be deduced from these definitions that waste management aims at protecting the environment and public health.

Further, Gilpin (1996), regards the business of waste management as a professional practice which goes beyond the physical aspects of handling waste. It also "involves preparing policies, determining the environmental standards, fixing emission rates, enforcing regulations, monitoring air, water and soil quality and offering advice to government, industry and land developers, planners and the public".

Waste management, therefore, involves a wide range of stakeholders who perform various functions to help maintain a clean, safe and pleasant physical environment in human settlements. Effective waste management is, however, a growing challenge to all municipal governments, especially in developing countries.

2.2.1 Causes of Improper Waste Management

Technical Constraints

Inadequate human resources at both the national and local levels with technical expertise necessary for solid waste management has been a major constraint to improper waste management. Many officers in charge of solid waste management, particularly at the local level, have little or no technical background or training in engineering or waste management.

Financial Constraints

Ogawa (2005) noted that, solid waste management is given a very low priority in developing countries, except perhaps in capital and large cities. As a result, very limited funds are provided to the solid waste management sector by the governments, and the levels of services required for protection of public health and the environment are not attained. The problem is critical at the local government level where the local taxation system is inadequately developed and, therefore, the financial basis for public services, including solid waste management, is weak. This weak financial basis of local governments can be supplemented by the collection of user service charges. However, users' ability to pay for the services is very limited in poorer developing countries, and their willingness to pay for the services which are irregular and ineffective is low.

Institutional Constraints

The lack of coordination among the relevant agencies often results in different agencies becoming the national counterpart to different external support agencies for different solid waste management collaborative projects without being aware of what other national agencies are doing. This leads to duplication of efforts, wasting of resources, and unsustainability of overall solid waste management programmes. The lack of effective implementation of legislation for solid waste management, which is a norm in most developing countries, is partially responsible for the roles/functions of the relevant national agencies not being clearly defined and the lack of coordination among them (Ogawa, 2005).

2.2.2 Effects of Improper Waste Management

Environmental Effects

A major adverse effect of solid waste is its attraction of rodents and vector insects for which it provides food and shelter. Impact on environmental quality takes the form of foul odours from leachate and unsightliness caused by windblown litter. These impacts are not confined merely to the disposal sites. On the contrary, they pervade the area surrounding the site and wherever the wastes are generated, spread, or accumulated (Fei-Baffoe, 2010).

Furthermore, improper waste disposal can contaminate soil, surface and groundwater especially where most of the disposal sites have been built without any sound engineering design such as liners and leachate interception and collection system. Pollution of the air is also not left out as odour from rotten organic matter and wind transported particles fills the air, sometimes impairing vision. The methane produced from the decomposition of organic waste does also contribute to global warming and climate change since it is a greenhouse gas.

Impacts on ecosystem are other aspects that cannot be overlooked. For example, leachate migrates vertically and laterally into the environment by direct discharge into adjacent streams. Toxic compounds like ammonia in leachate contribute to eutrophication which affects aquatic life. Fishes which are the last in the food chain in aquatic eco-system are most affected by toxic compounds and cause other animals and human beings, which feed on fish, to be subjected to the same toxic effect.

Health Effects

Common diseases like malaria, intestinal worms, and upper respiratory infections are among the most common health problems reported at the out-patient facilities in Accra, and majority of these cases are residents in and around the slums (Songsore and McGranahan, 1993) where sanitation is poor.

Socio-economic Effects

The locations of the disposal sites raise the problem of decreasing value of land and landed property in these communities where they are located. According to the Ghana Ministry of Local Government (2003) report, assets such as land and houses around the dump sites have lost value as a result of the presence of the leachate from waste, odour, rodents and flies.

Leachate contaminated soil and water have to be treated very well before use. The cost of treatment is most often than not expensive and sometimes, the treatment is inadequate to make it useful.

2.3 LANDFILL SITES

Landfilling as "fate of waste" has been playing an important role in waste management, and is still the most common technique for waste management in most countries. The placement of solid waste in landfills is probably the oldest and definitely the most prevalent form of ultimate garbage disposal. From the outset, it must be recognized that many "landfills" are nothing more than open, sometimes controlled, dumps. The difference between landfills and dumps is the level of engineering, planning, and administration involved. Open dumps are characterized by the lack of engineering measures, no leachate management, no consideration of landfill gas management, and few, if any, operational measures such as registration of users, control of the number of "tipping fronts" or compaction of waste. 'Sanitary' landfills, on the other hand, are sites where waste is allowed to decompose into biologically and chemically inert materials in a setting isolated from the environment (Haiyun, 2008; Zerbock, 2003). Thurgood (1997), stated that as a minimum, four basic conditions should be met by any site design and operation before it can be regarded as a sanitary landfill:

1. Full or partial hydrogeological isolation. Where a site cannot be located on land which naturally contains leachate security, additional lining materials should be brought to the site to reduce leachate from contaminating surface water, groundwater and surrounding soil.
2. Formal engineering preparation. Designs should be developed from local geological and hydrogeological investigations. A waste tipping plan and a final restoration plan should also be developed.

3. Permanent control. Trained staff should be based at the landfill to supervise site preparation and construction, the depositing of waste and the regular operation and maintenance.
4. Planned waste emplacement and covering. Waste should be spread in layers and compacted. A small working area which is covered daily helps make the waste less accessible to pests and vermin.

2.3.1 Landfill Site Selection

Proper landfill site selection is the fundamental step in sound waste disposal and the protection of the environment, public health and environmental quality as noted by Ball (2005). For example, a well-selected landfill site will generally facilitate an easy design and provide ample cover material, which would facilitate an environmentally and publicly acceptable operation at a reasonable cost (Ball, 2005). Numerous weighted criteria must be taken into consideration in the landfill siting. These criteria include natural physical characteristics as well as socioeconomic, ecological, environmental, socio-political, and land use factors (Ball, 2005; Luthbom and Lagerkvist, 2003; Rahman *et al*., 2008).

2.3.2. Criteria for Selecting Site for Landfilling

The selection of a landfill site is a big question that faces local authorities because it represents a point of confluence of science, social science, and planning. Urban planners and city managers throughout the world are now confronting this issue within a much broader social development context. "Not in my backyard" may be the mantra facing decision makers as the volume of solid waste generated in rural and urban areas increases (UNEP, 1996).

The criteria for selecting a dumping site are almost similar all over the world with some constraints related to locality. However, some of the criteria factors may conflict with each other; therefore, some compromises or tradeoffs between criteria will be necessary if the process is to materialise. Several countries (like Australia, Malaysia, Niger, Philippines, Uganda, and the United States among others) have put in place guidelines for selecting suitable sites for sanitary landfills for waste management. These guidelines and policies act as the primary mechanism used to protect the environment and avoid nuisance to the host community. Among the factors that govern the selection of the landfill site are:

- Adjacent Land Uses or Land cover: Location of a landfill facility should not endanger any environmentally sensitive areas or have adverse impact on existing or future land uses. Risks to public health and impacts on the areas surrounding the landfill can be limited by providing buffer zones between the landfill and sensitive areas. Several researchers have recommended appropriate buffer distances between a landfill facility and other land uses. For example; at least 100 metres from public roads, and at least 200 metres from industrial developments.
- Airports: Because the solid waste attracts birds, the distance from an airport should be a minimum of 30 km, unless there is a clear demonstration of bird control measures.
- Climate: Local climatic conditions should be considered when siting a waste disposal facility. For example; areas with heavy rainfall need extra care to avoid side effects of drainage and erosion; sites with prevailing winds require extra efforts to control litter and dust.

- Distance from environmentally sensitive or protected areas: A landfill must not be located in close proximity to sensitive areas such as fish sanctuaries, mangrove areas and areas gazetted for special protection would be excluded. Therefore, a 3,000 metres buffer is necessary to surround an environmentally sensitive area. However, The Ghana EPA (2007) recommends that a buffer within the landfill of at least 500 metres width should be provided and maintained around the site. A lesser buffer within the landfill may be provided where it is considered compatible with the surrounding area and land uses so that there will be an effective buffer of 500 metres between the landfill and any potentially sensitive or incompatible land use.
- Distance from urban areas: the landfill should be situated at a significant distance away from urban residential areas due to public concerns, such as aesthetics, odour (Tagaris *et al*., 2003), noise, decrease in property value (Zeiss and Lefsrud, 1995), and health concerns, which may avoid contamination of freshwater aquifers through leaching (Nagar and Mizra, 2002). Urban buffers may range from 150 metres (Lin and Kao, 1999) to 5 km (Zeiss and Lefsrud, 1995).
- Groundwater: An extremely deep water table region is suitable so that underground water is not contaminated by the leachate of the waste. North Dakota Department of Health (2009), explained that the bottom of disposal trench should be at least four feet above the water table (about 1.2 metres). In addition, Chang *et al*. (2008), recommend 50 metres buffer zone around water wells to prevent contamination from landfill due to leaching of pollutants.

- Infrastructure: Although landfills should have suitable transport access, with power and water available, landfills should not be located within 100 metres of any major highways, city streets or other transportation routes. Twumasi *et al*. (2006), recommended a distance of 300 metres. However, it would be more cost efficient for landfills not to be located so far away in order to avoid high transportation costs, so Baban and Flannagan (1998) used a 50-metre buffer for roads
- Local Flora and Fauna: Sites that contain protected or endangered fauna and/or flora, or sensitive ecosystems are unsuitable for landfill facilities. Possible impacts on ecosystems, flora and fauna include the contamination of sensitive wetland areas by leachate. In addition, landfills often attract large numbers of birds, thus increasing the risk to public health by spreading scavenged items away from the landfill facility.
- Local Topography: Landforms in the vicinity of the disposal site should be considered since they may influence; the type of disposal method that can be utilized, the suitability of the site for construction of service facilities, surface water drainage management, groundwater conditions, soil erosion risk, access to the site, ability to screen the site from view, and the impact of winds on the site. Preference is given to a landform that is located in flat or undulating land. Other than on the site of a disused quarry, major landfills must not be sited in hilly areas, with ground slopes nominally greater than 10 per cent. However, Ghana EPA (2007), recommends a slope less than 5 per cent, and North Dakota Department of Health (2009), recommends 15 per cent slope or less.

- Population: Gaim (2004) recommends that areas with a population density less than 200 are regarded as suitable or landfills.
- Site Capacity: A site should provide at least 10 years of use in order to; minimize costs for site establishment and closure, smooth running of operations, and provision of adequate time for acquiring the next site.
- Soils: Soil structure should be suitable for construction of landfill cells and drainage works. The soil should also be of sufficiently low permeability to significantly slow the passage of leachate from the site. Sites in clay-rich environments are preferable, due to the low permeability, good workability and superior leachate retaining characteristics of these soils. Sufficient soil should be available to provide adequate covering for wastes.
- Surface Water: The distance between the areas demarcated for waste disposal and the nearest surface water (permanent or intermittent) or the 100 year flood plain should be a minimum of 100 m. However, North Dakota Department of Health (2009) recommended a minimum distance of 200 feet (about 60 m) to the nearest surface water. However, Bagchi (1994), stated that a landfill should not be located within 100 feet (30.48 m) of any non-meandering stream or river and at least 300 feet (91.44 m) from any meandering stream or river.
- Unstable Areas: Major Landfills must not be located within 100 metres of an unstable area. Unstable areas can include poor foundation conditions, areas susceptible to mass movement, soft sandy and collapsible soils, and karst terrains. North Dakota Department of Health (2009) supplemented that environmentally sensitive or unstable areas do not provide safe, long-term waste disposal. Such areas include; wetlands, gravel pits, flood plains, and

shallow water table areas. All these are environmentally sensitive to surface water and groundwater pollution

2.4 ROLE OF REMOTE SENSING AND GIS IN MUNICIPAL SOLID WASTE MANAGEMENT

The role of Geographic Information Systems (GIS) in solid waste management is numerous as many aspects of its planning and operations are highly dependent on spatial data. In general, GIS plays a key role in maintaining account data to facilitate collection operations; customer service; analyzing optimal locations for transfer stations; planning routes for vehicles transporting waste from residential, commercial and industrial customers to transfer stations and from transfer stations to landfills; locating new landfills and monitoring the landfill. For example, Alam Flora Sdn. Bhd. (AFSB) a company responsible for the collection, transportation, and disposal of 70% of Malaysia's solid waste has setup a GIS like ArcInfo and ArcView as key components for managing its information (Keir, 1997). GIS is a tool that not only reduces time and cost of the site selection, but also provides a digital data bank for future monitoring program of the site.

Remote sensing provides satellite images and aerial photographs of locations that can be processed to generate land use/land cover data to present conditions of the study area.

2.4.1 Role of GIS in Landfill Site Selection

Many approaches have been employed in looking for the perfect site for a landfill site. Most of these approaches heavily rely on mathematics and optimization techniques. Since, site selection is a spatial problem, mathematics and optimisation techniques are often inadequate to offer suitable solution because of their failure to incorporate all relevant aspects of the problem in the overall framework. An alternative framework that is capable of resolving site selection problem is GIS.

GIS is a suitable tool for site selection since it has the capability to manage large amount of spatial data that comes from various sources. Kao *et al*. (1996), point out that large amount of spatial data can be processed using GIS and thus, it potentially saves time that would normally be spent in selecting an appropriate site. Daneshvar *et al*. (2005), claim that GIS is an ultimate method for preliminary site selection as it efficiently stores, retrieves, analyses and displays information according to user-defined specification although it can be limited by existing sources of data.

GIS has been successfully applied in the past for site selection for which certain requirements have to be fulfilled (Burrough, 1983; Despotakis and Economopoulos, 2007). Examples include locating wind farms in a region (Baban and Parry, 2001; Bennui *et al*., 2007). The fundamental analytical functions of a GIS based spatial decision support system include query analysis, proximity or buffer analysis, overlay analysis, neighbourhood analysis and network analysis. Various combinations of these functions are commonly used during the geographical data analysis process.

The issue of landfill site selection was complicated and time consuming. During the last few decades and particularly when environmental planning emerged this issue became systematic and technical. The evolution of GIS made this field much easier and manageable. GIS gave the ability and functionality to find best location for certain purposes with many limitations.

GIS combines spatial data (maps, aerial photographs, satellite images) with quantitative, qualitative and descriptive information databases. The overall GIS-supported landfill site selection process contains two primary screening steps: (i) exclusion of areas unsuitable for landfill, i.e. prescreening step or GIS step, and (ii) weighting (ranking) of remaining areas, i.e. decision analyses step.

There are several available GIS software. However, one of the most popular that can be customized is ArcGIS Desktop. This system serves GIS professionals with a spectrum of geographic data management, spatial editing, and cartographic visualization functionality. The ArcGIS Desktop system contains a configuration of applications, such as ArcCatalog, ArcMap, ArcToolbox™, and ArcScene, and can support a variety of extension products such as ArcGIS Spatial Analyst, ArcGIS Geostatistical Analyst, ArcGIS 3D Analyst™ and others. The ArcGIS applications are engineered for ease of use and powerful geographic display, query, and analysis. By their design, they are generic and serve a broad audience of users (Daneshvar *et al.*, 2003).

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY AREA

The Obuasi municipality (shown in Figure 1), is a distance of approximately 54 km south west of Kumasi, Ghana and is situated within latitudes 5º35'N and 5 º65N, and longitudes 6º35'W and 6º90'W. The total area is about 162 km^2. It is bounded to the east by the Adansi South District, west by Amansie Central District and to the north by the Adansi North District. It has Obuasi as its Administrative Capital where the famous and rich Obuasi Gold Mine, now AngloGold Ashanti is located (OMA, 2012).

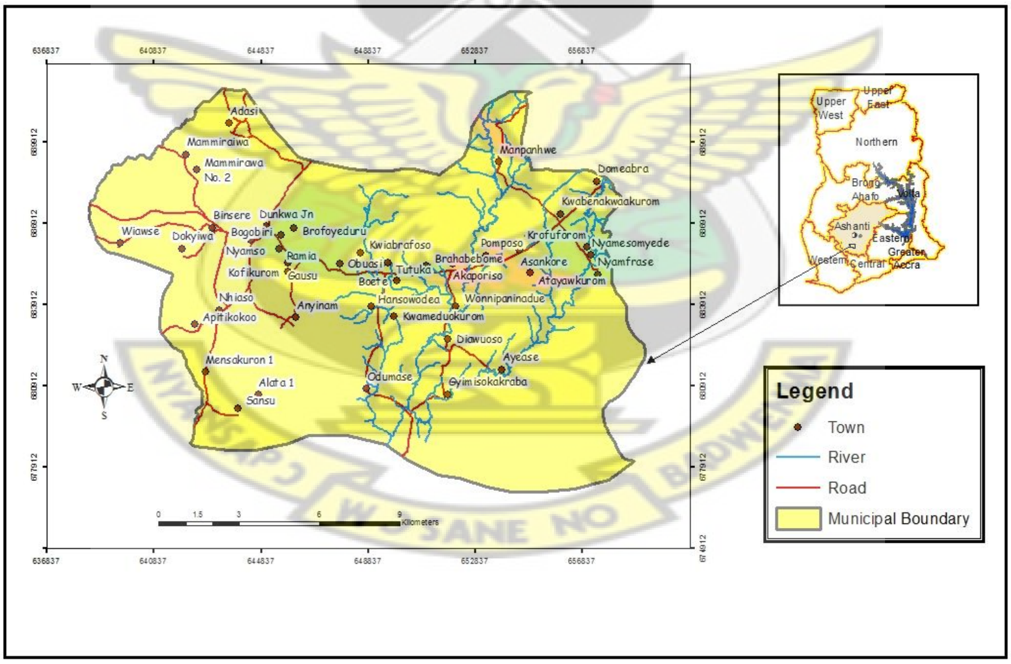

Figure 1 Map of the Obuasi municipality, 2013

3.1.1 Topography and Drainage

Topography refers to the altitude of the land surface. The Municipality has a rather undulating topography, with the altitude of the land surface ranging between 550 metres to about 1770 metres above mean sea level. The northern and southern areas as well as the south-eastern corner are seen to have the highest elevations above mean sea level (Griffis *et al*., 2002).

The Municipality is drained by streams and rivers which include; Pompo, Nyame, Akapori, and Kunka. Other perennial streams and rivers are Subin, Menson, Kwabrafo, Hweaseamo, Kyeabo, Ankafo, Gyimi and Nyam all of which depict dendritic pattern of flow. All these rivers are almost polluted by mining and other human activities including farming. Again the municipality is endowed with springs which can be tapped as potable drinking water (OMA, 2012).

3.1.2 Geology

The area is geologically situated within the principal greenstone belt of Proterozoic (Birimian) age which consists of volcano-sedimentary and igneous formations. Rocks in the Municipality are mostly of Tarkwain (Pre-cambrian) and Upper Birimian formation which are noted for their rich mineral bearing potentials (Griffis *et al.*, 2002).

3.1.3 Vegetation

The vegetation of the area is predominantly a degraded and semi-deciduous forest, forbs re-growth and swamp. The forest consists of limited species of hard wood which are harvested as lumber. Large tracts of teak plantation covering areas of 12.1 km^2 have been conserved as green belts by AngloGold Ashanti within its concession.

This, together with the hilly nature of the environment gives the municipality nice scenery view (Obuasi Municipal Assembly, 2006).

3.1.4 Climate

The Municipality experiences semi-equatorial climatic conditions with a double maximum rainfall regime with the major reaching its maximum in May and June and the minor in October. The month of July, August and early September are generally much drier than the remaining months. The mean annual rainfall ranges between 1250 and 1750 mm (Griffis *et al*., 2002).

Temperatures are uniformly high all year with the hottest month being March when 30^{o}C is usually recorded. The mean annual temperature is 25.5^{o}C and relative humidity is 75 - 80% in the wet season.

3.1.5 Population

Information on population size is always a relevant factor in estimating majority of municipal services. Municipal Solid waste total generations are mainly dependent on per capita generation. For proper solid waste management plan and sustainability, it is mandatory to know and predict in some manner the future population based on available statistics. The area has a current population of over 168,641 (GSS, 2010) scattered over many small to large villages throughout the municipality. Besides mining, the majority of the people are farmers.

3.2 STATE OF SOLID WASTE MANAGEMENT IN THE AREA

It is estimated that the daily solid waste produced in the municipality is about 1,300 tons/day. The composition of the solid waste is mainly of household waste, building debris, agricultural waste, industrial waste and car workshops waste. It is reported that greater percentage of the household waste is made up of organic material with sand, plastic, glass, metals, etc. forming the other percentage (OMA, 2012).

Solid waste in the area is mainly managed by the Obuasi Municipal Assembly (OMA) which is the administrative body of the municipality. In its efforts to ensure an effective waste management in the area, the assembly adopted the public-private partnership policy, and ceded part of its waste management functions in the central business area to Zoomlion Ghana Limited and YNO Enterprise (OMA, 2012).

Currently, the YNO Enterprise manages the house-to-house (door-to-door) refuse collection. The system is operated in twenty one (21) communities with about three thousand (3,000) 120-litre capacity litter bins. Zoomlion Ghana Limited, on the other hand is responsible for collecting the central business area waste. There are seven (7) designated central solid waste collection points with twenty-two (22) twelve-cubic metre (12 m^3) skips and two (2) skip loaders in use for refuse evacuation to the final disposal site at Diawuoso (OMA, 2012).

3.3 DATA AND MATERIALS

Having reviewed relevant literature, certain key issues were identified in relation to the objectives of the study. These were: criteria for assessment and selection of landfill site and also, the role of Geographic Information Systems (GIS) in selecting such sites. Based on this, an appropriate methodology was developed to collect data on the key issues enumerated above. In this light, secondary and primary data were gathered using varied techniques. The next section discusses the sources into detail.

3.3.1 Secondary Data

Secondary data were obtained from books, articles, newspapers and internet sources. The data obtained include: satellite imagery, shapefiles of surface water, road network, soil, geology, settlement and forest, all from Centre for Remote Sensing and GIS (CERSGIS).

3.3.2 Primary data

Primary data were collected through preliminary field investigation and face-to-face interviews with experts on the field. Data obtained include Global Positioning System (GPS) coordinates of some selected areas within the study area.

3.3.3 Equipment and Software

The equipment and software used in the study included:

- Garmin Handheld GPS
- Geoprocessing and thematic map production with ArcGIS 10.0
- Land cover map production with ERDAS Imagine 10.0
- Suitability map production with ERDAS Imagine 10.0
- Results generation and Analyses with ArcGIS 10.0

3.4 METHODS

3.4.1 Land Cover Classification Analysis

Land cover classification involved categorizing the region into various land use and land cover types. The land cover map displays the land utilized by human and the natural cover in the region. This provided a thematic map of the region which was used for overlay analysis. It was developed by image interpretation and classification of a 2012 Landsat ETM+ imagery of 30 m spatial resolution obtained from United States Geological Survey (USGS) website. The image had a total cloud cover of 0% with radiometric and geometric corrections effected.

In ERDAS Imagine the band combination of the image was set to 4, 5 and 3 representing red, blue and green portions of the electromagnetic spectrum respectively. This was done to enable easy identification of reflectance of various features. With the aid of a 2012, 5 m spatial resolution aerial photograph of the study area and coordinates of points picked with a handheld GPS from the field, training samples were generated in ERDAS Imagine using the Create Polygon AOI icon from Area of Interest tool (AOI) palette. This provided the needed signatures for supervised classification through digitizing. The signatures were then saved in Signature Editor using Create New Signature(s) from AOI icon option. This option added the spectral information about the signatures in the Editor.

The individual signatures were evaluated using the brightness count histogram for each band of each set. The histogram gave an indication of the nature of the training samples. That is whether;

- bi-modal: spectrally confused training sample

- uni-modal or normal distribution: ideal training sample which indicates spectrally separated signatures
- very narrow range: too small a sample that is sample not representative enough
- broad range: signatures possibly heterogeneous and confused with other features

A separability test was carried out using the transformed divergence (TD) which computed the statistical distance between signatures. The distance indicates how much each individual signature is distinct from the other. It also helped in determining the best subset of layers to be used in the classification.

A supervised classification was performed using the Supervised Classification Tool in ERDAS Imagine. Maximum Likelihood Algorithm (MLA) was used for the parametric rule, which classified the image according to the covariance and variance of the spectral response patterns of a pixel. The resultant classes were recoded to obtain seven classes indicating the cover type of each area including built up, forest reserve, rangeland, barren land etc. using Anderson's Classification System.

The Anderson's Classification System defines areas of varying land cover types as shown in Table 1**.**

Table 1 Anderson's Land Cover Classification System

Land Cover Type	Description
Built Up	It is comprised of areas of intensive use with much of the land covered by structures. Included in this category are cities, towns, villages, strip developments along highways, transportation, power, and communications facilities, and areas such as those occupied by mills, shopping centres,

	industrial and commercial complexes, and institutions that may, in some instances, be isolated from urban areas.
Forest Reserve	Forest lands have a tree-crown areal density (crown closure percentage) of 10 percent or more, are stocked with trees capable of producing timber or other wood products, and exert an influence on the climate or water regime.
Barren Land	Barren Land is land of limited ability to support life and in which less than one-third of the area has vegetation or other cover. In general, it is an area of thin soil, sand, or rocks. Vegetation, if present, is more widely spaced and scrubby than that in the Shrub and Brush category of Rangeland.
Water	It includes rivers, streams and other linear water bodies as well as dams
Farmland/Burnt Land	Cropland harvested, including bush fruits; land on which crop failure occurs; cropland in soil- improvement grasses and legumes; cropland used only for pasture
Rangeland	Land where the potential natural vegetation is predominantly grasses, grass-like plants, forbs, or shrubs and where natural herbivory was an important influence in its pre-civilization state.
Open Forest	Lands from which trees have been removed to less than 10 percent crown closure but which have not been developed for other uses also are included. For example, lands on which there are rotation cycles of clear cutting and block planting are part of Forest Land

3.4.1.1 Accuracy assessment

A vital step in the classification process is the assessment of the accuracy of the final image produced. This assessment allows users to evaluate the utility of a thematic map for their intended applications. It involves identifying a set of sample locations that were visited in the field. The land cover found in the field is then compared to that which was mapped in the image for the same location. Statistical assessments of accuracy are then derived for the entire study area, as well as for individual classes. The most widely used method for accuracy assessment may be derived from a confusion or error matrix. The confusion matrix is a simple cross tabulation of the mapped class label against the observed in the ground or reference data for a sample set (Stehman, 1999). The information in the matrix about which covers are being mistakenly included in a particular class (errors of commission) and those that are being mistakenly excluded (errors of omission) from that class can be used to refine the classification approach.

From the above information, the accuracy of the classified image was therefore assessed to enhance the degree of confidence in the results as well as to meet the project's objectives. A 2012 rapideye image of 5 m spatial resolution of the study area served as a reference data to assess the accuracy of the results. Hundred randomly generated points were plotted on the reference data using the Accuracy Assessment Tool in ERDAS Imagine. The overall accuracy as well as the Kappa statistics was computed and analysed.

3.4.1.2 Suitability Map

The suitability map was generated from land cover map using Knowledge Engineer in ERDAS Imagine. Hypotheses with rules and conditions were defined which grouped areas such as built up, water, and sensitive sites (forest reserve) as unsuitable. Areas such as farmland/burnt land, rangeland, barren land and open forests were also grouped as suitable land. This was done to exclude areas which were susceptible to environmental contamination by the existence of landfill and its operation and make readily available those which are less prone to environmental contamination. It is from this that further analysis was done to generate optimal sites.

3.4.2 Spatial Analyses

3.4.2.1 Slope Map

The topography of an area is an important factor on site selection, structural integrity, and the flow of fluids surrounding a landfill site. Deciding the type of landfill design (area, trench, and depression-type landfills) is directly related to topography of a site. Flat and gently rolling hills that are not subjected to flooding are the best sites for landfills (Choudhury and Das, 2012). Therefore, landform with ground slopes less or equal to 20% is considered suitable for this work. A slope map was therefore generated from a Digital Elevation Model (DEM) in ArcGIS using the Spatial Analyst tool.

3.4.2.2 Infiltration Map

An infiltration map was also developed by taking into account the key soil types in the study area and their properties. The infiltration rate plays an important role in determining potential risk of contamination of the groundwater and hence is a key criterion for the development of a landfill at a particular site. Depending on the infiltration rate, the area has been divided into high/medium/low zones. The western part of the study area has been shown to possess a high infiltration rate. The south-eastern part of the region has thick clayey soils with predominantly low infiltration rate.

3.4.2.3 Buffer Maps

Maps with buffer zones for rivers, roads and settlements exhibit the permissible distance beyond which the landfill can be sited for various criteria using the Euclidean distance option (Spatial Analyst tool) in ArcGIS. This shows that the areas within the buffer are unsuitable for landfill development for solid waste disposal.

They were generated on the basis of pre-existing published landfill criteria. For example, to generate the buffer for rivers, a buffer distance of 500 m was applied around each river. Similarly, buffer zones for roads and settlements were created at a distance of 500 m and 300 m, respectively.

3.4.3 Weighted and Overlay Analyses

3.4.3.1 Reclassification of Datasets

Since it is not possible to combine the resultant datasets (river, slope, road, settlement and soil) in their present form—for example, combining a cell value in which slope equals 15 per cent with a cell value for land use that equals 3 (water) — and get a meaningful answer that can be compared to other locations, they were first set to a common measurement scale, 1 to 10, in this study. This common measurement scale determined how suitable a particular location—each cell—is for siting a landfill. Higher values indicate more suitable locations for the landfill site.

In ArcGIS, the reclassify option in the Spatial Analyst tool was used to redefine all the classes giving areas of interest the highest value of influence.

3.4.3.2 Weighting and Combining Datasets

With all the datasets set to a common scale (1 to 10), the next action was to weight and combine them giving high weights to those of greater influence. This process of weighting is by assigning a percentage value (weight) for each criterion on account of reflecting their relative importance to the decision.

Since values representing areas of 'not suitable'in the suitability map and higher slope percentages were not needed in the analysis, such areas were restricted. This eliminated those areas from the process before the weights were applied.

Determining the weights is, however, quite controversial and is basically accomplished through reviewing the criteria and the relative importance they contribute.

A percentage scale was used to measure the relative importance among criteria. The higher the percentage, the more influence a particular input will have in the suitability model.

The following percentages of influence were assigned to the inputs:

- Reclassified distance to river: 15%
- Reclassified distance to roads: 10%
- Reclassified distance to settlement: 15%
- Reclassified land cover: 10%
- Reclassified slope: 20%
- Reclassified soil: 30%

3.4.4 Optimal Sites Selection

From the resultant layer obtained from the weighted overlay, each pixel has a value that indicates how suitable that location is for a landfill site. Pixels with the values of 7, 8, 9 and 10 were considered most suitable or optimal sites and pixels with values less or equal to 6, not suitable.

To extract these optimal sites to enable further analyses, a conditional expression in the Con tool in ArcGIS was used. Sites considered optimal have a suitability value of 7, 8, 9 and 10. In the conditional expression, all areas with a value of 7, 8, 9 and 10 retain their original values. Areas with a value of less than or equal to 6 were considered as areas with no data.

Another criterion for an optimal location is the size of the suitable area. A suitable location would include several pixels with value of 7, 8, 9 and 10 being connected. There are many single cells (pixels) representing optimal locations; these 30-metre cells which are too small for the landfill site were eliminated using the Majority Filter tool in Spatial Analyst Tools toolbox Generalization toolset.

3.4.4.1 Selecting Best Sites

Selecting best site for landfilling requires that the land be available, and the capacity be of at least 0.5 km^2 in order to make room for increasing waste per capita as a result of population increase.

For this reason, the optimal sites obtained were screened with respect to their capacity to hold waste for at least 10 years. Sites with total area of at least 0.5 km^2 were selected using selection by attribute option in ArcGIS.

This was obtained by converting the optimal sites result, which was in a raster format to a separate vector theme mainly because vector data represents geographic features with greater precision compared to grid data (ESRI, 2000).

In the attributes table of that vector theme (shapefile), total area for each polygon was computed using the Calculate Geometry option. Areas of interest were then selected using the Query Builder option.

3.4.5 Qualitative Evaluation/Validation of Sites

This was done by Ground Truthing, which involved visiting the potentially identified sites. The geographic coordinates of some of the sites were extracted from the resultant map and with the help of a handheld GPS, the sites were navigated to.

Visual verification of the nature of the land cover was also done to ascertain their conformity with selected criteria.

However, the accuracy of the obtained results is subject to; the time of satellite imagery (the time when the satellite images were taken), the accuracy of the data (that was obtained from CERSGIS), and the weights assigned to parameters.

CHAPTER FOUR

RESULTS

4.1 LAND COVER CLASSIFICATION ANALYSIS

The result of the supervised classification performed is as shown in Figure 2, and total areas occupied by the various land cover classes with their corresponding areas presented in Table 2. It can be deduced from the land cover map that majority of the built up class is located in the western part of the area. The total area considered for this study was 204.43 km^2. Farmland / burnt land formed the largest land cover type (36.3%), followed by built up areas (32%), with range land forming the least land cover type (0.78%).

The assessment of the accuracy of the supervised classification scheme revealed that the overall accuracy was 85% whereas the overall Kappa statistics was 0.8125.

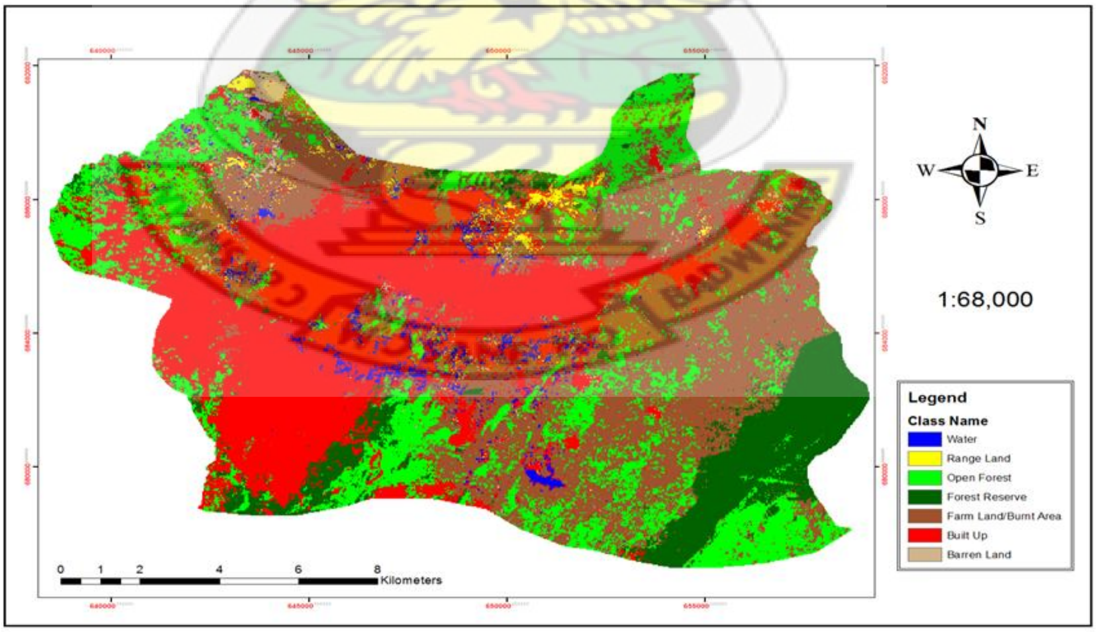

Figure 2 Land Cover Map of Obuasi Municipality, 2013

Table 2 Land Cover types in Obuasi Municipality with corresponding areas, 2013

Land Cover Type	Total Area (sq. kilometres)	Total Area (%)
Built Up	65.48	32.03
Closed Forest	19.91	9.74
Farmland/Burnt Land	74.13	36.26
Open Forest	37.66	18.42
Range Land	15.88	0.78
Water	34.38	1.68
Barren Land	22.32	1.09
Total Area	**204.43**	**100**

4.1.1 Suitability Map

Figure 3 shows the suitability map for the study area. From the suitability map, it can be deduced that about 57% of the total area met the suitability criteria for landfills, and included farmland/burnt land, open forest, range land and barren land (Table 3). About 43% of the area is considered unsuitable and most of these areas are found at the western and south eastern part of the region.

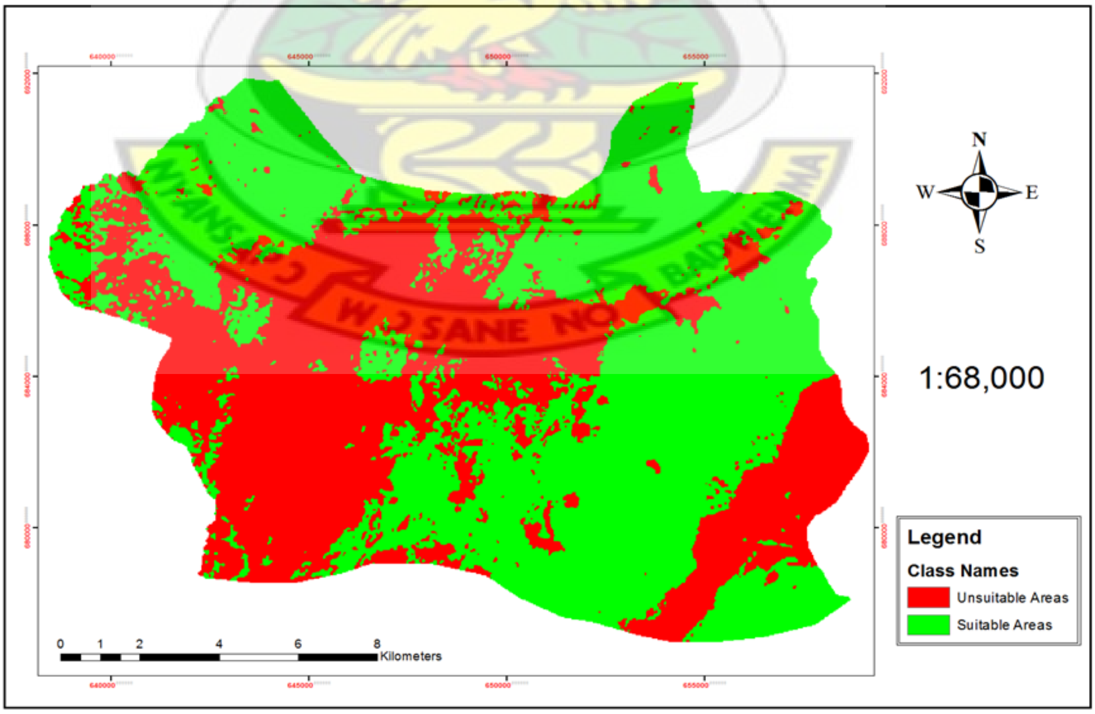

Figure 3 Suitability Map of Obuasi Municipality, 2013

Table 3 Land Cover types in Obuasi Municipality and their suitability, 2013

Land Cover Type	Total Area (sq. kilometres)	Area (%)	Suitability
Farmland/Burnt Land	74.13	36.26	Suitable
Open Forest	37.66	18.42	Suitable
Range Land	15.88	0.78	Suitable
Barren Land	22.32	1.09	Suitable
Built Up	65.48	32.03	Unsuitable
Closed Forest	19.91	9.74	Unsuitable
Water	34.38	1.68	Unsuitable
Total Area suitable	**115.61**	**56.55**	
Total Area unsuitable	**88.82**	**43.45**	

4.2 SAPTIAL ANALYSES

4.2.1 Slope Map

Classes determined for slope according to decreasing suitability is shown in Figure 4. Areas having percentage values from 0 to 5.5 (deep green) are considered highly suitable. Areas with medium suitability are marked with slope values from 13% to 24% (light green areas). Low suitability areas have percentage slope values 13% to 24% (yellow). The orange and red areas are marked unsuitable since their percentage slope values are beyond 24%. The red areas are of high elevations ranging from 1000-1700 m above mean sea level.

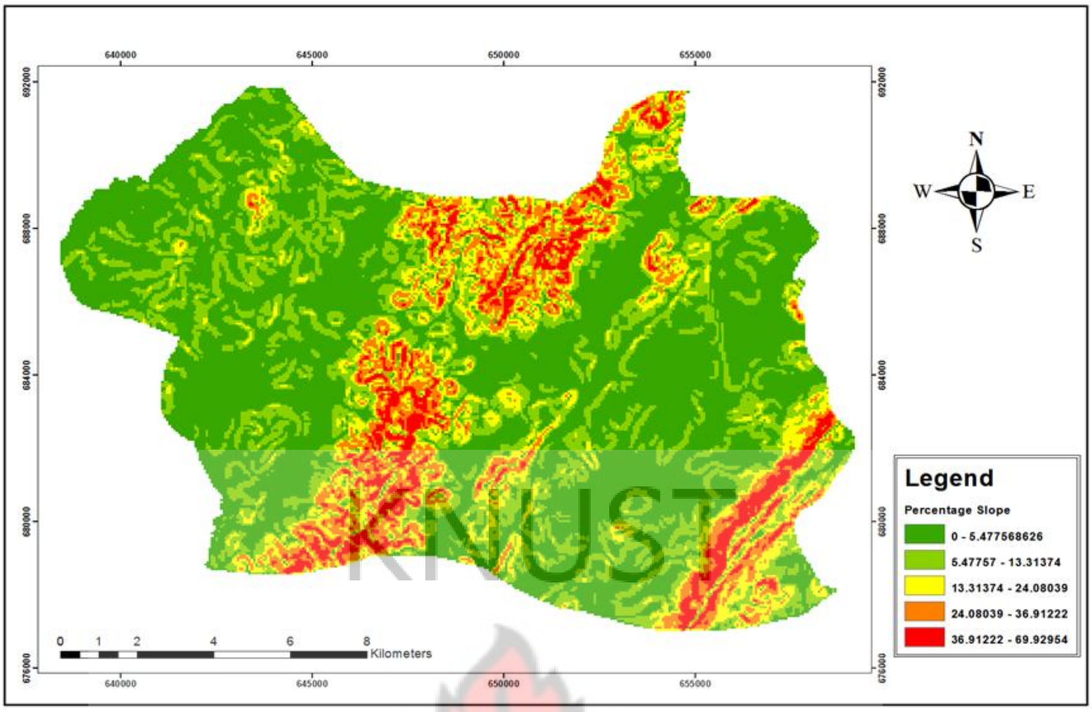

Figure 4 Slope Map of Obuasi Municipality, 2013

4.2.2 Infiltration Map

Areas showing low infiltration rates are mainly deep to very deep, yellow brown, moderately to imperfectly drained soils. Medium infiltration areas also are moderately shallow to moderately deep, red and brown concretionary and/or gravelly soils. It can be observed that the south-eastern part of the area as well as south-western parts are all suitable for landfill siting since soils in the area have the ability to retain water (Figure 5).

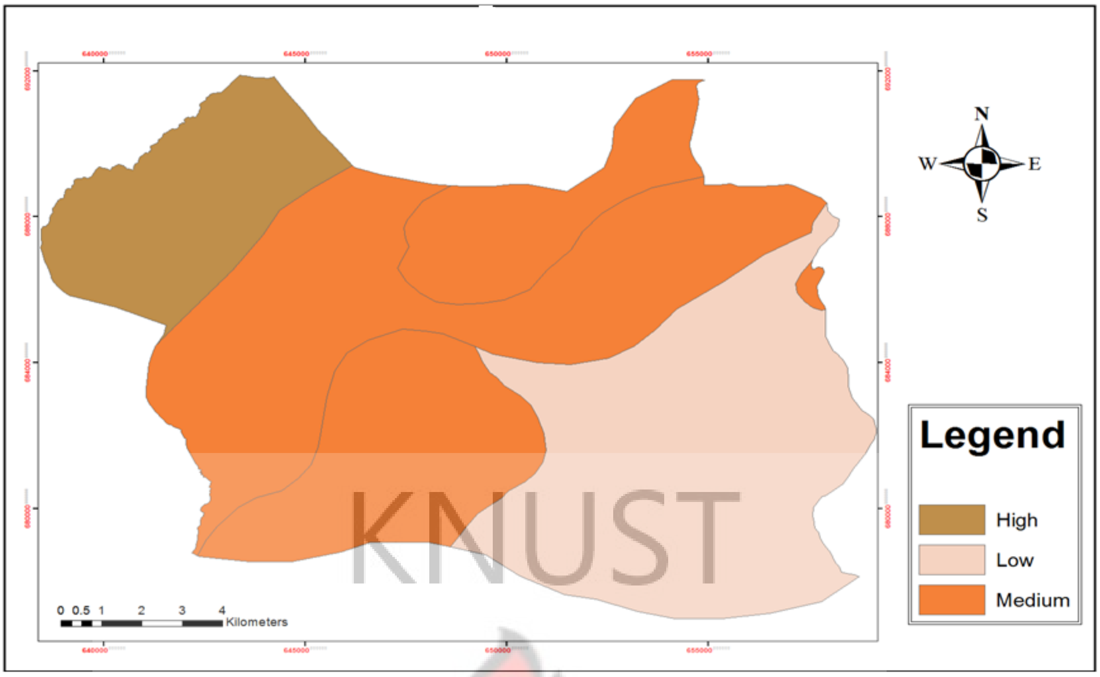

Figure 5 Infiltration Map Derived from Soil Data

4.2.3 Buffer Maps

The landfill site should not be placed within surface water or water resources protection areas so as to protect surface water from contamination by leachate. Safe distances of 500 m from meandering and non-meandering rivers were considered to prevent waste from eroding into rivers and major streams. From Figure 6, it is seen that, as the distances increased further away from the river, the sites became more suitable.

Landfill location must be close to road network in order to facilitate transportation and consequently to reduce relative costs. However, for aesthetic and logical reasons, a buffer of 300 m has been considered for each major and minor road in this study. From Figure 6, areas which are above 3 km fall within the deep brown areas are less suitable compared to those within the light brown areas. However, areas within the cream region are considered unsuitable.

The built up areas were buffered by 500 m to prevent odour and noise from disturbing surrounding communities. This will also prevent the "NIMBY" syndrome. The result of the buffer is as shown in Figure 6. Areas in close proximity to settlements, about 500 m away are within the region marked green, which are not suitable. Light green, yellow and orange areas are 1000, 1500 and 2000 meters away which makes them more suitable compared to red areas of about 3 km away from settlements.

The result of the buffer is as shown in Figure 6.

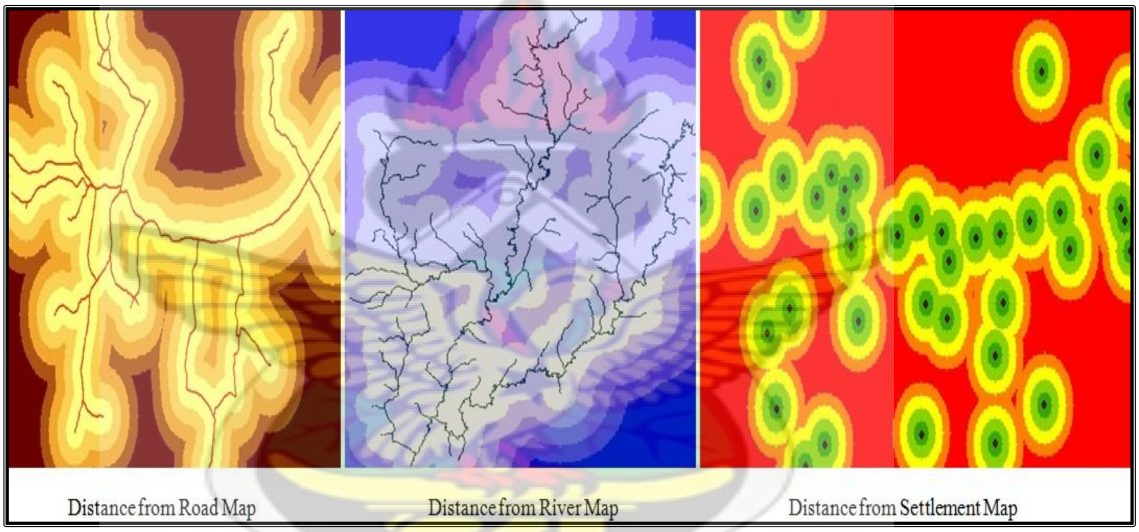

Figure 6 Distances from Feature Map

4.3 WEIGHTED AND OVERLAY ANALYSES

4.3.1 Reclassified Datasets

The results of all the selected criteria (distance to road, settlements, river, as well as the infiltration and slope maps) were reclassified (set to a common scale of 1 to 10) to enhance further analyses. From Figure 7, it can be deduced that as distance from the river, road and settlements increased, the scale value increased. The scale also defines the order of suitability considering each criterion.

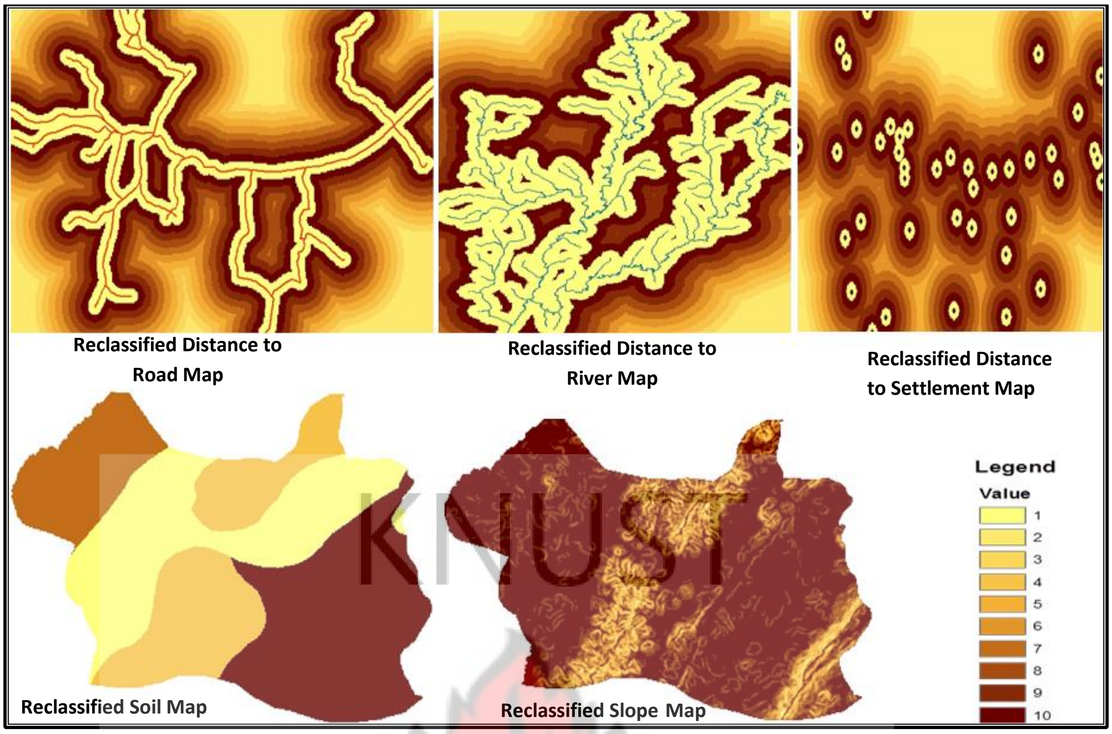

Figure 7 Distance Map reclassified into Ten (10) Classes

4.3.2 Weighted and Overlay Results

The ranking method of adding weights to criteria were used to evaluate the importance of weights each criterion under consideration is ranked. This resulted in a map showing areas which are considered optimal and can be selected as sites for landfilling (Figure 8).

The total area obtained after performing weightage overlay analysis was 91.89 km^2. A total area of 58.73 km^2 was considered unsuitable whereas 33.25 km^2 represented suitable areas (optimal sites).

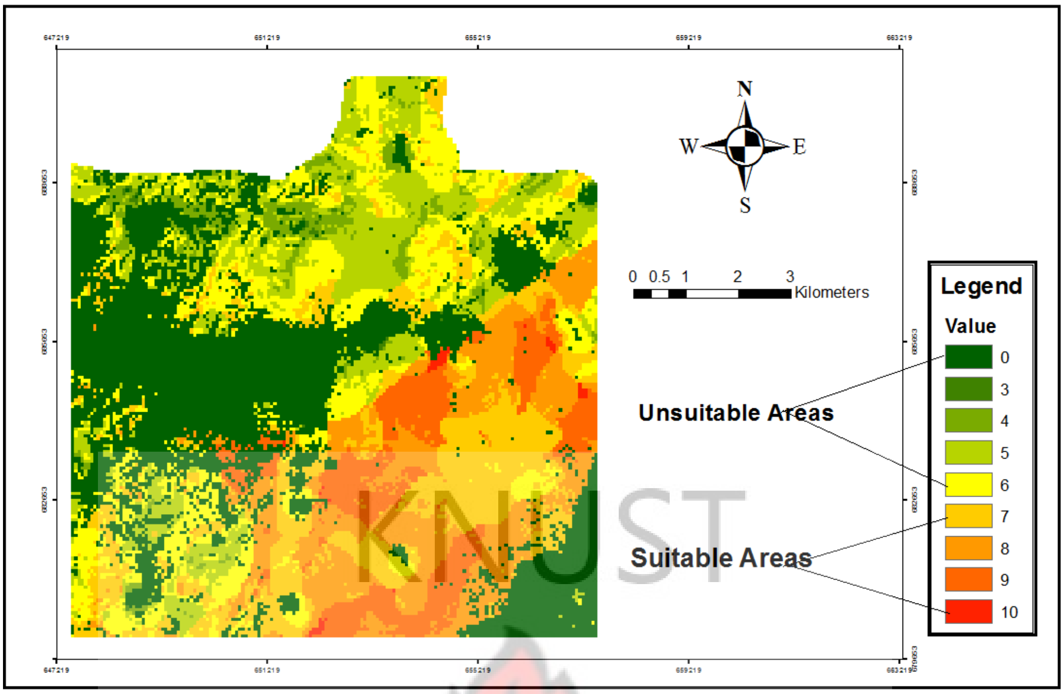

Figure 8 Results of Combined Weighted Datasets

4.4 OPTIMAL SITES SELECTON

From weighted results the optimal sites (33.25 km^2) were extracted for further analysis. In “a”, the raw result of the extracted optimal sites is presented. This includes areas which are very small in size. A further operation was carried out in ArcGIS to filter those small areas (pixels) out to get a more refined result. This is presented in “b”. “c” shows the results of “b” in a vector format. This was done to aid in easy computation of the total area each polygon represents. The Total area after filtering was 32.33 km^2. Figure 9 shows the map containing “a”, “b” and “c”.

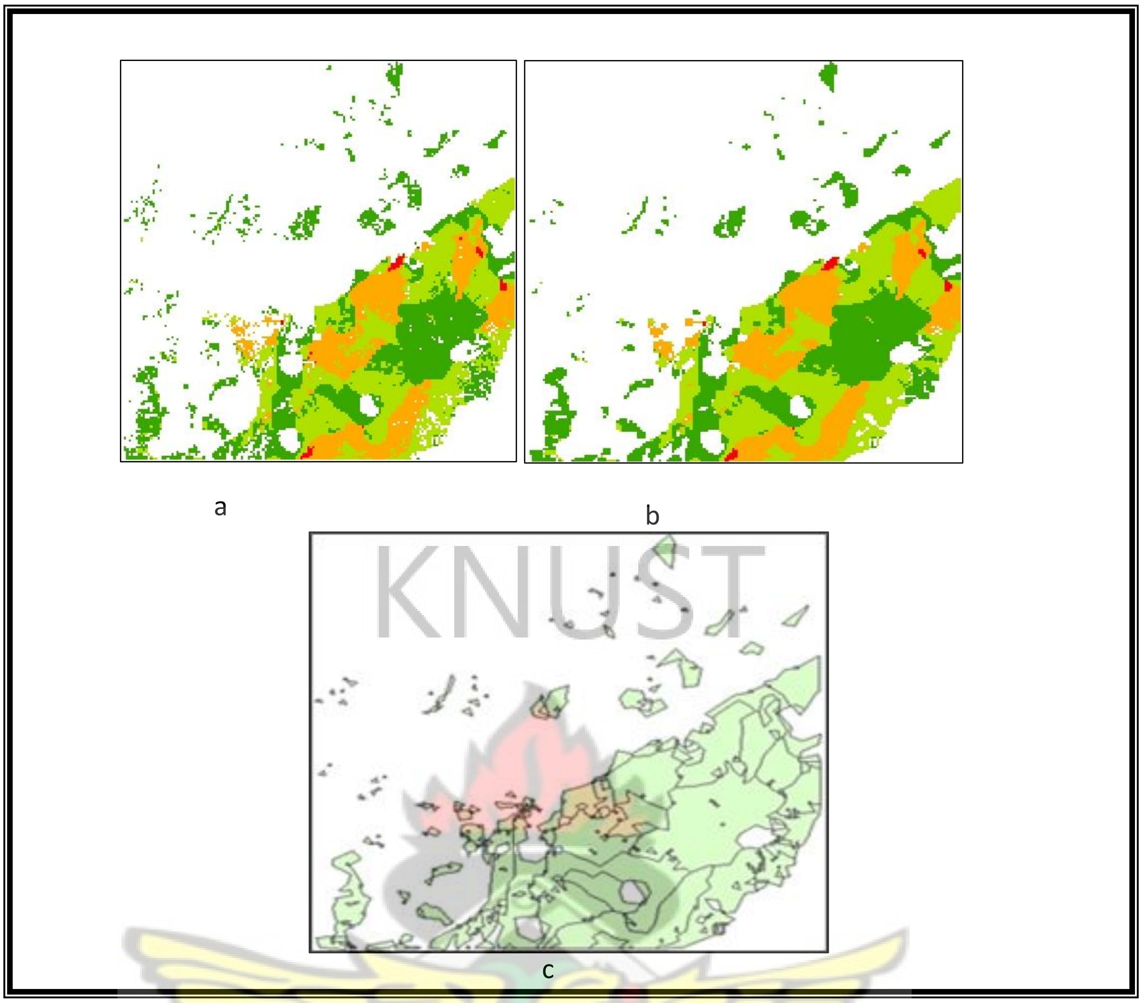

Figure 9 Optimal Sites (a) Before Filtering, (a) After Filtering and (c) As a Polygon Feature.

4.4.1 Selected Best Sites

Having selected the optimal areas for waste disposal, the next condition to be met is that the suitable areas are large enough for storing the waste for a prolonged period. In order to be able to use the site for a long period and according to landfill size requirements the minimum area should be 0.5 km^2.

A spatial query was therefore carried out to select polygons which have total area of at least 0.5 km^2. A total of seventeen (17) polygons or areas were selected after the operation representing 24.53 km^2 out of the 32.33 km^2. The result is shown Figure 10.

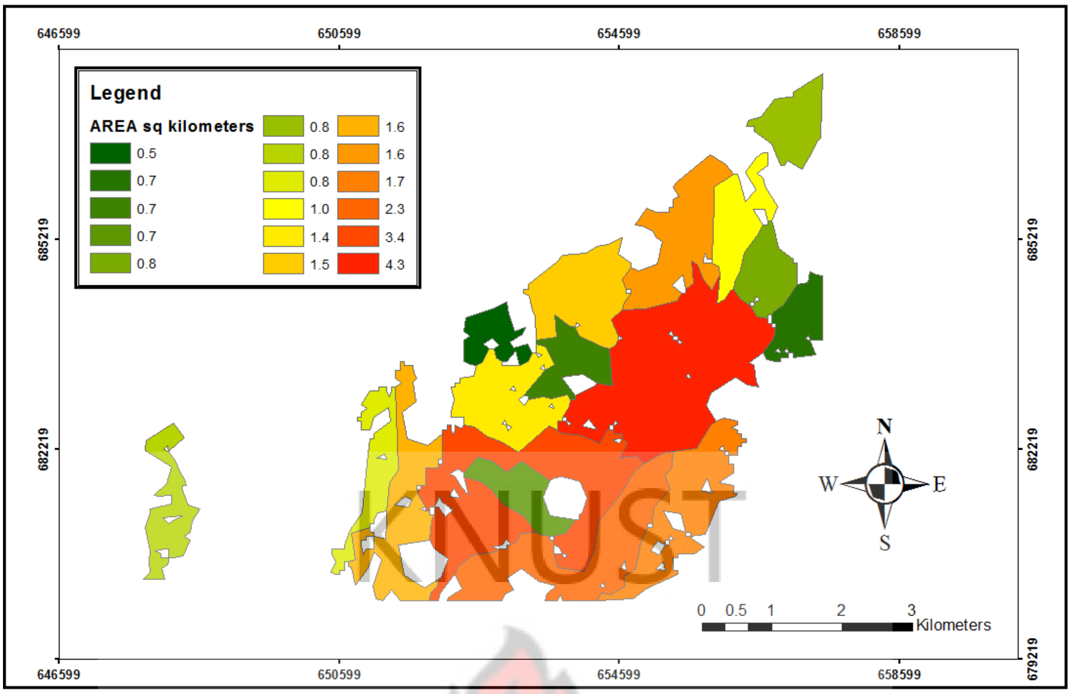

Figure 10 Potential landfill sites in Obuasi Municipality, 2013

The best selected sites are embedded in the land cover map and shown in Figure 11 and summarized in Table 4 below.

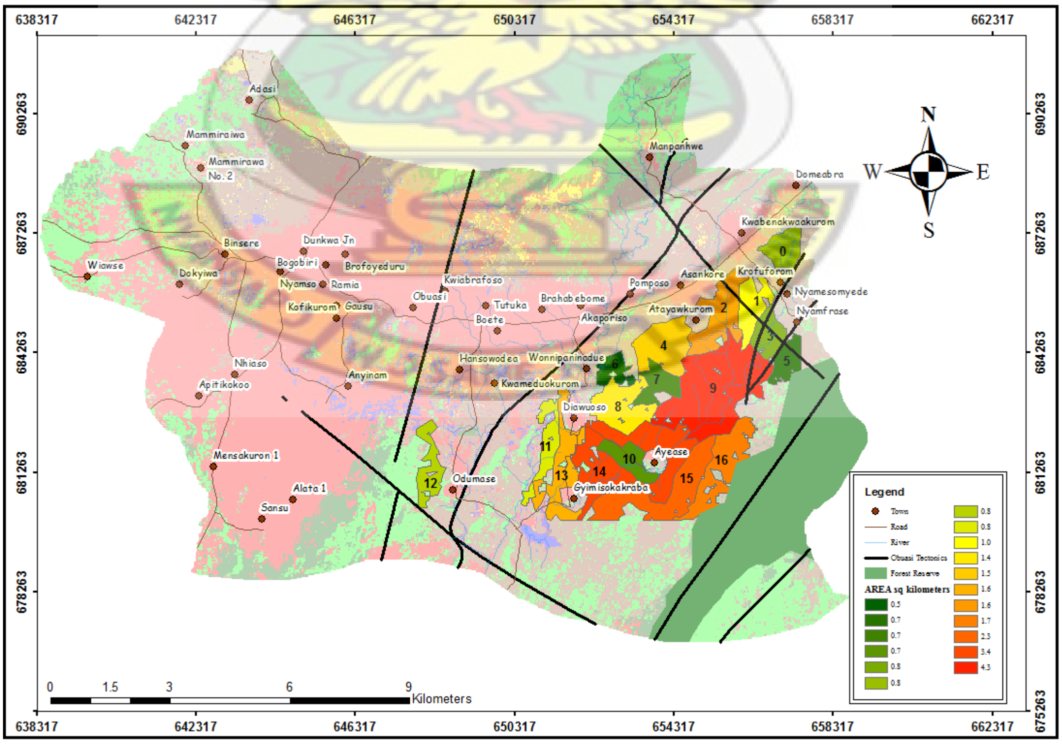

Figure 11 Map of the potential landfill sites embedded in the land cover map, 2013

Table 4 Ranking of the potential landfill sites.

ID	Rank	Area (sq. km)
0	13	0.5
1	11	0.7
2	12	0.7
3	16	0.7
4	7	0.8
5	17	0.8
6	4	0.8
7	6	0.8
8	5	1.0
9	10	1.4
10	8	1.5
11	2	1.6
12	1	1.6
13	3	1.7
14	9	2.2
15	14	3.4
16	15	4.3
Total Area	**25**	

From Table 4, the best selected sites are ranked based on their size and their distances from a major road, along with other features.

CHAPTER FIVE

DISCUSSIONS

5.1 LAND COVER CLASSIFICATION AND ACCURACY ASSESSMENT

The major goal of the landfill site selection process is to ensure that the disposal facility is located at the best location possible with little negative impact to the environment. For a sanitary landfill siting, a substantial evaluation process is needed to identify the best available disposal location which meets the requirements of government regulations and best minimizes economic, environmental, health, and social costs (Siddiqui, 1996). To ensure this in the study, a land cover classification was carried out to ascertain areas which are highly susceptible to environmental contamination by the existence and operation of the landfill.

Land cover classification is usually carried out using patterns, tones, textures, shapes, and site associations to derive information about land to aid in analysis and decision making. The results of this exercise revealed that the major land cover types included built-up, farmland, range land, closed and open forests, barren land and water, with farmland and built-up forming the majority. The majority of the built up class is located in the western part of the area. This is because the built up consists of settlements as well as mining pits, tailings dams and other mining infrastructure. The largest area defined as water is the "Gyimi Dam" which serves as the main source of drinking water for the municipality. The small water areas are mostly as a result of mined pits holding water.

Due to human error (when creating signatures), errors due to time of acquisition of satellite imagery as well as sensor properties, accuracy assessment was done to determine if the classified image meets the minimum accuracy of 85%. From the assessment, the overall accuracy was 85% which fell within the acceptable minimum requirement of 85% (Anderson *et al*., 1976). This achievement was as a result of the signatures being screened before used and also, the reference data being of the same year as the original image used in the classification. The reference data and signatures used confirms Lillesand and Kiefer's (2008) argument that the quality of reference data and training sample play a vital role in the success of accuracy assessment as well as improving it. The land cover accuracy assessment is important because it allows users to evaluate the utility of a thematic map for their intended applications (Caetano, 2009).

Kappa statistics, which is a generic term for several similar measures of agreement used with categorical data, is typically used in assessing the degree to which two or more raters, examining the same data, agree when it comes to assigning the data to categories. In this study, it shows how much the reference data agrees with the sample points as well as how distinct the individual classes are from each other. The value was 0.8125 which appears to be lower than the overall accuracy (85%) because according to Lillesand and Kiefer (2008), the technique applied in its computation has the effect of taking into account the change agreement in the classification as well.

The final result indicated that areas most suitable (less susceptible to environmental contamination) for siting a landfill represented about 57% of the total area under study whereas the remaining 43% was unsuitable. Further analysis done excluded this percentage (43%). The results of the accuracy assessment paved way for further work to be done.

5.2 SPATIAL, WEIGHTED AND OVERLAY ANALYSES

A landfill site must be situated in such way as to reduce pollution impact on the environment and people. As well it should not be sited too far from waste production centre and road networks to reduce cost of waste management. Suitability of the area under study was determined through a combination of factors including land cover type, the slope/terrain, infiltration, and distance from road, rivers and settlements as well from geologic faults.

These factors were combined and weighted in a GIS environment using various approaches. From the results, the eastern part of the study area met the slope and infiltration criteria in that, it had a relatively flat terrain and had soil characteristics of being able to retain water. In terms of distance to road, river and settlements, the eastern part further proved more suitable for selecting a landfill (Figure 11). This area was therefore subjected to further analysis to select the final sites.

5.3 SELECTED SITES

The GIS-based constraint mapping technique was employed for the entire study area and at the end of the analyses; a total number of 17 potential sites were identified. These sites generally satisfied the minimum requirements of selecting landfill sites. Any area selected as a landfill site must also comply with existing plans. Hence, the immediate local conditions prevailing at the present moment were assessed and the 17 potential sites were further screened through careful field checks. This led to the elimination of most of the sites due to the existing environmental and geological conditions, such as; proximity to a fault zone, restricted areas and distance from waste generation sites.

According to the Federal Municipal Solid Waste Landfill (MSWLF) standard of the USEPA (2012), landfills are built in suitable geological areas away from faults. This will minimise the potential that ground movement associated with active fault will damage the landfill containment system and compromise its performance. As a result of this criterion, sites 0, 1, 2, 3, 5 and 9 (Figure 11) were rejected in that operational activities such as the movement of heavy/earth moving equipment on these sites may make them more susceptible to groundwater contamination due to the possibility of damaging the containment system of the landfill. Additionally, landfill site must not be built in restricted and ecologically sensitive areas such as forest reserve, national parks and wetlands (USEPA, 2012). Even though these areas were restricted during the overlay analysis, further analysis of the selected suitable sites showed that some of the sites lie in close proximity to the Dampia Range which happens to be a restricted forest reserve in the study area. This led to the rejection of sites 15 and 16.

The remaining ten sites were all optimal and any of them could be developed for the purposes of landfill construction however, sites 12, 11 and 13 are considered to be most optimal because of their geographical location. All three sites are large enough (1.6, 1.6 and 1.7 km^2 respectively), providing a wider area for suitable location of site. The geographical location of these sites will also minimize transportation costs.

Site 12 is considered the most suitable since its location is more central and serves all communities with most distances falling within the 10 km suggested by Baban and Flannagan (1998). This location also has an existing land fill site which suggests it will be more acceptable to the people (Al-Hanbali *et al*., 2011). The total area of the site is 1.6 km^2 providing a large area which can be used over a longer period. There is also an existing road network which reduces the cost of constructing one.

Alternatively, Site 11 and Site 13 present equally good options for location of a landfill site. They are located further away from faults and settlements and have larger areas (1.6 km^2 and 1.7 km^2 respectively).

Through field verifications it is obvious that the selected sites are environmentally friendly for the sitting of a landfill site having satisfied the basic requirements. However, the selection of the final site requires further geotechnical and hydrogeological boring and testing.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

This study used the integration of GIS and Remote Sensing in identifying the best sites for the construction of a landfill in a typically urbanizing city. A multi-criteria approach was employed in conjunction with GIS-based overlay analysis to identify the most suitable site for landfill development in the Obuasi Municipality. The study was based upon a set of key criteria, which were selected in relation to already available knowledge from research literature as well as the pre-existing local level factors of the area. The climatic characteristics of the region were determined, however, they were not used as a layer because similar climatic conditions prevail throughout the area. A set of seventeen (17) potential sites were identified in the first level of analysis while subsequent screening and refinement on the basis of existing microscopic factors led to optimized selection of the three (3) most suitable sites for landfill construction.

The sites were ranked on the basis of area availability, nearness to waste generating sites, presence of fault lines and others. Sites 12, 11 and 13, covering areas of 1.6 km^2, 1.6 km^2 and 1.7 km^2, respectively, were chosen as the most suitable for landfill construction. They are located in areas comprised of wasteland and they also fulfill all of the selected criteria. Sites 0, 1, 2, 3, 5 and 9 were least suitable due to the presence of fault line, closeness to forest reserve and being far away from waste generating sites.

The integration of GIS and Remote Sensing techniques contributed to the achievement of the results obtained. Remote Sensing techniques made it possible to study the various land cover types within the study area whereas GIS aided in the modeling and preparation of needed maps. Indeed, it has been an effective and efficient tool in carrying out this study.

6.2 RECOMMENDATIONS

The following recommendations are being made;

- A detailed study of the pre-existing groundwater and air quality conditions should be conducted and used in a further research.
- The ecological value of the flora and fauna should be considered in further studies.
- The political and financial/economic criteria could be considered in future study.

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DECLARATION

I, Gladys Ama Assan hereby declare that this submission is my own work towards the MSc. Environmental Science and that, to the best of my knowledge it contains no material previously published by another nor material which has been accepted for the award of any other degree of the university except where due acknowledgement has been made.

Gladys Ama Assan …………… ………………

(Student) Signature Date

Certified by:

Mr. Eric Agyapong …………… ………………

(Supervisor) Signature Date

……………. …………… ………………

Rev. S. Akyempong Signature Date

(Head of Department)

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I cannot leave my supervisor, Mr. Eric Agyapong, who took time out of his busy schedule to thoroughly go through this piece, correcting both grammar and technical errors. Mr. Agyapong, may the Almighty Lord bless you and grant you all your heart's desires.

And to all those who helped in diverse ways to finish this work, not forgetting lecturers of Dept. of Environmental Science, KNUST, Mr. Eric Stemn of Steric Consults and Mr. George Owusu of CERSGIS, it is my fervent prayer that God catapults all your efforts to higher heights.

ABSTRACT

Landfill constitutes one of the primary methods of municipal solid waste disposal. Optimized landfill site selection is the fundamental step in sound waste disposal and the protection of the environment, public health and quality of life. Siting decisions have gained considerable importance in order to ensure minimum damage to the various environmental sub-components as well as reduce the stigma associated with the residents living in its vicinity thereby prolonging its life span. Waste disposal in the Obuasi Municipality in Ghana, has mainly been by open dumping which has resulted in contamination of both surface and ground water and other environmental problems. This research therefore focused on siting a new landfill in the Obuasi Municipal using a multi-criteria decision analysis (MCDA) and overlay analysis in a Geographical Information Systems (GIS) and Remote Sensing (RS) environment. Several factors considered in the siting process included fault lines, distances to surface water, roads and settlements, land use and sensitive sites. Weightings were assigned to each criterion depending upon their relative importance and ratings in accordance with the relative magnitude of impact. It is found that three (3) out of the seventeen (17) potential sites selected best meet all the criteria used. The integration of GIS and RS techniques has been an effective and efficient tool in carrying out this study in that RS techniques made it possible to study the various land cover types within the study area whereas GIS aided in the modelling and preparation of needed maps. The results is a databank in which the municipal authorities can refer to when the need of constructing a landfill site arises.

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LIST OF ABBREVIATIONS AND ACRONYMS

AOI	Area of Interest
CERSGIS	Centre for Remote Sensing and GIS
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
ERDAS	Earth Resources Data Analysis System
ESRI	Earth Sciences Resources Institute
ETM+	Enhanced Thematic Mapper Plus
GIS	Geographical Information System
GPS	Global Positioning System
GSS	Ghana Statistical Service
MCDA	Multi-Criteria Decision Analysis
MDGs	Millennium Development Goals
MLA	Maximum Likelihood Algorithm
MSW	Municipal Solid Waste
NIMBY	Not In My Backyard
OMA	Obuasi Municipal Assembly
OMAMTDP	Obuasi Municipal Assembly Medium Term Development Plan
RS	Remote Sensing
TD	Transformed Divergence
UNEP	United Nations Environmental Program
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey